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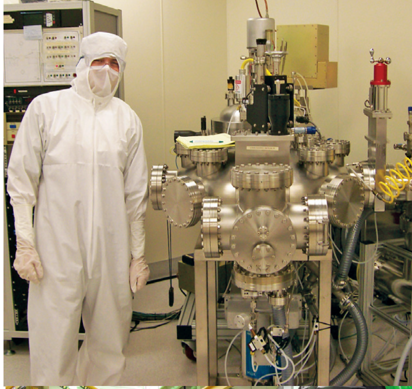
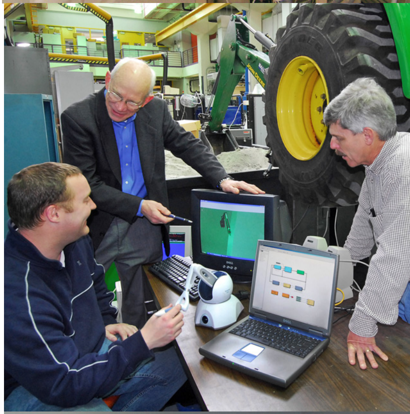
6th ANNUAL REPORT

VOLUME 1





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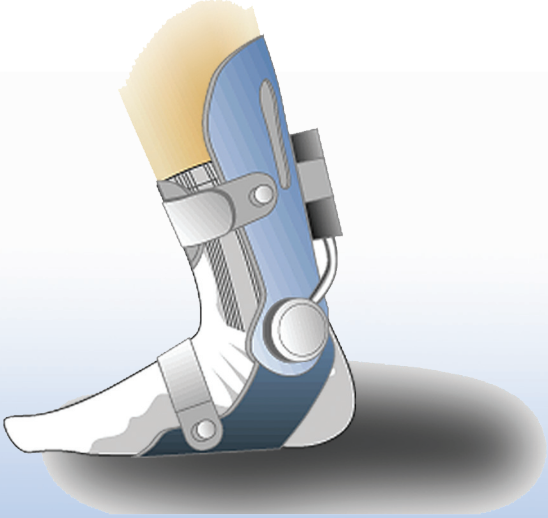

CENTER FOR COMPACT AND EFFICIENT FLUID POWER

A National Science Foundation Engineering Research Center

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Georgia Institute of Technology
Milwaukee School of Engineering
North Carolina Agricultural & Technical State University
Purdue University
University of Illinois at Urbana-Champaign
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PROJECT SUMMARY

The Center for Compact and Efficient Fluid Power (CCEFP) is a network of researchers, educators, students and industry working together to transform the fluid power industry—how it is researched, applied and studied. CCEFP research projects are organized in three thrusts that achieve the following societal benefits: creation of new fluid power technology that, with improved efficiency, will significantly reduce petroleum consumption, energy use and pollution; creation of new fluid power technology that, with improved effectiveness, will make fluid power clean, quiet and safe for its millions of users; and creation of new fluid power technology that, with improved compactness, will exploit its attributes in a new generation of human scale devices and equipment. The CCEFP's education and outreach program is designed to transfer this knowledge to diverse audiences—students of all ages, users of fluid power and the general public.

Intellectual Merit:

CCEFP research is demonstrated on four test beds spanning four orders of magnitude of power and weight. These test beds and the classes of equipment they represent are: excavator (mobile heavy equipment, 50 kW-500 kW), hydraulic hybrid passenger vehicle (highway vehicles, 10 kW-100 kW), compact rescue robot (mobile human scale equipment, 100W-1kW), and the orthosis (human assist devices, 10W-100W). Although stationary applications will also benefit from CCEFP research, the test beds are mobile applications where the advantages of fluid power are most evident. The test beds will integrate research aimed at overcoming the nine technical barriers of fluid power: efficient components, efficient systems, control and energy management, compact power supplies, compact energy storage, compact integrated systems, safe and easy to use, leak-free and quiet. Three of the barriers are transformational, efficient components, compact power supplies and compact energy storage. Through its strategic planning process, CCEFP has identified the following important goals: 1) doubling fluid power efficiency in current applications and in new transportation applications, 2) increasing fluid power energy storage density by an order of magnitude, and 3) developing new fluid power supplies that are one to two orders of magnitude smaller than anything currently available. The CCEFP fills a void in fluid power research that existed for decades. Until the Center was established, the U.S. had no major fluid power research center (compared with thirty centers in Europe). Fluid power researchers, who were previously disconnected, are now linked through the CCEFP.

Broader Impact:

The CCEFP's Education and Outreach Program is intentionally ambitious. It is designed for many audiences—pre-college and college students, fluid power industry stakeholders and customers, and the general public—in recognition that hydraulics and pneumatics is neither well-understood nor often taught. Given the scope of this challenge, the CCEFP maximizes the impact of its more than twenty education and outreach projects, along with additional related initiatives, through three strategic approaches: partnering with effective and broadly distributed education and outreach networks, focusing on projects that can be replicated and/or adapted by others for audiences outside the Center's reach, and selecting its program menu in such a way that the accomplishments of a given project will bolster the progress and chances of success for another. Informed by the CCEFP's research, the Center's Education and Outreach programs enrich understandings of fluid power technology. But its projects share in a broader goal: to heighten interests in technology and engineering among an increasingly diverse student population.

The CCEFP's 47 corporate members as well as a number of other sponsors and participants are key contributors to its success; the partnerships that continue to develop between industry and academia are among the most important of the CCEFP's legacies. Industry will ensure that research results are commercialized and members' interest in and support of the CCEFP's education and outreach programs assure that channels for effective knowledge transfer in fluid power will continue to flourish.

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Participants Table

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Name of Institution	City	State
University of Minnesota, *Lead University*	Minneapolis	Minnesota
Georgia Institute of Technology	Atlanta	Georgia
University of Illinois at Urbana-Champaign	Urbana - Champaign	Illinois
Milwaukee School of Engineering	Milwaukee	Wisconsin
North Carolina Agricultural and Technical State University	Greensboro	North Carolina
Purdue University	West Lafayette	Indiana
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Faculty Researcher	Ashlie Martini	Mechanical Engineering	Purdue University
Faculty Researcher	Paul Michael	Fluid Power Institute	Milwaukee School of Engineering
Faculty Researcher	Zongxuan Sun	Mechanical Engineering	University of Minnesota

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Faculty Researcher	Vito Gervasi	Applied Technology Center	Milwaukee School of Engineering
Faculty Researcher	Michael Goldfarb	Mechanical Engineering	Vanderbilt University
Faculty Researcher	Chris Paredis	Mechanical Engineering	Georgia Institute of Technology
Faculty Researcher	Robert Webster	Mechanical Engineering	Vanderbilt University

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Faculty Researcher	Ken Cunefare	Mechanical Engineering	Georgia Institute of Technology
Researcher	J.D. Huggins	Mechanical Engineering	Georgia Institute of Technology
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Faculty Researcher	Zongliang Jiang	Industrial and Systems Eng.	North Carolina A & T
Faculty Researcher	Eui Park	Industrial and Systems Eng.	North Carolina A & T
Faculty Researcher	Richard Salant	Mechanical Engineering	Georgia Institute of Technology
Faculty Researcher	Silvanus Udoka	Industrial and Systems Eng.	North Carolina A & T
Faculty Researcher	Jun Ueda	Mechanical Engineering	Georgia Institute of Technology

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Visiting Scholar, Test Bed 3	Feng Wang	Mechanical Engineer	University of Minnesota

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1. SYSTEM VISION AND VALUE ADDED OF THE CENTER

Transforming fluid power into a compact, efficient and effective method of energy transmission remains the vision of the Engineering Research Center for Compact and Efficient Fluid Power (CCEFP). The Center's work continues to make progress towards reducing our Nation's energy usage and increasing the ways in which fluid power—through human-scale applications—will improve our quality of life. This will spawn entirely new industries in the process.

While the CCEFP strategy has continued to evolve and mature, the vision has remained constant. The needs that inspired it and the accuracy of the course in pursuing it are affirmed by the international fluid power research community and by industry.

As it completes its sixth year, the CCEFP is already transforming fluid power. The Center has become the catalyst in energizing the Nation's fluid power industry and research community. For the first time in decades, the fluid power industry in the U.S. is undertaking university-industry collaborations on research. U.S. universities are emerging as international leaders in fluid power research, as evidenced by best paper awards presented to Center researchers and their students at recent prominent international conferences. The CCEFP, National Fluid Power Association (NFPA) and the Department of Energy (DOE) conducted a survey to determine the impact of fluid power on our Nation's energy use. This will lead to a national fluid power energy research and development plan that involves partnering among industry, universities and national labs. And, as a direct consequence of a past CCEFP site visit, the fluid power industry has developed a research-technology roadmap, an invaluable reference for guiding future research.

1.1 SYSTEMS VISION

The CCEFP systems vision has been continuously modified and refined over the last six years of operation. The test beds demonstrate the systems vision. The current test beds are based on the observation that it is not well known how fluid power scales with size as measured by weight or power, and that the competitive advantage of fluid power is greatest in mobile applications. Therefore, CCEFP has chosen mobile test beds spanning the entire range of power and weight of interest.

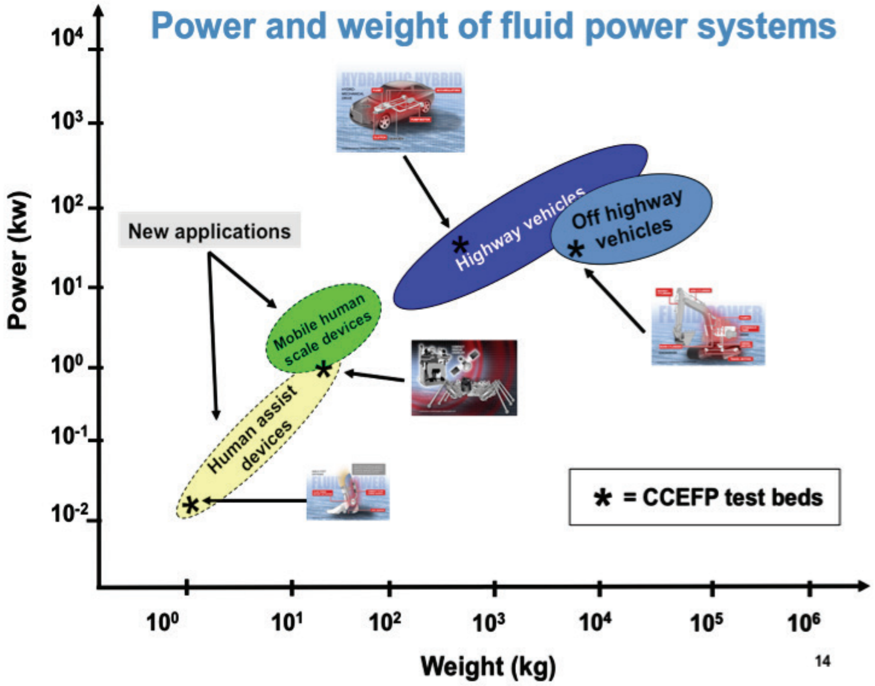
The figure below shows the range of power and weight for fluid power applications. Four families can be identified, as listed below. The four test beds are representative members of these four families.

1. Mobile Heavy Equipment (50 kW-500 kW): Excavator (Test Bed 1)

2. Highway Vehicles (10 kW-100 kW): Hydraulic Hybrid Passenger Vehicle (Test Bed 3)

3. Mobile Human Scale Equipment (100W-1kW): Compact Rescue Robot (Test Bed 4)

4. Human Assist Devices (10W-100W): Orthosis (Test Bed 6)



CCEFP Testbeds

The test beds chosen represent mobile applications where fluid power is the best solution. They span four orders of magnitude of power and weight. They encompass current and future applications of fluid power, influence neighboring applications and solve important societal problems.

The CCEFP has identified the following transformational goals necessary to realize our vision:

1. Doubling fluid power efficiency in current applications and in new transportation applications.

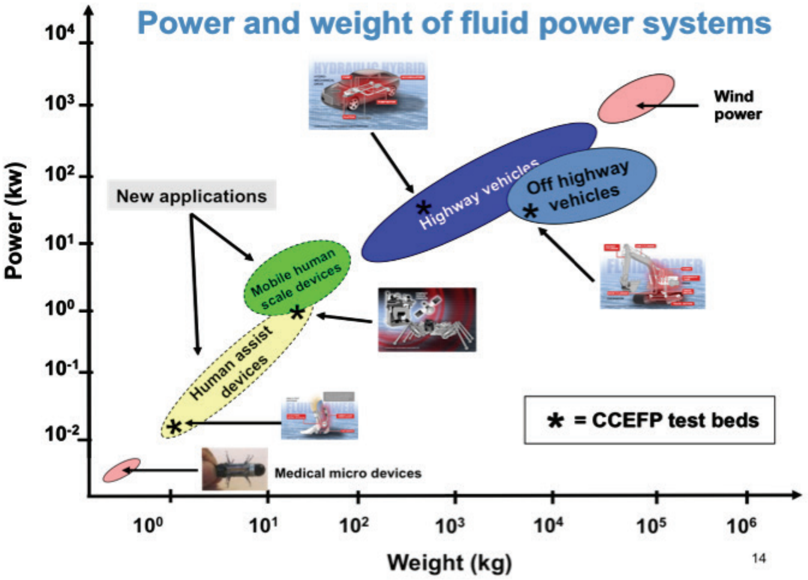
2. Increasing fluid power energy storage density by an order of magnitude.

3. Developing new miniature fluid power components and systems including power supplies that are one - two orders of magnitude smaller (10 W-1 kW) than anything currently available.

Doubling the efficiency in current off-road applications and future on-road applications would lead to a large reduction in energy consumption. Increasing the energy storage density is a requirement for hydraulic hybrid passenger vehicles to compete with electric hybrids. Developing new smaller fluid power components and systems is needed for mobile human scale devices and mobile human assist devices.

Associated Test Beds

There are fluid power application opportunities at power and weight levels that are both higher and lower than the four CCEFP test beds. These include wind power at larger scales (500 kW-5 MW) and *in vivo* biomedical devices (100 mW-1 W) at smaller scales. These new opportunities are depicted in the figure below.



CCEFP Associated Testbeds

Current budget limitations prevent the CCEFP from funding added test beds. Therefore, we are seeking other sources of funding to support test beds in higher and lower power and weight ranges. A new $8 million DOE industry-university cooperative wind power research center has been awarded to the University of Minnesota, and hydrostatic transmission of wind power is being investigated as part of this center. Seed funding for this test bed has been provided by the Initiative for Renewable Energy and the Environment (IREE), an internal organization at the University of Minnesota, and additional funding has been obtained as we have partnered with one of our industry members in a DOE-funded project on hydrostatic transmissions for off-shore wind power. Further funding is anticipated as we continue to develop our capabilities, and since hydrostatic power transmission promises to be more reliable and extract more power than existing mechanical gearboxes. The MRI surgery research initiative has been supported by internal funds and infrastructure at Vanderbilt University, with external funds to be sought after preliminary results are available. Unlike electro-mechanical actuation, pneumatics do not interact with the magnetic fields of the MRI, providing the possibility of precision surgical procedures aided by MRI sensing.

Why Fluid Power Is Transformational

Society benefits as the transformational work of the CCEFP leads to the reduction of energy consumption and the creation of new human-scale fluid power devices. Savings will be realized by reducing energy use in current fluid power applications. In the past year, the NFPA has conducted an authoritative energy study funded by DOE that confirmed the importance fluid power in saving energy. This authoritative survey found that fluid power consumes between 2.3% and 3.0% of our energy. Fluid power system efficiencies range from less than 8% to as high as 40% (depending upon the application), with an average efficiency of 21%, confirming that new technology has the potential for significant energy savings. The survey found that a 5% improvement in efficiency is easily achievable within the next five years saving $9B to $11B per year in energy costs. A strategic R&D program focusing on new controls, manufacturing and materials could result in a 15% improvement in efficiency over the next fifteen years saving $19B to $25B per year in energy. Just as important, an aggressive program in energy efficient fluid power can invigorate this industry that is the backbone of U.S. manufacturing and increase U.S. competitiveness in the growing world market. Using fluid power more widely in transportation through the development of hydraulic hybrid vehicles will save an additional $50 billion. More than dollars are at stake. Reducing energy consumption is directly related to reducing carbon dioxide emissions, the major cause of global warming. Further, new compact fluid power systems will enable human-scale, untethered systems such as the compact rescue robot and the orthosis.

Theory and Science

Fluid power can be applied over many orders of magnitude of weight and power, but in these differing size regimes, equipment takes highly varied forms. While many of the basic scientific facts are known, the technological systems solutions employed are not well understood. They depend on optimizing in an environment of multiple, complex interacting factors.

Fluid power and electrical power are the main competing approaches for transmitting power in mobile applications. Fluid power transmission has important competitive advantages over electric power transmission including a higher power to weight ratio for actuation, a higher energy to weight ratio of fuel compared to batteries, higher forces or torques, and continuously varying transmission. Fluid power also is superior in producing or absorbing high power transients, has a higher control bandwidth for the same power, can hold loads without expending energy, and has flexible routing. Weaknesses of current fluid power systems are component and system inefficiencies, energy storage density, limitations in currently available compact power supplies, and unresolved environment issues such as leakage and noise. These weaknesses are the fundamental barriers that CCEFP research is addressing.

In defining the CCEFP's systems vision, certain fluid power areas have been intentionally excluded from specific focus. Even so, the results of our efforts will translate directly into benefits for these areas. Excluded applications include stationary manufacturing applications in materials processing and factory automation, and large marine and aerospace applications. The manufacturing applications are out of scope because they are stationary. The large marine and aerospace applications are out of scope because the primary propulsion system does not use fluid power. Nevertheless, CCEFP research results will lead to important improvements in these excluded areas. In this context, the distinction between what is "important" and what is "transformational" is germane. While CCEFP research will not transform aerospace, marine and stationary applications, it is expected to make important improvements in these areas. An exception is wind power, a stationary application in early stages of development, where fluid power has the potential to be transformational.

Our strategic planning process identified nine important fluid power attributes listed in the table below. Improving these attributes define the technical barriers of the Center. All are important to attaining our systems vision; of these twelve, three are transformational.

Fluid Power Technical Barriers	Transformational
Efficient components Efficient systems Control and energy management Compact power supplies Compact energy storage Compact integrated systems Safe and easy to use Leak-free Quiet	Efficient components Compact power supplies Compact energy storage

Response to Site Visit Team SWOT Report

Following the 2011 NSF Site Visit, the CCEFP provided very detailed responses to the following concerns noted in the NSF SVT Report. A summary of the most important points is given below.

Test Beds

SVT: The objectives of the test beds need to be explicit, attainable, and clearly defined. The value that the CCEFP can add to ongoing efforts elsewhere needs to be justified.

Response: It is absolutely correct that beginning with the end in mind is very important. CCEFP commits to review the test bed objectives at a minimum on a biannual basis tied to the project selection cycle. Once the objectives are defined, the creation of a well-defined plan with deliverables and milestones is a requirement.

SVT: In reviewing the test beds, the SVT was more positive about TB1 (Excavator) and TB6 (Orthosis) and less positive about TB3 (Hydraulic Hybrid Passenger Vehicle) and TB4 (rescue robot).

Response: We believe that all of these test beds are well conceived strategically, and that the criticism has its main origin in the slower progress of TB3 and TB4. To refocus our efforts it is important to have a clear plan for each test bed that integrates research results from projects in a meaningful way. In this regard, getting help from well-chosen industry partners can contribute to faster progress and more clearly defined goals.

SVT: The Center should determine which hardware and configurations best support test bed goals, if appropriate effort and significant results can be demonstrated in a timely manner. Assess Center expertise to test bed goals. Assess how the test bed could quickly and efficiently make the strongest impact.

Response: Hydraulic hybrid vehicles have advantages in cost, reliability, better performance and fuel economy, versus electric hybrids. CCEFP recognizes that industry's effort in the hydraulic hybrid area is rapidly advancing as a potential threat to CCEFP's leadership. The TB3 team is re-evaluating its strategy to maximize impact with available resources. Test beds should: 1) Serve as integration and testing platforms for new components and systems and 2) Address architectural and systems level research questions (e.g. less investigated approaches such as power-splits).

The Gen 1 vehicle will serve as the integration platform. The Gen 2 vehicle will serve as the control development platform and will demonstrate fuel economy improvement on Federal drive-cycles. The Gen 3 vehicle will be developed with an industry partner, with the benefit of experience from the architectural and control studies. The CCEFP is continually seeking industry collaborators for these endeavors. Demonstration and testing of new components of the redesigned Gen 1 vehicle is expected by April 2011. A dynamometer test facility is being constructed to speed up control development, experimentation and evaluation. The Gen 2 hardware (Folsom transmission) is installed on a Ford F150 with control development and fuel economy testing commencing summer 2012. The principle is to learn what we can and use that knowledge to launch the Gen 3 vehicle.

SVT: The merits of this test bed are not clear, the case for its commercialization remains vague, there is little novelty and few technological breakthroughs of any significance. The case for further development of TB4 is weak, except for the free-piston engine compressor R&D. The test bed should demonstrate innovations in human-machine interfaces and the compact energy supply and storage subsystems.

Response: The complexity of the rescue robot with twelve degrees of freedom created specifically for this purpose, and a totally novel operator interface station by some measures exceeds any of the other test beds. The complexity is appropriate for the evaluation of some human interface aspects of the category of devices: human scaled, untethered, with new application potential. The use of fluid power at this scale and in this manner is novel and the approach is quite different from current and past rescue or defense oriented robots. The objectives for the rescue robot included the ability to provide forces to lift 500 pounds to free a trapped victim. The pneumatic version will employ auxiliary tools.

Since this original response was written in May 2011, we have determined a new direction for the Test Bed 4. The CCEFP is exploring a collaboration with the NSF Engineering Research Center Quality of Life (QoLT), headquartered at the University of Pittsburgh to utilize the compact rescue robot as a patient mover in medical settings. There is a significant number of injuries to staff and patients associated with moving disabled, ill or elderly patients who are unable to be mobile. We have recognized this as an unappreciated problem. We are working now to redirect the robot and collaborating with the QoLT. The CCEFP will design and build the machine, QoLT will test it at their facilities. The TB4 team will engage existing robot manufacturers and key end users to better understand the industry, the operational requirements, and to work to develop collaborations between the manufacturers, QoLT and CCEFP. The team will review and update its integrated test bed plan to include well defined deliverables.

SVT: The test bed milestone charts display the corresponding arrows for thrust technology import has been helpful. These charts communicate the component integration across thrusts to test beds. There should also be some discussion of how the project management is handled.

Response: CCEFP already has a well-defined progress review process. Progress reviews are conducted twice a year. All projects and test beds are rated using a traffic light - green, yellow and red. Follow up teleconferences between the Director, Deputy Director and ILO and project or test bed participants are scheduled for any project or test bed for which there is significant concern so that effective correctives can be found for anything that is hindering progress.

Research

SVT: The energy storage portfolio is thin.

Response: The SVT is correct in recognizing that storage density is an important challenge for fluid power, most urgently for the hydraulic hybrid vehicle. The entire industry is seeking new ways to store fluid energy with higher efficiency and density. Of the two projects funded to date in this area, the elastomeric accumulator is currently being funded, but the open accumulator has graduated to other funding sources with a focus on wind power applications. With improvement, either of these two approaches might ultimately be used in vehicles.

SVT: Project 1E.3. High Efficiency, High Bandwidth, Actively Controlled Variable Displacement Pump/Motor. Future plans for the project involve the application of the pump/motor concept to test beds 1 and 3. The application of the digital pump to test bed 1 may lead to marginal cost advantages. Therefore, it is suggested that a more suitable demonstrator should be considered.

Response: Williamson and Ivantysynova (2007) compared two different pumps with a maximum total efficiency difference of 5%. The dynamic simulations showed 20% less energy consumption using the more efficient pump for the same duty cycle. The reason for this difference is during a portion of the duty cycle the pumps were operating at less than 20% displacement. The difference in efficiency was more significant at low displacement. The authors observed that the largest differences in energy consumption occurred when the actuators were stationary or moving very slowly. Their aim was to show that the impact of pump efficiency on displacement controlled actuation systems is significant. At the site visit while describing the experimental results of TB1, it was noted that because valve metering losses are reduced, the largest loss of power is through the pump/motors. The improvement of pump/motor efficiency, particularly at the lower power settings as being targeted in 1E.3, will lead to another significant improvement in overall system efficiency.

SVT: In the closed door IAB session, there was some concern expressed that CCEFP does not use industry advisors proactively in strategic planning and project selection and that CCEFP researchers do not take full advantage of their industry members' expertise.

Response: The interaction between the research teams and the subject matter experts in our industry member companies should be increased. We believe that this interaction is important to provide input regarding industry's needs. To reinvigorate the interaction, the Project Champions sub-committee is seeking a chairman from industry. With industry's support, we can turn this around and infuse the research teams with the expertise and sense of urgency felt by the member company employees.

SVT: Specific attention was requested by industry to research related to meeting the impending CAFE Standards in 2016, energy efficiency in general, and leaks, noise, vibration and harshness.

Response: Industry holds a wide variety of opinions about the role of CCEFP in fluid power research. The largest and most technically sophisticated members would prefer that CCEFP concentrate of longer term goals and fundamental research. Industry consensus on CCEFP research goals may not be possible, but communication is the key to fostering an atmosphere of cooperation and to avoid the real threat identified by the SVT of our "inability to deliver on industry expectations."

We support the goal of increasing fuel economy. TB1 and TB3 and projects in the efficiency thrust are explicitly working on improved fuel economy, but it is unrealistic to expect that CCEFP would help industry to meet the 2016 CAFE standards. We support the goal of decreasing "leaks, noise, vibration and harshness" (LNVH) and CCEFP has made important research contributions to these areas. Solving LNVH problems is primarily an industry responsibility with research playing a supporting role.

SVT: Technologies that are competitive with fluid power may prevail if fluid power advances do not come to market in a timely fashion.

Response: We agree with this statement. One example is hybrid vehicles. We believe that the hydromechanical transmission in passenger cars holds a great deal of promise, but the work need a stronger sense of urgency in order to achieve commercial success. We will be meeting with Ford, Chrysler, and other companies to tell them of our work and to propose possible joint hydraulic hybrid programs.

SVT: Inability to deliver on industry expectations.

Response: We observe a wide diversity of expectations among our industry members. They vary by size of company, type of business (component, system, OEM), and other aspects. The key to meeting or exceeding the expectations is communications. The IAB meetings that are being held 3-4 times a year at our member universities. Effective multi-way communications is critical to assure this alignment.

Intellectual Property and Technology Transfer

SVT: Technology transfer efforts have continued to be an issue. The SVT made a strong recommendation to focus more attention on how the licensing to member companies could be improved, the conundrum that neither industry nor the university has sufficient motivation to patent many of the CCEFP's breakthroughs still exists.

Response: The CCEFP membership agreement sets the Center policy for intellectual property (IP) issues such as licensing. The goal is to use or create an NSF best practice that meets the multiple goals of facilitating technology transfer, encouraging increased industry participation, and being start-up friendly, among others. The Center is considering methods to provide greater differentiation between the membership categories as it updates its membership agreement. The goal is to provide our industry members with greater value as they move to a higher membership level so that they are motivated to join at the highest level. One idea is to increase the differentiation to use a portion of the incremental dues collected at the higher level in a patent protection fund.

SVT: Improve mechanisms for industry "hand-off" of CCEFP technologies.

Response: At present, the pre-competitive research is funded by the Center and any additional development is funded by an industry member company as an affiliated project. We are considering of a "co-funding" process to help bridge the chasm between the fundamental, pre-competitive research that makes up a large percentage of the Center's work and the technology readiness level at which our members companies have a strong interest in pursuing commercialization of the technology.

Communication and Public Outreach

SVT: Communication and interaction at all levels within the CCEFP needs further improvement.

Response: While significant progress has been made in improving Center communications, we agree that additional improvements in both internal and external communications are needed.

SVT: The SVT finds project reports in the annual report to be well thought out. The documentation occasionally relies on references not readily available to the SVT.

Response: In following up on the SVT request, CCEFP learned that it is illegal to post copyrighted material on the web without permission. Password protected sites are not excluded from the law. A compromise was agreed to between the Center Director and Bruce Kramer in the summer of 2010. We grant permission to post one important article for each project and test bed would be obtained so that the article could be posted publically on the website. Citations for all CCEFP articles will be listed. This practice will be followed in the future.

SVT: The 2010 Site Visit Report stated that public outreach efforts appear to be focused on the state of Minnesota. This observation remains, as the activities for 2011 suggest that the primary public outreach activities are Interactive Exhibits and the Fluid Power Video. Participating Core universities should consider collaborating with their local science museums to display interactive exhibits.

Response: The impact of the videos has already extended far beyond Minnesota, including out-of-state PBS affiliates. The videos are also available in streaming form on the NFPA and CCEFP web sites. Foreign fluid power industry associations have distribution rights and dubbed in several foreign languages. CCEFP distribute the videos free to anyone who requests a copy; several thousand copies have been broadly distributed around the country, mainly to schools and community groups. The interactive fluid power exhibits at the Science Museum of Minnesota will eventually extend far beyond Minnesota. Science museums around the country work as an informal network where ideas for displays are actively shared. A traveling display is in our future plans but successful traveling displays require several years of fund-raising and coordinated planning to be successful.

Students and Diversity

SVT: The SLC SWOT analysis is comprehensive, thorough, thoughtful and generally complimentary of the CCEFP experience. It highlights two particular issues. First, the students are concerned the SLC has no clear role and, in particular, the faculty may be doing a poor job of communicating the importance of the SLC. The SLC proposed providing opportunities for visits or extended stays at partner universities or member firms.

Response: The role of the SLC is important and it will work better if the students define their own role. We have a created a process to do that and this is what the SLC has committed to do: 1) The SLC has formed a task force including SLC officers, graduate students, faculty and consultants 2) First task force meeting will be held at the IAB Summit at GeorgiaTech in May 2011. 3) A follow-up meeting will be held at the CCEFP Student Retreat in August 2011. 4) Action items include a newly defined role, SLC organizational model and other modifications as determined.

SVT: There are imbalances in underrepresented minority students among the partner institutions, particularly with regard to Hispanic and African American students.

Response: The Center is committed to a community of diverse people that provides our program, our society and our culture with unique and inspirational perspectives. We are considering the following approaches: 1) Apply for NSF Graduate Research Diversity Supplements funding to support two diverse graduate students in the CCEFP through the NSF. 2) The Center will continue to improve the diverse makeup of the REU, Fluid Power Scholars and RET programs to help influence the direction of students into graduate schools within the CCEFP network. 3) The Center is considering an incentive program for faculty that more diligently and deliberately prioritizes the recruitment of students of underrepresented status by providing an additional disbursement of research funding. 4) The Center is collaborating with the NFPA to host a student-focused industry summit in connection with the CCEFP Annual Meeting at UIUC in the Fall of 2012. The CCEFP will recruit a diverse student audience to this technical and networking event. 5) The Center will employ and leverage other programs (e.g. The GEM Consortium), both within and beyond the Center institutions, to promote the graduate level activities in the CCEFP.

Sustainability

SVT: The end of NSF funding is approaching. CCEFP needs to work at sustainability more urgently.

Response: Center sustainability is a high priority objective, a task force is in place. One key to achieving sustainability is the growth of affiliated projects leveraging Center resources and focusing on projects that are of strong interest to our industry members. The research portfolio at sustainability will be supported by industry membership fees, associated projects funded by government and industry and by large funding initiatives for industry-university collaboration on major challenges for fluid power.

1.2 VALUE ADDED AND BROADER IMPACTS

Research

The four CCEFP test beds were strategically chosen to span the power and weight range of existing and future fluid power applications. The primary purpose of these test beds are as follows:

- Test Bed 1, the excavator, demonstrates efficiency improvements in existing fluid power applications.
- Test Bed 3, the hydraulic hybrid passenger vehicle, demonstrates a cost-effective competitive alternative to electric hybrids.
- Test Bed 4, the compact rescue robot, demonstrates a small tele-operated device capable of performing useful work over an extended duration.
- Test Bed 6, the orthosis, demonstrates the practical limits of miniature fluid power systems.

A displacement controlled actuator has been implemented on the excavator test bed. The results indicate that a 40% energy savings is possible compared to the existing design. For multiple actuators, the displacement controlled design allows energy recovery by having one axis feed another directly through the engine shaft. Experiments have revealed new control challenges with displacement control. Approaches to overcome the control problems have been developed. In the future even greater energy savings will be demonstrated by using more efficient fluids, more efficient pumps and motors, better control, better engine management and improved human-machine interface. These are all being pursued in associated CCEFP projects.

The first generation (Gen 1) hydraulic hybrid passenger vehicle test bed has been constructed and tested. The Gen 1 test bed uses a Polaris Ranger all-terrain vehicle (ATV) chassis. Although it is not truly an on-highway passenger vehicle, these early efforts have provided extremely valuable learning that will be incorporated in later test bed vehicles. The parallel, series and power-split architectures were studied on the Gen 1 test bed. The power-split architecture was shown to have the best fuel economy. For all architectures, fuel economy is highly dependent on hydraulic component and system efficiency. The importance of more efficient pumps, motors and fluids is well understood. A three-level control strategy was developed. The top level controls the engine on/off function, the middle level causes the engine to operate at or near its optimal efficiency, and the low level maintains tracking of the control commands. It has been shown that operating the engine near its most efficient speed and torque is crucial to realizing efficient operation.

The Gen 1 test bed has had recurring development and reliability issues. In order to overcome these problems, a new transmission was designed in-house, fabricated and installed in the vehicle. A number of hybrid system components were also updated and the Gen 1 test bed will continue to be used in research. Based on the lessons learned from the Gen 1 test bed, a second generation test bed (Gen 2) was designed and is being constructed. The Gen 2 test bed is a Ford F-150 pickup truck that was modified to use a hydromechanical power-split transmission. CCEFP researchers will hybridize the vehicle, develop and implement controls, and test the vehicle. The Gen 2 test bed vehicle will benefit greatly from the expertise of our industry partners, Ford Motor Company and Folsom Technologies International and the experience the test bed team has with the Gen 1 test bed.

Unlike the excavator and the vehicle that are focused on making advances in products currently commercially available, no true rescue robot exists. There are robots available that can perform reconnaissance, but none can do meaningful rescue work. A high-level system study has been conducted to clearly understand the rescue task system requirements and develop a set of specifications to meet these requirements. These requirements overcome barriers in energetic, control and operator interface. An associated CCEFP project is developing a free-piston engine pneumatic system that will be demonstrated on the test bed. Gait control has been demonstrated using three approaches: limb-by-limb control, autonomous control and follow-the-leader control. Remote operation of multiple degrees-of-freedom has been demonstrated using a haptic and visual interface.

Like the rescue robot, the portable powered ankle foot orthosis (PPAFO) is a novel device and system level requirements must be based on subject experiments rather than from commercially available products. An untethered pneumatic orthosis has been demonstrated on human subjects. It provides gait assistance, but did not meet the weight and operation time requirements. A systems analysis has shown that for a fluid power solution to be lighter than a competing electromechanical solution, 250 psi (17 bar) hydraulics are required. The next generation orthosis test bed design is underway.

Considerable progress has been made on all test beds in the last year. The excavator has undergone field tests at Caterpillar and the orthosis has been tested on subjects. These results are described as research highlights in the report. Extensive progress has been made on both the Gen 1 and Gen 2 hydraulic hybrid vehicles. The Gen 1 test bed drivetrain and hybrid system has been completely resigned. The new version will be available for field tests this summer. The implementation of the Gen 2 test bed vehicle has been delayed due to a transmission failure in testing at the manufacturer. The transmission has been rebuilt with Ford's assistance and is being reassembled at Folsom. Delivery of the Gen 2 vehicle is expected in the summer of 2012. The compact rescue robot test bed recently made a significant upgrade to the operator interface with haptic control which provides improved remote operation of the robot. Integration of the free piston engine compressor to enable untethered operation for extended periods of time is planned for 2012. The orthosis test bed will introduce a Gen 1.1 PPAFO and integrate the miniature HCCI free-piston engine compressor into the test bed in 2012. Research on a hydraulically powered ankle foot orthosis (HAFO) is also ongoing and a more integrated Gen 2 HAFO is planned for 2013.

Education Outcomes

The CCEFP continues to provide a culture that prepares students to be effective in industry and academia. Undergraduate and graduate students working on research projects learn to approach their problem from a top-down systems level and from a bottom up detail level. Students connect with industry through the project champions program, the webcast series (led by the Center's Student Leadership Council), the student retreat, the site visits and annual meetings, the IAB Summits, campus and facility visits and one-on-one interaction. Students become familiar with industry practice through summer internships including the Fluid Power Scholars Program, an industry internship program, and by learning about professional development topics, such as the importance of intellectual property, disclosure, ethics and diversity, in the center's webcast series. The Center has hosted 105 REUs over the years including eighteen during summer 2011. Industry members hosted eight interns, in 2011, as part of the Fluid Power Scholars program; 16 students since the program launch in 2010. Scheduling the Center's 6th Annual Meeting with NFPA's Industry Networking Summit in the Fall of 2012 provides CCEFP students with unparalleled opportunities to see the fluid power marketplace first-hand. In turn, the industry audience for learning about the Center's work--through the CCEFP poster session, student-industry speed meetings and resume exchanges, in presentations at the technical sessions, and in discussions prompted by visitors to the joint CCEFP-NFPA event—is far greater than any number possible without this co-location.

We are making significant impacts within the fluid power industry and education. in 2011, the CCEFP industry members hosted eight undergraduate interns, four graduate student interns and one faculty member exchange during 2011. Our recent longitudinal survey revealed the following: 61% of all former CCEFP students are working in fluid power in some way, 50% of all former CCEFP students are working in some industry, 11% of all former CCEFP students are employees of CCEFP fluid power industry member companies, 67% of CCEFP fluid power scholars are hired into the fluid power industry, 55% of all former CCEFP undergraduate researchers enter graduate school, and 33% of those are PhD candidates.

The Center is having a growing impact on the undergraduate and graduate education at its seven universities. Within this recent reporting year, over ten courses have been modified and taught by Center faculty who are incorporating fluid power into the curriculum, including fundamentals as well as the results of CCEFP research, and there are three new courses at the graduate level. New efforts to more actively engage industry in fluid power capstone projects began this year, five projects were initiated. The CCEFP is now playing the role of matchmaker between industry and engineering programs. Every NFPA board members has agreed to sponsor a capstone project. In doing so, these industry leaders are setting examples for all association members, hence we expect the numbers of such projects to increase.

The pre-college outreach program maximizes its impact by leveraging existing networks. Project Lead The Way (PLTW) has incorporated fluid power topics into several of its pre-engineering courses, PLTW teachers have participated in the CCEFP RET program and CCEFP is beginning to develop fluid power training materials for the PLTW summer teacher training workshops. Hands-on fluid power workshops have been developed, including a portable hydraulic excavator demonstrator and a pneumatics training kit. Many hands-on workshops have been conducted for audiences ranging from middle school students to FIRST Robotics teams to 4H Chapters to Girl Scout Troops to RET teachers. The workshops continue to be refined and have been disseminated throughout the Center. The general public is learning about fluid power through a new set of interactive floor exhibits developed and built by the Science Museum of Minnesota, and by proposed interactive multimedia modes of education and outreach.

Industrial Collaboration and Tech Transfer Interactions

Industry participation in the CCEFP remains strong and continues to grow. Eight industry partners contributed approximately $100K this year in equipment, product and cash in support of in support of CCEFP research. Seven students participated in internship in industry through our Fluid Power Scholars program. Our Deputy Director, Prof. Perry Li, took a 6 month sabbatical at one of our IAB member companies.

Industry continues to be very active in selecting research projects. For years 5-6 and again for the year 7-8 funding cycle, experts from the IAB member companies played a strong role in developing the call for proposals and selecting the funded projects. After a thorough review process, the IAB provided their funding recommendation to the IAB representatives on the Executive Committee who were active participants in the final selection.

Industry is being engaged in the planning effort as the CCEFP develops its plan for sustainability after year 10. We have reviewed the plan with the IAB and are now working closely with key members to develop a value proposition and business plan that meets their needs as key stakeholders.

The IAB site visits have become a valuable part of our engagement with industry. Approximately once a quarter, an IAB meeting is hosted by one of our member institutions. These one and a half day events include presentations by researchers on funded projects and typically a facility tour that showcases the university. The networking that occurs at these meeting has proven to be a valuable outcome. Approximately twenty IAB member representatives typically attend these meetings.

Team and Diversity
The interdisciplinary makeup of the CCEFP team is appropriate to achieve its vision. As shown in Figure 1a (section 2.1), most of the faculty are in mechanical engineering or closely related disciplines. However, mechanical engineering is a very broad field with widely varying disciplines. Efforts continue to broaden the disciplines represented in the CCEFP, and for example, the Center's new Education Director, Professor Paul Imbertson is electrical engineering from the University of Minnesota.

In the Y4 report, women, under-represented minorities, Hispanics, and participants with disabilities all had substantial increases. Last year and this year the distribution remained at about the same level for women and Hispanics, although there has been an increase in underrepresented racial minorities in the recent year.

Quantifiable Outputs
Table 1, "Quantifiable Outputs", and Table 1a, "Average Metrics Benchmarked Against All Active ERCs and the Center's Tech Sector" give a snapshot comparison of CCEFP compared to other ERCs. CCEFP conforms to the norms of other centers on funding, research activity metrics and diversity. There were metrics that significantly exceeded norms and are detailed below.

The number of industry members has remained relatively constant. Industrial/Practitioner (member dues) income received in year 6 at reporting time was $628,167, slightly under the total collected in year 5 - $641,250. In addition to the $628,167 collected in year 6, promised membership payments total and added $150,225. Former member contributions both paid and promised, will bring industry income to $804,392, before the end of year 6. Six new industry members joined this year: CNH America, Freudenberg - NOK, Nitta Moore, StorWatts, Walvoil Fluid Power and Woodward Inc. Three companies have paperwork underway to become members in the next few months. The change in Industrial/Practitioner involvement from 54 in year five to 47 in year six is primarily related to involvement type changes as follows: CCEFP changed requirements for non-profits, therefore two Industrial/Practitioners became "Contributing Organizations" and another became an "Innovation Partner". In year six, The Toro Company continued to support CCEFP at the same level it had as member, but as a Contributor. Two other Industrial/Practitioner(s) moved to contributing members through in-kind donations (Bimba Manufacturing and Festo Corporation) during year 6. One or two small Industrial/Practitioner(s) support commitments ended after five years, in year 5. These factors explain the small change in number of industry members.

Because of its extensive education and outreach activities, CCEFP exceeds most norms in these categories. These include summer program participants -- REU students and Fluid Power Scholars (26), undergraduate students (123), courses modified to include CCEFP research content (19), and K-12, general public and generic outreach (10,000+).

Table 1: Quantifiable Outputs

Outputs	Early Cumulative Total [1]	Feb-01-2007 - Jan-31-2008	Feb-01-2008 - Jan-31-2009	Feb-01-2009 - Jan-31-2010	Feb-01-2010 - Jan-31-2011	Feb-01-2011 - Jan-31-2012	All Years
Publications Resulting From Center Support							
In Peer-Reviewed Technical Journals	0	0	12	27	22	12	73
In Peer-Reviewed Conference Proceedings	0	19	57	51	59	52	238
In Trade Journals	0	1	2	23	0	2	28
With Multiple Authors:	0	12	70	101	76	51	310
Co-authored With ERC Students	0	12	51	71	50	51	235
Co-authored With Industry	0	0	2	4	3	2	11
With Authors From Multiple Engineering Disciplines	0	0	4	12	3	6	25
With Authors From Both Engineering and Non-Engineering Fields	0	2	9	\	2	6	26
With Authors From Multiple Institutions	0	0	11	7	10	9	37
Publications Resulting From Associated Projects in the Strategic Plan							
In Peer-Reviewed Technical Journals	0	6	8	16	6	5	41
In Peer-Reviewed Conference Proceedings	0	18	19	23	7	10	77
Publications Resulting From Sponsored Projects							
In Peer Reviewed Technical Journals	N/A	0	0	6	0	0	6
In Peer-Reviewed Conference Proceedings	N/A	0	0	24	0	0	24
Participating Organizations							
Industrial Practitioner Members	114	57	58	54	54	47	384
Innovation Partners	0	0	0	0	0	1	1
Funders of Sponsored Projects	0	0	0	0	0	0	0
Funders of Associated Projects	10	3	6	6	17	10	52
Contributing Organizations	0	0	0	2	5	7	14
ERC Technology Transfer							
Inventions Disclosed (by researchers or tech transfer office)	0	7	8	9	7	12	43
Patent Applications Filed	0	5	5	6	4	4	24
Patent Awarded	0	1	0	0	1	2	4
Licenses Issued	0	0	0	0	2	0	2
Spin-off Companies Started	0	0	0	1	0	0	1
Estimated Number of Spin-off Company Employees	0	0	0	0	0	0	0
Building Codes Impacts	0	0	0	0	0	0	0
Technology Standards Impacts	0	1	1	2	4	1	9
New Surgical and Other Medical Procedures Adopted	0	0	0	0	0	0	0
Degrees to ERC Students							
Bachelor's Degrees Granted	0	6	26	44	18	10	104
Master's Degrees Granted	0	9	15	32	14	10	80
Doctoral Degrees Granted	0	2	6	5	9	6	28
Job Sector of ERC Graduates							
Undergraduates Hired by:							
Industry:	N/A	N/A	N/A	N/A	N/A	4	4
ERC Member Firms	N/A	N/A	N/A	N/A	N/A	0	0
Other U.S. Firms	N/A	N/A	N/A	N/A	N/A	4	4
Other Foreign Firms	N/A	N/A	N/A	N/A	N/A	0	0
Government	N/A	N/A	N/A	N/A	N/A	0	0
Academic Institutions	N/A	N/A	N/A	N/A	N/A	4	4
Other	N/A	N/A	N/A	N/A	N/A	0	0
Undecided/Still Looking/Unknown	N/A	N/A	N/A	N/A	N/A	2	2
Undergraduate ERC Graduates Total	0	0	0	0	0	10	10
Master's Graduates Hired by:							
Industry:	N/A	N/A	N/A	N/A	N/A	8	8
ERC Member Firms	N/A	N/A	N/A	N/A	N/A	2	2
Other U.S. Firms	N/A	N/A	N/A	N/A	N/A	6	6
Other Foreign Firms	N/A	N/A	N/A	N/A	N/A	0	0
Government	N/A	N/A	N/A	N/A	N/A	0	0
Academic Institutions	N/A	N/A	N/A	N/A	N/A	2	2
Other	N/A	N/A	N/A	N/A	N/A	0	0
Undecided/Still Looking/Unknown	N/A	N/A	N/A	N/A	N/A	0	0
Master's ERC Graduates Total	0	0	0	0	0	10	10
Ph.D.s Hired by:							
Industry:	N/A	N/A	N/A	N/A	N/A	2	2
ERC Member Firms	N/A	N/A	N/A	N/A	N/A	1	1
Other U.S. Firms	N/A	N/A	N/A	N/A	N/A	1	1
Other Foreign Firms	N/A	N/A	N/A	N/A	N/A	0	0
Government	N/A	N/A	N/A	N/A	N/A	0	0
Academic Institutions	N/A	N/A	N/A	N/A	N/A	3	3
Other	N/A	N/A	N/A	N/A	N/A	0	0
Undecided/Still Looking/Unknown	N/A	N/A	N/A	N/A	N/A	1	1
Ph.D. ERC Graduates Total	0	0	0	0	0	6	6
ERC Influence on Curriculum							
New Courses Based on ERC Research That Have Been Approved by the Curriculum Committee and Are Currently Offered [1]	0	1	3	2	8	2	16
Currently Offered, ongoing Courses With ERC Content	0	0	15	12	12	19	N/A
New Textbooks Based on ERC Research	0	0	2	1	1	0	4
New Textbook Chapter Based on ERC Research	0	0	0	1	0	0	1
Free-Standing Course Modules or Instructional CDs	0	0	0	0	0	3	3
New Full-Degree Programs Based on ERC Research	0	0	0	0	0	0	0
New Degree Minors or Minor Emphases Based on ERC Research	0	2	0	1	0	0	3
New Certificate Programs Based on ERC Research	0	0	0	0	0	0	0
Total Full-Degree Programs Based on ERC Research	0	0	0	0	0	0	0
Number of Students Enrolled	0	0	0	0	0	1710	1710
Number of Students Graduated	0	0	0	0	0	0	0
Total Certificate Programs Based on ERC Research	0	0	0	0	0	0	0
Number of Students Enrolled	0	0	0	0	0	0	0
Number of Students Graduated	0	0	0	0	0	0	0
Active Information Dissemination/Educational Outreach							
Workshops, Short Courses, and Webinars [2]	0	8	23	9	9	83	132
Number of Participants That Attended Activity	N/A	N/A	0	86	135	2322	2543
Innovation-focused Workshops, Short courses, Webinars, and Seminars	N/A	N/A	N/A	N/A	5	39	44

Number of Participants That Attended Activity	N/A	N/A	N/A	N/A	25	1172	1197
Seminars, Colloquia, Invited Talks, Etc.	0	24	44	24	35	18	145
ERC Sponsored Educational Outreach Events for K-12 Students	N/A	N/A	0	14	28	15	57
Number of Students That Attended Activity, Etc.	N/A	N/A	0	4365	3251	10926	18542
Number of Teachers That Attended Activity, Etc.	N/A	N/A	0	26	30	100	156
ERC Sponsored Educational Outreach Events for Community College or Undergraduate students	0	0	0	8	9	9	26
Number of Students That Attended Activity, Etc.	0	0	0	244	125	5000	5369
Number of Teachers That Attended Activity, Etc.	0	0	0	24	9	50	83
Personnel Exchanges							
Student Internships in Industry	0	12	11	4	14	12	53
Faculty Working at Member Firm	0	0	0	1	1	1	3
Member Firm Personnel Working at ERC	0	2	2	6	0	0	10

[1] New courses currently offered and approved by the curriculum committee are only counted in the first year that they are offered so there is no multiple counting of these courses.

[2] For years prior to 2009, the values include 'Workshops and short courses to industry' and 'Workshops and short courses to non-industry groups'.

Table 1a: 2011 Average Metrics Benchmarked Against All Active ERC's and the Center's Tech Sector

	Average All Active ERC's FY 2011	Average Advanced Manufacturing Sector FY 2011	Average Class of 2006 FY 2011	Minnesota Twin Cities-CCEFP Total	Minnesota Twin Cities-CCEFP Total
Metric	**(13 ERC's)**	**(4 ERC's)**	**(5 ERC's)**	**FY 2011**	**FY 2012**
Organizations Within Non-Industry Sectors	**15**	**14**	**21**	**14**	**7**
Organizations Within Industry Sectors	**28**	**36**	**36**	**62**	**57**
Small	46%	47%	50%	45%	44%
Medium	11%	16%	15%	21%	7%
Large	43%	37%	35%	34%	49%
Industrial/Practitioner Member Firms	**24**	**30**	**32**	**54**	**47**
Innovation Partners	**4**	**3**	**4**	**0**	**1**
Funders of Sponsored Projects	**1**	**0**	**2**	**0**	**0**
Funders of Associated Projects	**12**	**14**	**16**	**17**	**9**
Contributing Organizations	**2**	**3**	**2**	**5**	**7**
Total Number of Organizations	**43**	**50**	**57**	**76**	**64**
Total Membership Fees Received	**$329,083**	**$528,417**	**$460,293**	**$673,250**	**$753,917**
Direct Sources of Support [1]	**$5,957,867**	**$5,484,643**	**$6,310,718**	**$6,008,595**	**$5,830,875**
NSF	70%	70%	75%	71%	69%
Other Federal	0%	0%	0%	0%	0%
State Government	1%	0%	0%	0%	0%
Local Government	0%	0%	0%	0%	0%
Foreign Government	0%	0%	0%	0%	0%
Quasi-Government Research	0%	0%	0%	0%	0%
Industry (U.S. and Foreign)	10%	13%	11%	15%	17%
University (U.S. and Foreign)	17%	16%	14%	13%	14%
Other	1%	0%	0%	0%	0%
Associated Project Support	**$4,606,231**	**$6,039,861**	**$4,923,357**	**$2,750,278**	**$2,311,570**
ERC Personnel & Educational Participants	**3,113**	**2,481**	**2,969**	**3,690**	**16,366**
Leadership Team [2]	15	14	13	11	10
Faculty [3]	44	35	40	42	36
Graduate Students	79	80	73	94	81
Undergraduate Students	36	45	35	63	123
REU Students	18	18	24	26	19
K-12 Teachers	13	20	14	39	21
K-12 Students (Young Scholars)	9	8	3	0	0
Faculty/Teachers That Attended ERC Sponsored Educational Outreach Events for K-12 Students [4]	156	128	91	30	100
Students That Attended ERC Sponsored Educational Outreach Events for K-12 Students [4]	1,802	1,450	2,099	3,251	10,926
Faculty That Attended ERC Sponsored Educational Outreach Events for Community College or Undergraduate Students [4]	43	71	52	9	50
Students That Attended ERC Sponsored Educational Outreach Events for Community College or Undergraduate Students [4]	899	612	525	125	5,000
% Women [5]	27%	30%	30%	26%	24%
% Underrepresented Racial Minorities [6]	15%	15%	15%	26%	34%
% Hispanic [6]	10%	10%	10%	2%	2%
Publications	**Average**	**Average**	**Average**	**Total**	**Total**
In Peer-Reviewed Technical Journals	28	29	36	22	12
In Peer-Reviewed Conference Proceedings	29	16	28	59	52
Multiple Authors: Co-Authored With ERC Students	40	32	47	50	51
Multiple Authors: Co-Authored With Industry	5	3	7	3	2

Metric	Average All Active ERC's FY 2011 (13 ERC's)	Average Advanced Manufacturing Sector FY 2011 (4 ERC's)	Average Class of 2006 FY 2011 (5 ERC's)	Minnesota Twin Cities-CCEFP Total FY 2011	Minnesota Twin Cities-CCEFP Total FY 2012
Intellectual Property	**Average**	**Average**	**Average**	**Total**	**Total**
Invention Disclosures	6	6	5	7	12
Patent Applications	7	6	5	4	4
Patents Awarded	2	2	1	1	2
Licenses (patents, software)	1	1	0	2	0

Education and Outreach Outputs	**Average**	**Average**	**Average**	**Total**	**Total**
New Courses Developed	5	6	6	8	2
Currently Offered, Ongoing Courses With ERC Content	12	11	14	12	19
New Full Degree Programs	0	0	0	0	0
New Degree Minors or Minor Emphases	0	1	0	0	0
New Certificate Programs Based on ERC Research	0	1	0	0	0

[1] - Includes new support (unrestricted cash, restricted cash, and in-kind donations) from Table 9 only. Residual funds carried over from previous years are not included in benchmarking figures.

[2] - Includes Directors, Thrust Leaders, Education Program Leaders, Research Thrust Management & Strategic Planning, Administrative Director, and Industrial Liasion Officer.

[3] - Includes Directors, Education Program Leaders, Thrust Leaders, Senior Faculty, Junior Faculty, and Visiting Faculty.

[4] - Includes participant values from Table 1 Quantifiable Outputs.

[5] - Calculated out of total number of personnel.

[6] - Calculated out of total number of U.S. Citizens or Permanent Residents.

1.3 HIGHLIGHTS OF SIGNIFICANT ACHIEVEMENT AND IMPACT

Highlights for Discovery, Learning and Infrastructure are described below. Since Year 6 is a renewal year, the highlights cover the last three years, that is, Years 4, 5 and 6. All of the highlights listed below were being actively pursued and improved during the entire period except for the Fluid Power Scholars Program. This program was initiated in Year 5 and is currently active and growing.

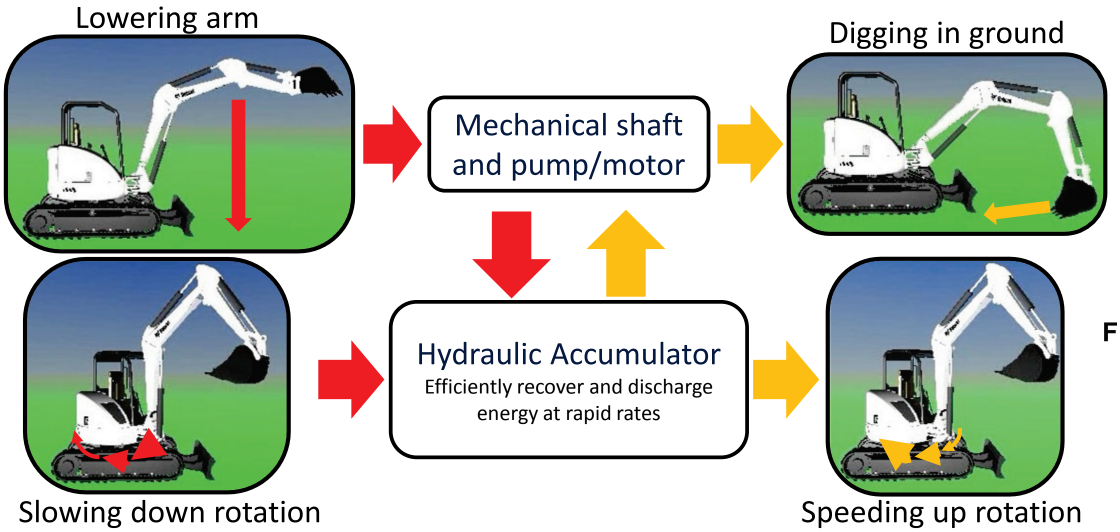
DISCOVERY HIGHLIGHTS:

Displacement Controlled Hydraulic Hybrid Systems Bring Promise of Fuel Savings and Smaller Engines for Mobile Machines (Y4-Y6) - Displacement control is an alternative hydraulic actuation technology that uses variable displacement pumps to control actuator motions, rather than valves. Displacement control reduces power losses and allows energy recovery from gravitational and braking loads. A prototype displacement controlled excavator has been developed within the CCEFP and, in 2010, independent measurements of a truck loading cycle performed by Caterpillar showed 40% fuel savings for the prototype compared to a standard machine with control valves.

Due to the improved efficiency of the displacement controlled hydraulic system, the average engine power required for the mobile machine is dramatically reduced. As a result it is possible to use a smaller and less powerful engine to do the same work if an energy storage device is added. Hydraulic accumulators are optimal energy storage devices for excavators and similar mobile applications because unlike batteries, energy can be captured or discharged quickly and efficiently with accumulators. Additionally the high energy density of batteries is not needed because duty cycles for the machine are relatively short (10 to 20 seconds) and result in small energy storage requirements.

A new hybrid technology that takes advantages of displacement controlled actuation combined with energy storage in hydraulic accumulators is currently under development by researches in the CCEFP. A patent has been filed for the hybrid design which uses displacement controlled actuation for the hydraulic cylinders and a technology known as secondary control (having a hydraulic accumulator for energy storage) for rotary actuators. Simulations of the new hybrid excavator system predict that the max engine power could be reduced by 50% for a truck loading cycle, and fuel savings of greater than 50% could be achieved. In the hybrid excavator system, energy can be transferred to the accumulator either directly from the hydraulic motor when it slows down the rotation of the upper structure or energy that is recovered by the linear actuators when lowering the heavy arm can pass through a mechanical path to drive a pump/motor and charge the accumulator. This energy can then be released to assist in accelerating the rotation of the upper structure or to provide additional power to the cylinders when digging in the ground.

The CCEFP's industry members continue to show their keen interest in this technology and their support for research on the excavator prototype, its implications for other construction and agricultural equipment, and the resulting potential for economic and environmental benefits.



Fluid

Fluid-

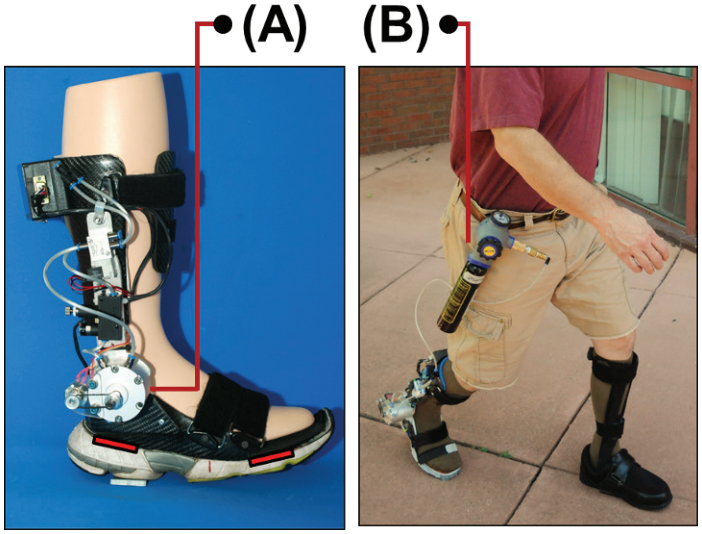
In the figure above, red arrows indicate energy being captured and orange arrows indicate energy being discharged.

Powered Orthosis Can Enable Millions (Y4-Y6) - The fluid-powered Ankle-Foot-Orthosis (AFO) has facilitated the development of miniature fluid power systems by pushing the practical limits of weight, power and duration for compact, untethered, wearable fluid power systems. New market opportunities for the fluid power industry will result from this research. At the same time, the centerpiece for the research, an ankle-foot-orthosis, holds the promise of enabling people with mobility impairments to walk with greater stability, confidence and independence, including those with stroke, cerebral palsy or acute trauma. NSF's ERC program has enabled the cooperative efforts on this CCEFP test bed among researchers and students at five universities in the Center network.

The portable powered ankle-foot-orthosis (AFO) uses pneumatic power, provided by compressed CO_2, to move the ankle in the dorsiflexion (toes up) or plantarflexion (toes down) direction. Recent results demonstrate that the AFO is capable of providing untethered functional assistance for people with lower leg weakness. One test participant had plantarflexor weakness due to a spinal injury and could no longer generate torque at the ankle to push his toes down. This impairment affected his ability to propel himself forward while walking making extended walking exhausting. Another test participant had muscular dystrophy, a disorder that caused weakness in both her calf and shin muscles.

The CCEFP AFO was able to provide functional assistance to both users. Although the AFO was not capable of providing enough power to fully restore normal propulsive torque, it was able to generate sufficient power to assist propulsion. For the person with plantarflexor weakness, the added plantarflexor torque resulted in increased single leg support on the assisted side and more normal ankle motion. For the person with dorsiflexor weakness, the AFO controlled the motion of the foot during swing. The assistance eliminated a tripping hazard by keeping her toes from contacting the ground during swing.

CCEFP researchers from the University of Illinois, University of Minnesota, Milwaukee School of Engineering, Georgia Institute of Technology, and North Carolina A & T together are working on the development of a next generation AFO that will push the limits of fluid power technology. These innovative projects will deliver a miniature and integrated power supply, novel actuators, valves, transmission lines and housing, and will also address the complex engineering issues to create novel powered exoskeletons that can assist persons with disabilities.



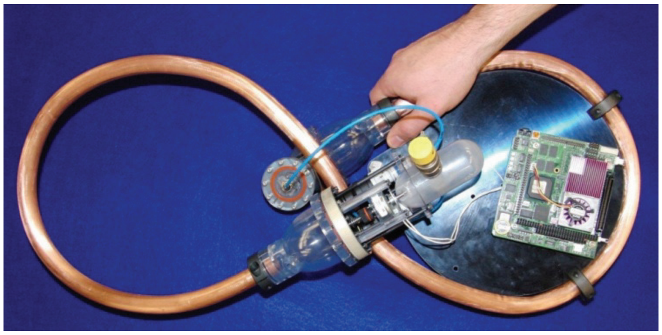
(Left) The Ankle-Foot-Orthosis (AFO); (Right) Untethered use of the AFO. The rotary actuator (A) was powered using a compressed CO_2 bottle (B).

CCEFP Research in Small Free-piston Engine Compressors May Open New Markets to the Fluid Power Industry (Y4-Y6) - CCEFP researchers at Vanderbilt and the University of Minnesota, with support from Center colleagues at the University of Illinois and Georgia Tech, have developed two free-piston engine compressors: a medium power, high inertance compressor for application devices comparable in size to a compact rescue robot (a Center test bed) and a miniature free piston engine compressor for the fluid power orthosis (another of the Center's test beds). This work in compact pneumatics has the potential for enabling small mobile applications hence opening new markets for the fluid power industry. It also illustrates the benefits of inter-university collaboration which an ERC fosters.

The high inertance free piston compressor represents a significant advancement in the field of compact pneumatic power. The system has an energy density that is five time higher than a battery-powered motor actuated system. This means that an untethered device—self-propelled or carried—can be lighter and operate for longer. Replacing batteries with the engine/compressor and replacing motors with high power density pneumatic actuators results in a device that is more powerful, runs longer and is ultimately more useful. This is achieved by using a novel liquid piston trapped between elastic diaphragms. The device exploits the fluid hammer effect of liquid in a long pipe—the same effect that bangs your water pipes inside your walls when you suddenly turn the faucet off. Since this is a free-piston engine, it can instantly turn on to produce power when it is needed or stay idle for seconds, days, or months without wasting fuel.

Developing a small size engine compressor is not as straightforward as developing a larger scale device because designing tiny valves, sensors, actuators is challenging and the behavior of ignition is different. In addition, fabricating miniature components with tight tolerances is not easy. But here, many components are constructed using stereolithography which dramatically lowers the total weight and allows for intricate, strong, and compact components. The unique "figure 8" arrangement of the liquid piston self-balances the device to reduce vibrations and eliminate the need of opposing cylinders. The device features on-board electronics and seamless tubing to lower hydraulic friction and improve efficiency.

The second engine is a tiny homogeneous charge compression ignition (HCCI) engine compressor that creates air at 80 psi for small powered devices such as an active ankle foot orthosis or a powered construction tool. The prototype device is the world's smallest air compressor. Developing the tiny engine requires comprehensive mathematical models of the ignition, fluid flow and mechanical motion of the parts and clever manufacturing methods. Recent results have led to the first ever models of the small engines that power model aircraft, useful benchmarking devices for the new CCEFP engines. Performance measurements on the tiny engine-compressor prototypes are being used to improve and calibrate the mathematical models. Extensive work is going into accurate models of the combustion and scavenging processes as they are key to high operating efficiency. Plans include improving the tiny engine compressor efficiency and to use di-methyl ether (DME) fuel, a low emission, non-toxic alternative that has excellent combustion and emission characteristics.



High inertance free-piston compressor with self-balancing "figure 8" design.

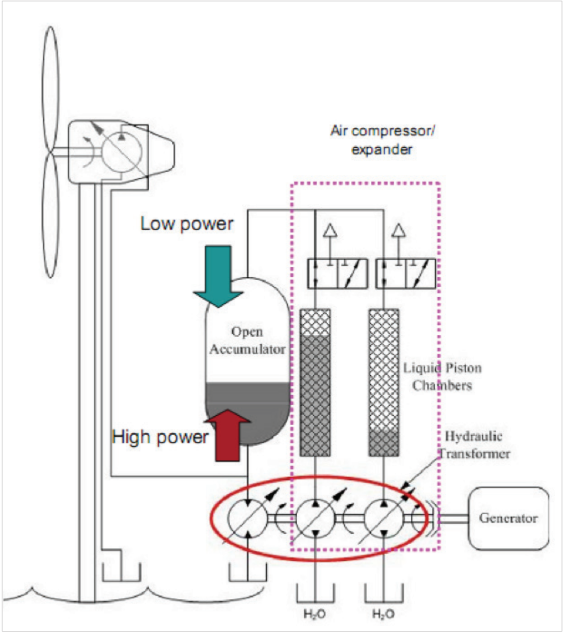
World's smallest free-piston engine for small, mobile fluid power applications.

Open Accumulator Developed for Off-shore Wind Power Energy Storage (Y4-Y6) - Because of the intermittent and unpredictability nature of wind power and the fact that wind is generally more abundant during nighttime hours when demand is low, the ability to store wind power can significantly increase the usefulness, predictability and availability of this renewable, clean energy source. For off-shore wind farms, where transmission and connections are more costly, localized energy storage can also increase the annual energy output of these critical pieces of the electrical infrastructure. However, storing large amounts of energy (in the order of several MW-hrs) economically, efficiently and with the capability of high conversion rates (at several MWs) is a challenge.

In answering to this challenge, CCEFP researchers have recently applied for and received a four- year, $2 million research grant from the National Science Foundation (NSF) Engineering Frontiers for Research and Innovation (EFRI) program to develop a fluid power-based approach to wind energy storage. This grant is one of four awards made in the renewable energy storage area, a focus topic for the 2010 NSF competition. The grant enables the CCEFP to extend its research efforts into an application area with higher power and weight levels than that of other Center projects. In doing so, a multi-disciplinary, multi-university team of researchers will draw on the open accumulator energy storage concept, already developed within the CCEFP.

The research team is developing a method to store excess wind energy as high pressure compressed air in pressure vessels at or near the wind turbine. The compressed air is then released to generate electricity when the instantaneous wind power is not sufficient to meet current power demand. This way, power output from the wind turbine will be more predictable and steady, and energy that would otherwise be wasted will be captured. Because energy storage occurs prior to generation of electricity, many electrical components can be downsized. By enhancing heat transfer inside the air compressor/expander, a near isothermal process is achieved thus attaining high efficiency.

The open accumulator concept makes use of the high power capability of hydraulics (liquid fluid power) and the high energy density of pneumatics (gas fluid power) in a single architecture. The open accumulator architecture allows the system to operate at nearly constant pressure, regardless of the energy content, so that efficiency and power capability can be maintained at all times. Research currently focuses on effective heat transfer and fluid mechanics to make the air compression/expansion process occur efficiently at a nearly constant temperature, on design of efficient machine elements, and on system optimization and control.



Open accumulator energy storage concept enables energy storage at the turbine.

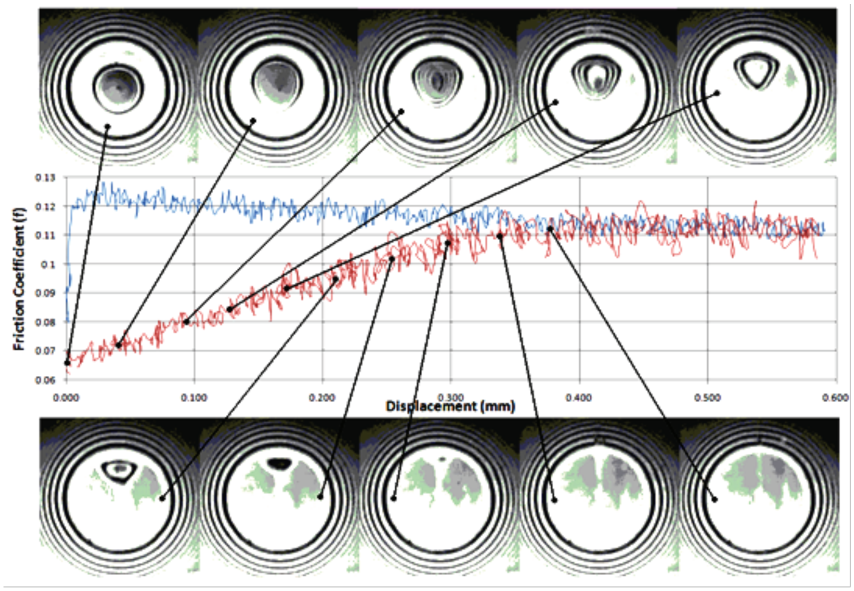
Understanding Friction in High-Pressure Films and Its Impact on Fuel Efficiency (Y4-Y6) - Certain hydraulic motors are now sized larger than is necessary for steady operation because of the need to overcome significant start-up friction. Larger motor size results in greater costs and decreased efficiency. But the work of researchers at the CCEFP is increasing understanding of friction in high pressure contacts, improving modeling capabilities, and pointing toward practical applications that could lead to reducing equipment and fuel costs while increasing efficiency.

Among their findings, participants in the research team have observed that dimples filled with highly pressurized oil, known as elastohydrodynamic lubrication entrapments, appear in the contacts between components made of hardened steel following a sudden halt to rolling or sliding motion or after an impact. These entrapments may support a significant portion of the contact load and could, therefore, reduce the startup friction by providing less resistance to sliding for a portion of the contact area.

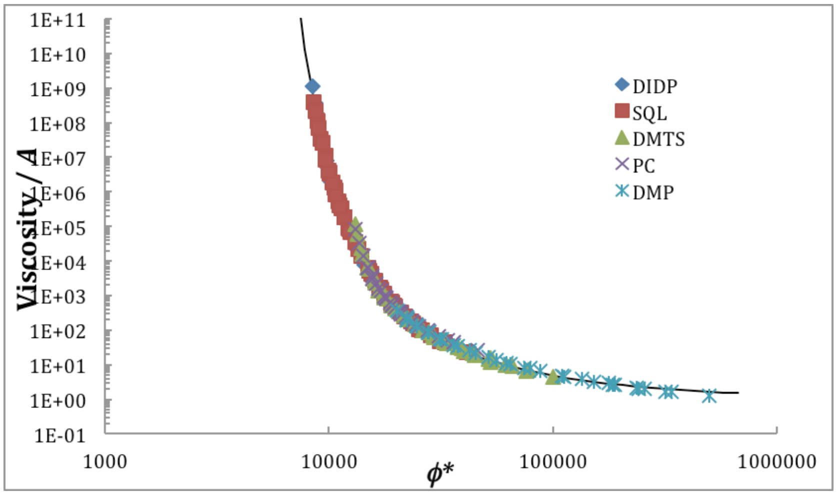
In testing their hypotheses, a specialized rig was constructed to slide a sapphire plate against a hardened steel ball. In some tests, an entrapment was formed between the ball and plate. The friction at the start of sliding was measured and the tests with an entrapment were compared to those without.

This experiment demonstrates that entrapments can substantially reduce start-up friction (about 50% shown above) and give new insights into how they may be used to improve the performance of hydraulic motors.

Further, this team, in cooperation with colleagues from eight laboratories in five countries, has been able to accurately calculate friction of a high-pressure, sliding contact in the thermal regime from the measurable properties of the liquid. This required a correlation of the transport properties of the liquid, viscosity, and thermal properties with respect to temperature and pressure. The team also established a framework for thermodynamic scaling of transport properties of liquids which rolls the temperature and pressure dependence into a single parameter. This framework was and is being used in friction calculations. A new normalization of the scaling parameter for viscosity provides a single equation to describe behavior of a broad range of temperature and pressure that previously required two different forms of the free volume relation, (Batchinsky and Doolittle). The new equation should be superior for extrapolation to extremes of temperature and pressure.



One comparison of the effect of an entrapment on sliding friction: The upper (blue) curve corresponds to the friction measured without an entrapment whereas the lower (red) curve is the friction measured with an entrapment. Ten micrographs of the contact showing the shape and position of the entrapment surround the plot. Lines in the figure show the position on the friction plot corresponding to each micrograph.



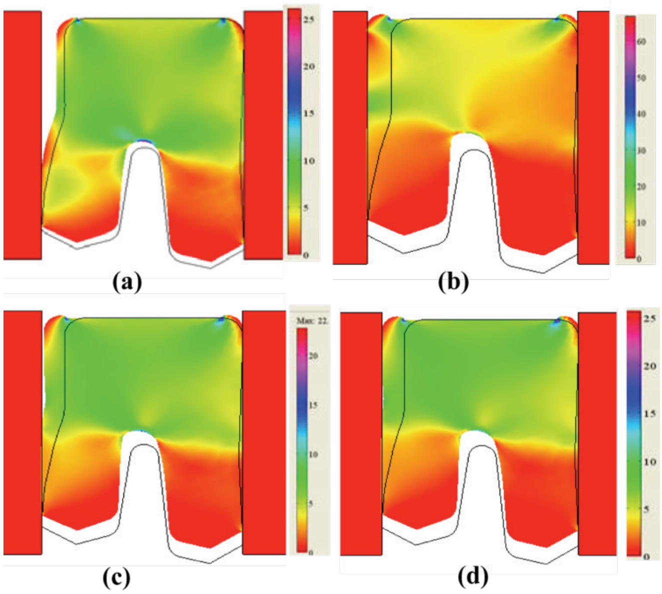
This figure plots the viscosity of five very different liquids; dimethyl pentane, a fuel; propylene carbonate, a solvent; decamethyl tetrasiloxane, a silicone oil; squalane, a hydrocarbon oil; and diisodecyl phthalate, a diester oil for temperatures to 150°C and pressures to 1.2 GPa (175,000 psi). A single relation, plotted as the curve, describes the viscosity of all materials at all conditions with a standard deviation of relative viscosity of 16%.

Viscoelastic Seal Modeling, Developed by CCEFP Researchers, Brings Significant Benefits to the Fluid Power Industry and the Environment (Y4-Y6) - Virtually every fluid power manufacturer recognizes that in order to expand the industry's markets, leakage of hydraulic fluid from fluid power systems must be eliminated or, at the very least, significantly reduced. The elastomeric rod seal is vitally important to this effort. This seal type seals the gap between the protruding rod and the housing of a linear hydraulic actuator, one of the most critical elements in a hydraulic system. As such, the elastomeric rod seal must prevent the leakage of hydraulic fluid directly into the environment. Until now, these seals have been developed through empirical means, using trial and error techniques, since the fundamental physics of seal operation have not been well understood.

Now, however, researchers at the CCEFP have developed a numerical viscoelastic model of the rod seal that is capable of predicting key seal performance characteristics, especially seal leakage and friction. It can also serve as a design tool. The model simulates the dominant physical processes governing the operation of the seal. It analyzes the behavior of the hydraulic fluid in the interface between the seal and the rod, the contact between asperities on the seal and the rod, and deformation of the seal.

Previous models treat the seal material as elastic, reacting instantaneously to changes in the sealed pressure within the actuator. However, CCEFP reseaarchers have found that the polymeric materials used for seals are viscoelastic and have a delayed reaction to pressure changes. Since they have a memory, the behavior of the seal depends on its past history. Such viscoelastic effects are taken into account in the CCEFP model.

In developing this model, CCEFP researchers have not only provided a tool but also the physical understanding that allow for the development of seals that will eliminate or substantially reduce leakage from fluid power components such as actuaors, valves and pumps. The benefits to the fluid power industry and to the environment are significant.



An example of a graphical output from the model: Deformed seal configurations and von Mises stress fields at various times.

LEARNING HIGHLIGHTS

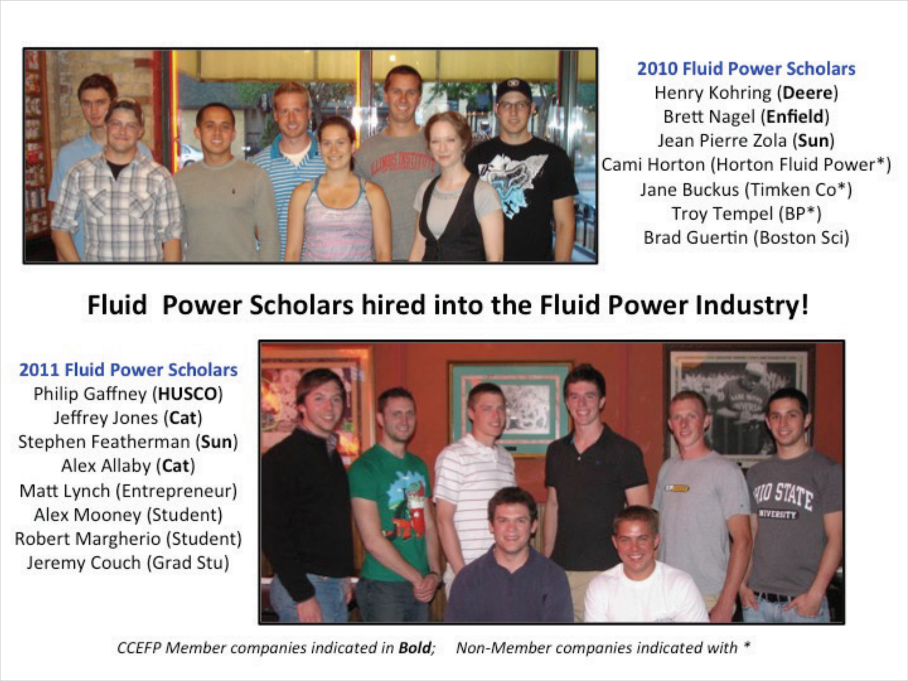
Engineering Students and the Fluid Power Industry Benefit from the CCEFP Fluid Power Scholars Program (Y5-Y6) -

> *I gained an immeasurable amount of experience—nothing you can read from a textbook or learn in a class. The internship experience really opened up my eyes to the amount of work, resources and right people it takes to take a design from concept to product.*
>
> [I gained] *a great understanding of how the engineering process works—from the initial idea, through the research and development states, to the testing of the component.*
>
> *The biggest thing I gained was a full-time job! I was happy to find out that they* [the sponsoring company] *wanted to hire me full time at the end of the summer!*

These are among the responses to the CCEFP Fluid Power Scholars Program post-experience survey question, “What did you gain from your internship experiences?” While heartening in themselves, these responses also are representative of a broadly positive assessment of the program—start to finish—from students and industry mentors alike. Key elements and outcomes include:

- To date, 16 Fluid Power Scholars have been engaged in the program’s first two years—2010 and 2011. Subsequently, seven of these Scholars have been hired full-time by their internship host company (a CCEFP member company), and three Scholars have been hired by companies with interests in fluid power but that are not CCEFP members. Looking at the numbers in another way, 63% of Fluid Power Scholars are working in the fluid power field.
- Nine Fluid Power Scholars will be supported by eight fluid power companies in the summer of 2012, the program’s third year.
- The program itself was designed jointly by a team of CCEFP staff and members of the Center’s Industrial Advisory Board. Based on this plan, supporting companies of the CCEFP volunteer to provide summer-long engineering internships in their companies to undergraduate engineering students. They also provide stipends for room and board during an intensive orientation to fluid power at the Milwaukee School of Engineering’s (MSOE) Fluid Power Institute before the internships begin. The CCEFP covers these instructional costs. And, while CCEFP staff recruit student applicants, it is the companies themselves that make their scholar/intern selections based on students’ on-line application materials and subsequent interviews.
- The fluid power orientation draws on the teaching expertise of MSOE, one in the CCEFP’s network of seven schools. All 16 of the selected scholars/interns pointed to the strength of the initial two and one-half day program in their evaluations; several asked that it be longer. Going forward, it will be. In 2012, the orientation will be expanded to three and one-half days. For their part, companies noted that with this learning experience at the outset, students arrived at their internships ready to “hit the decks running.”
- More than 40 students applied to the program in 2010, with 60+ in 2011, and over 50 in 2012 (several of whom are repeat candidates). Applicants came from schools within and outside of the CCEFP network. Of the sixteen scholar/interns selected in the program’s first two years, 69% represented schools outside of the CCEFP: Case Western Reserve University, Clarkson University, Illinois Institute of Technology, Montana State University, University of Florida, University of Michigan, University of Missouri-Columbia, and the University of South Florida. Additional scholars represented the University of Minnesota, Georgia Institute of Technology and Purdue, all CCEFP schools.
- Deltrol Fluid Products, HUSCO International, Caterpillar, Sun Hydraulics, Case New Holland, John Deere, and Parker Hannifin will host scholar/interns in 2012; all of these companies have participated in the program in 2010 and/or 2011. Eaton Corporation will join them as a sponsor.

The CCEFP's Fluid Power Scholars Program is an outstanding example of an effective industry/university partnership spawned by NSF's ERC program. At every stage and at every level, CCEFP corporate supporters worked enthusiastically—first with CCEFP staff and then with their selected students—in creating environments where scholar/interns could effectively apply what they had learned about fluid power in the classroom to hands-on, real-world applications.



2010 Fluid Power Scholars
Henry Kohring (**Deere**)
Brett Nagel (**Enfield**)
Jean Pierre Zola (**Sun**)
Cami Horton (Horton Fluid Power*)
Jane Buckus (Timken Co*)
Troy Tempel (BP*)
Brad Guertin (Boston Sci)

Fluid Power Scholars hired into the Fluid Power Industry!

2011 Fluid Power Scholars
Philip Gaffney (**HUSCO**)
Jeffrey Jones (**Cat**)
Stephen Featherman (**Sun**)
Alex Allaby (**Cat**)
Matt Lynch (Entrepreneur)
Alex Mooney (Student)
Robert Margherio (Student)
Jeremy Couch (Grad Stu)

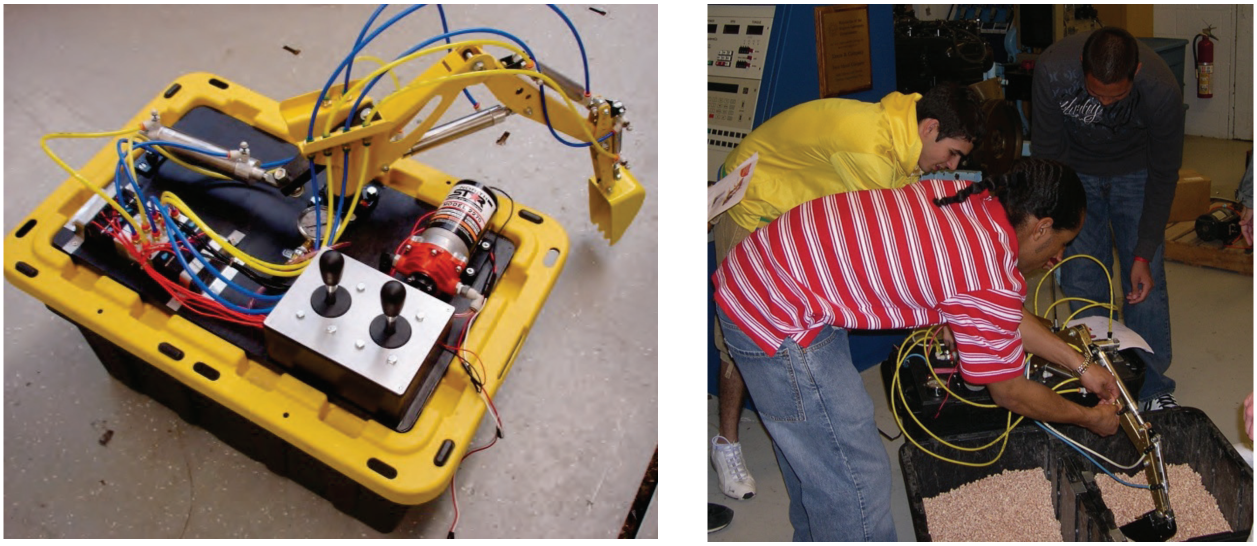
*CCEFP Member companies indicated in **Bold**; Non-Member companies indicated with **

CCEFP Faculty and Students at Purdue Develop Hands-on Learning Tools (Y4-Y5) - At Purdue, water hydraulics has proven to be an effective medium in helping pre-college and undergraduate students better understand fluid power: A micro-fluid power excavator, useful in illustrating a fluid power system and its attributes, is the centerpiece for educational outreach activities well-suited to pre-college students, and a water hydraulics test stand has been developed for use in one of the university's undergraduate instructional labs. The micro-excavator is already being duplicated for work with a number of student audiences and plans are underway to replicate the test stand, too. Both projects illustrate the benefits of partnering and multi-disciplinary teamwork, both hallmarks of ERC programs.

Micro-excavator: A micro-excavator, powered by water hydraulics (or pneumatics) and small enough to fit in a hand-carried storage bin, is providing a new platform for increasing understandings of the importance of fluid power as well as insights into the technology itself. This innovative, learning resource is well-suited for many audiences—in classrooms, museums, even in corporate lobbies. The micro-excavator was built at Purdue by a team that included faculty, engineering undergraduate and graduate students, high school teachers who are also involved in Project Lead The Way, and staff members of the Minnesota Science Museum (SMM). The National Fluid Power Association (NFPA) assisted the CCEFP in providing financial support. Both SMM and NFPA, an industry trade group, are affiliated organizations of the Center.

Extensive field tests with students, in and out of school settings, indicate that the micro-excavator is an effective hands-on teaching tool. An accompanying curriculum guide lays out effective strategies for maximizing the teaching power of the micro-excavator while working with students in grades 8-12. (Teachers involved in the project have assured that this curriculum correlates with education standards and outcomes [Indiana].)

The kit is easily replicated. A complete, working micro-excavator can be built and readied for classrooms and hands-on displays for approximately $800. The kit includes a water pump, necessary power supplies, hardware (nuts, bolts, etc.), cylinders, valves, tubing, fittings, an excavator arm and a storage case. No special assembly tools are needed; the demonstrator is built using common shop tools (wrenches, screwdrivers, hacksaw and drill). A construction manual, bill of materials and the curriculum guide are all posted for free download at the CCEFP website (www.ccefp.org).

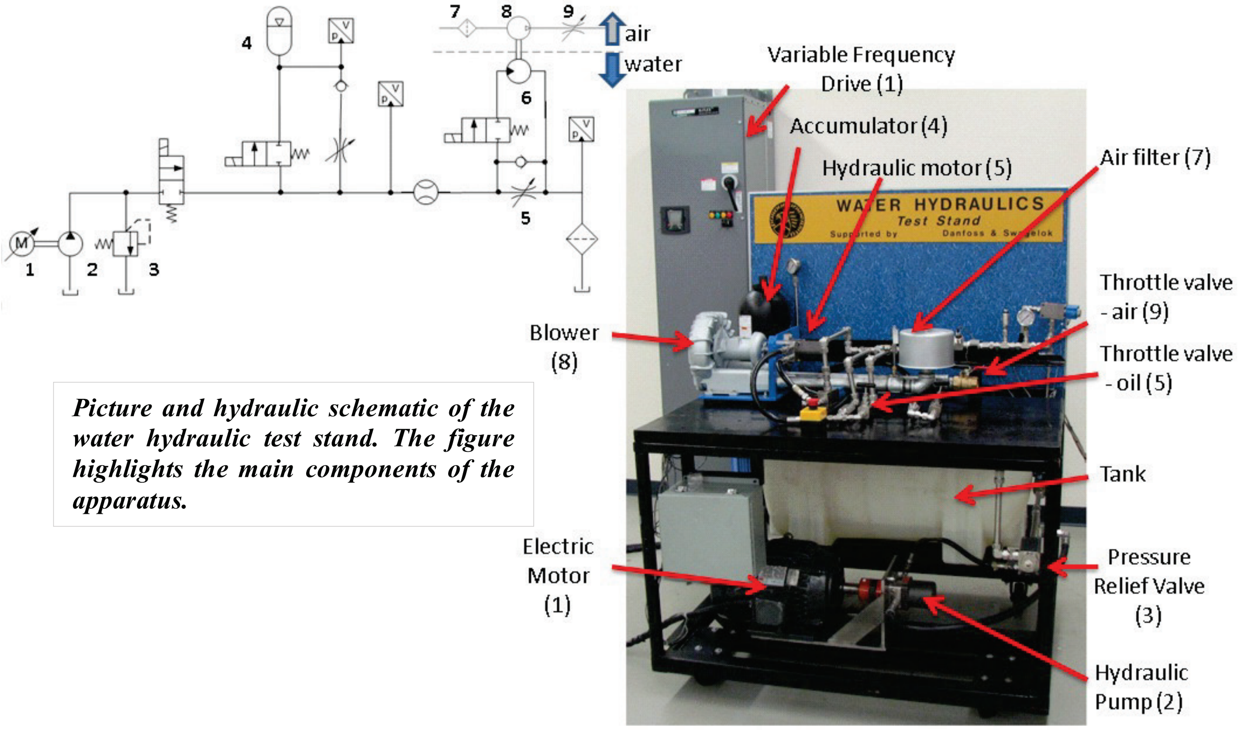


Electronically-controlled portable fluid power demonstrator.

Test stand: A high pressure (p_{max}=140 bar) test stand, using tap water as the working fluid, has been developed within the *Fluid Power in Fluid Mechanics* project supported by the CCEFP and the National Fluid Power Association (NFPA). Installed at the Fluid Mechanics Lab in Purdue's Mechanical Engineering Department, the test stand enables undergraduate students to better understand fluid power principles within the context of their fluid mechanics courses. The stand is complemented by a mini-book containing basic examples of hydraulic systems. While the mini-book provides the theoretical understanding of the operation of fluid power components according to the basic principles of fluid mechanics, the rig offers:

- characterization of pumps and motors,
- study of the operation of pressure relief valves and variable throttle orifices,
- analysis of the operation of an open circuit hydrostatic transmission,
- study of a hydraulic air blower-drive system,
- energy storage in hydraulic accumulators and energy recovery in hydrostatic transmissions.

During fall 2011, 218 junior engineering students successfully operated the water hydraulic test stand, documenting their work in conventional lab report formats. Given the success of its first application, the teaching methodology developed within the *Fluid Power in Fluid Mechanics* project will become a standard for introducing fluid power concepts to Purdue's mechanical engineering students. Additional students will benefit from this project, too. Plans call for *Fluid Power in Fluid Mechanics* to be presented as a teaching model to CCEFP participating universities and to academic institutions outside CCEFP.



Picture and hydraulic schematic of the water hydraulic test stand. The figure highlights the main components of the apparatus.

Promoting STEM among Pre-college Students: the gidaa odaangiina anaangoog (Shooting for the Stars) Robotics Program (Y4-Y6) - The CCEFP's Education and Outreach program continues to promote STEM education. Students in and around Cloquet, Minnesota, site of the Fond du Lac Indian Reservation and the Fond du Lac Tribal and Community College, and Culver, Minnesota (just northwest of Duluth), site of the South Ridge School, are focal points of several Center efforts. Many of the students in both areas are Native Americans. The CCEFP has provided ongoing co-sponsorship of **gidakiimanaaniwigamig STEM Programs** (gidaa) for K-12 students over the last six years and, in 2009, launched the **gidaa odaangiina anaangoog (Shooting for the Stars) Robotics Program** at South Ridge School (formerly Albrook School). This program includes robotics education for students in grades 7 to 12 as well as a training component for local science and technology teachers; it has grown by leaps and bounds since its launch.

With support from the CCEFP, South Ridge has been able to offer its students a year-long robotics course that is integrated into the school day, as well as an after-school program that meets two nights a week over the course of three months. The robotics day course is open to high school students, grades 10-12, and is a conduit to STEM-relevant activities. The course allows students to explore the world of robotics through VEX Robotics Systems (a product from Innovation First International) and NXT Robotic Systems (a Lego Education product). The curriculum includes instruction and hands-on learning in various programming languages including "Graphic Based" and "C". Students use problem solving and programming to complete a series of tasks and challenges.

The robotics after-school program, tailored to grades 7-12, allows students to build a robot to compete in the annual RoboFest Robotics Challenge, a competition designed to promote and support STEM activities. In this competition students are asked to design, build, and program robots that do real work. RoboFest is a grass-roots program created by Lawrence Technical University in Southfield, Michigan. It is a program that serves the population of the gidaa students well.

So far, a total of over 60 students have participated in these two programs, 65% of students represent racial or ethnic minorities, and approximately half are female. With the support of the CCEFP, South Ridge School will host its third annual RoboFest Competition in Spring 2012. South Ridge School is currently the only site in the state of Minnesota to allow students to qualify for the International RoboFest Competition, held at Lawrence Technical University. (Last year the CCEFP helped to send the first South Ridge team to the International RoboFest Competition.) Additionally, South Ridge will be offering a robotics teacher training workshop for local technology educators who are motivated and showing interest in starting robotics programs in other schools. Because of these efforts, and the excitement about technology and engineering that they generate, South Ridge also plans to enter its first vehicle into the Super High Mileage Vehicle Competition held at Brainerd (Minnesota) International Raceway.

2011 South Ridge School RoboFest Competition.

INFRASTRUCTURE HIGHLIGHTS

Progress on an Excavator Human-Machine Interface Simulator Illustrates Benefits of CCEFP University/Industry Collaboration (Y4-Y6) - Researchers at Georgia Tech and North Carolina Agricultural and Technical State University, in cooperation with their CCEFP colleagues at Purdue University as well as with input and contributions from several of the Center's industrial partners, are making significant progress in their approaches to enhancing the work performance of mobile equipment operators. This multi-disciplinary team approach illustrates a key value of an ERC collaborative research project.

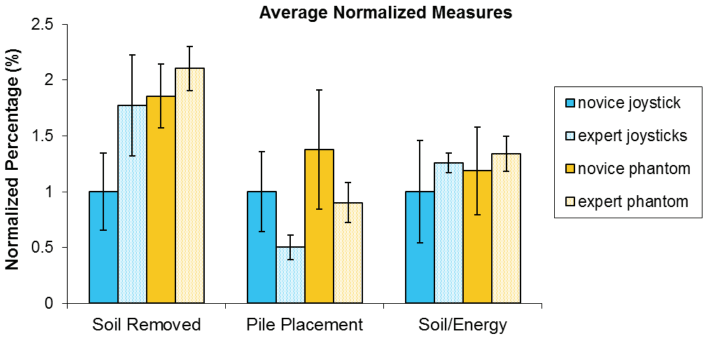
The excavator simulator, developed at Georgia Tech, combines the cab of a Bobcat 435 mini-excavator (the same model as the Center's excavator test bed at Purdue) with a full dynamic model of the excavator's hydraulic and mechanical systems and their interactions with the environment. A 52" LCD television screen, mounted vertically on the cab's windshield, is used to display the simulated excavator arm and environment.

The fidelity of the graphics program exceeds that of most academic simulators. In addition to donating an excavator to the project, Bobcat gave access to the CAD files of the machine, which allowed researchers to create a high-fidelity graphical model of the arm. The environment shown includes trees and bushes and the shadow of the excavator's arm to increase the operator's depth perception. The graphics program also plays a continuous engine noise track that varies in volume with the power demand of the pumps. The excavator's dynamics are calculated at 1 kHz in real time on an xPC® target. A new soil model was developed for the simulator that calculates environmental forces for any bucket trajectory through the soil. Researchers at Purdue made friction, line loss, and other measurements that were included in the model and improved its fidelity.

The machine's original hydraulic joysticks were removed and replaced with two electronic joysticks donated by Sauer Danfoss to provide baseline testing. Two new types of joysticks have been tested in the cab. The cab has been further upgraded to swing to match the simulation, and the display is being upgraded to a 3D display of the arm and the job site. The swing actuation uses the original Bobcat swing motor and donated valves from Sun Hydraulics.

Current work employs three new control joystick designs. The new devices seek to provide a more intuitive relationship between the operator's motions and the commanded motions of the excavator arm. Current research is ongoing on what type of feedback will improve operator performance. A 'ghost arm' has been added to the graphics program that shows the commanded arm position. In addition, NCAT is exploring operator behavior when using the various interfaces to enhance compatibility between machine and operator.

The implications for increased efficiency and improved performance resulting from this collaborative research are significant. Improvements in excavator productivity, fuel efficiency, accuracy of motion, and frequency of errors are indicators of performance. To date, performance improvements using these measures have been particularly dramatic for novice operators: they perform at the current level of experts.



Donation of Free Piston Engine Pump Enables Vitally Important CCEFP Research (Y4-Y6) - CCEFP researchers are hard at work in identifying ways to cut both fuel consumption and emissions for mobile applications. Hence, Ford Motor Company's donation of a hydraulic free piston engine (HFPE) to support the CCEFP's work at the University of Minnesota is of great significance. The presence of this unique engine facilitates research efforts for mobile applications (10-500kw) including both on-highway vehicles and off-highway heavy equipment. It also provides an outstanding example of the spirit of industry/university cooperation that is at the heart of the ERC program.

The HFPE is an opposed cylinder opposed piston engine with a linear hydraulic pump. Unlike a conventional crankshaft-based ICE driven rotational pump, this system can produce fluid power in real-time with linear motion and with much improved efficiency and reduced emissions. There are two opposed combustion cylinders in this engine. Combustion in one cylinder will compress gas in the other cylinder and pump high-pressure fluid at the same time. Alternating firing in the two cylinders will move the pump back and forth to produce fluid power.

There are three key advantages of the HFPE. First, the energy conversion efficiency is greatly improved from the conventional internal combustion engine (ICE), enabled by the variable compression ratio, advanced combustion such as homogeneous charge compression ignition (HCCI), and lower friction. Second, the linear hydraulic pump/motor offers higher efficiency due to a simpler design. Third, the output power can be adjusted quickly in real-time due to the modular nature of the free piston engine.

Hydraulic Free Piston Engine

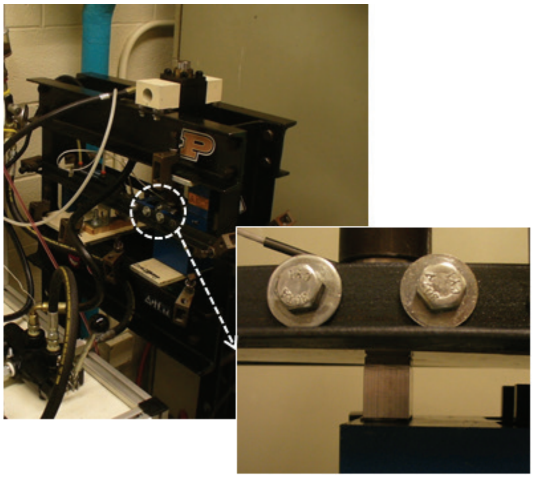
The ultimate goal of this project is to apply the HFPE in ways that enable new mobile applications, such as hydraulic hybrid vehicles or hybrid heavy equipment, to proactively answer to today's and tomorrow's energy and environmental needs. Toward that end, CCEFP-led fundamental research has been conducted with the help of this unique infrastructure; dynamic models for the combustion, fluid power and gas exchange dynamics have been constructed. Novel control methods to ensure robust and precise engine operation have been proposed and investigated. The results are very promising and have generated several publications and an IP disclosure.

High Load, Variable Contact, Start-Up Friction Test Rig (Y4-Y6) - Hydraulic motors are used in many applications because of their durability, serviceability, and high power in a compact package. However, they also tend to be very inefficient at start-up, primarily due to extremely high friction generated between its internal components as motion begins. This issue requires the designer of hydraulic systems to specify larger motors than necessary just to overcome start-up friction, making the overall weight and cost of the vehicle higher. The first step in addressing this limitation is gaining a fundamental understanding of the mechanisms underlying start-up friction so that it can be not only predicted, but modulated through design.

Toward this end, CCEFP researchers have developed a novel, first of its kind, test apparatus to measure start up friction. This instrument is capable of reproducing interface conditions typical of hydraulic motors; specifically, high loads induced by fluid pressure, variable contact area shapes, and the presence of a hydraulic fluid. So far, the research team has used this novel tool to study the effects of surface patterning and hydraulic fluid chemistry. Surface patterning was made possible through collaboration with researchers at the University of Illinois at Urbana-Champaign. The UIUC team provided samples containing dimples, of varying size and distribution on the surfaces, whose effect on start-up friction was investigated using the test rig. The goal of this aspect of the project was to identify optimal combinations of surface features that could be used by designers to minimize start-up friction.

The test rig was also introduced to study the effect of hydraulic fluid formulation. Although viscosity is a major factor in friction generally speaking, it is thought to play a less significant role in start-up friction since the maximal friction occurs before motion begins. Therefore the team studied hydraulic fluids with different chemical compositions but similar viscous properties, provided by researchers at the Milwaukee School of Engineering.

The project through which this test rig was build is ending in May 2012 (the PI has moved to a new institution and the current graduate student working on the project will graduate in April). The plan for the test rig is for it to be sent to the Illinois Institute of Technology where a former CCEFP PhD student is now a faculty member. He is in the process of building a fluid power research laboratory there.



The development and use of the test rig illustrates the value of an ERC program. Progress and full utilization of the test rig benefitted from the collaborative efforts of researchers at three CCEFP institutions. Future plans for the test rig illustrate additional benefits—this project's multiplier value and its reach. In this case a CCEFP graduate student is now a teacher at an institution outside of the CCEFP network where he is drawing on his knowledge of fluid power, gained through Center work. This test rig will be a very helpful tool as he involves additional students in developing the IIT fluid power program with its research laboratory.

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2. STRATEGIC RESEARCH PLAN AND OVERALL RESEARCH PROGRAM

The CCEFP research plan was strategically derived from the Center's vision and major goals. The four major goals are:

1. Increase efficiency in existing fluid power applications.
2. Expand fluid power use in transportation to reduce fuel consumption.
3. Create portable, un-tethered human-scale fluid power applications.
4. Making fluid power ubiquitous, meaning that fluid power is safe, quiet, clean and easy to use so that it can be used anywhere.

The test beds represent systems that were carefully selected to align with the goals. The heavy mobile equipment test bed was chosen to address efficiency of existing systems. The transportation test bed was chosen to expand fluid power use in transportation. The human-scale equipment and the human-assist device test beds were chosen as examples of future portable human-scale fluid power applications. The ubiquity issues apply to all test beds.

The technical barriers to overcome to realize the test beds' vision can be described using nine important attributes of future fluid power systems. The four test beds and their contributions to the nine important fluid power attributes are shown in the chart below.

	Technical Barriers								
	Efficient Components	Efficient Systems	Control and Energy Management	Compact Power Supply	Compact Energy Storage	Compact Integration	Safe and Easy to Use	Leak-free	Quiet
Test Beds									
TB-1 Mobile Heavy Equipment	●	●	●				●	●	
TB-3 Highway Vehicles	●	●	●		●		●	●	●
TB-4 Human-scale Mobile Equipment	●			●	●	●	●	●	
TB-6 Human Assist Devices	●			●	●	●	●	●	●
Associated TB - Wind Power	●	●	●		●			●	
Associated TB - Biomedical devices	●	●	●	●	●	●	●	●	●

2.1 STRATEGIC RESEARCH PLAN

The Center's strategic research plan utilizes a systems-based approach using test beds of associated projects to support the Center goals. For each Center test bed, a description of the goals and alignment with the Center goals, the research activities completed, in process, and planned, significant milestones, and demonstrated and potential benefits to the fluid power industry as described below.

Test Bed 1: Heavy Mobile Equipment – Excavator

Mobile off-road equipment is one of the largest users of hydraulic systems and components. The equipment is used in agriculture, construction, mining, and forestry. Some examples of the equipment include wheeled loaders, excavators, tractors, combines, and many others. Fluid power is widely used in this equipment for propulsion, steering, and performing the work the vehicle is designed to do. The high power density of fluid power makes it a critical technology in accomplishing these functions. Fluid power components and systems have historically been designed for maximum productivity with low emphasis on efficiency. The recent increases in energy prices, coupled with the EPA Tier IV off-road engine emissions regulations that are currently being implemented, have caused industry to seek ways to improve the efficiency of all vehicle components and systems, including the hydraulics.

CCEFP has selected an excavator as the vehicle for test bed 1 (TB1). It is one of the most common multi-actuator mobile machines in use today. The excavator will be used to demonstrate the improvements in hydraulic system operation made possible by integrating the advanced component and system designs resulting from CCEFP research.

1. Statement of Test Bed Goals

Prior to February 2012

From the start, the goal of TB1 has been to study new system concepts based on throttle-less actuator technology and to demonstrate fuel savings and improved performance and compactness using this technology for the large sector of construction, agricultural and forestry machinery. Also, the test bed has served to study and demonstrate effective control strategies for complex multi actuator systems and robot like machine functions, including new human/machine interfaces such as those with haptic feedback.

In the past and in conjunction with project 1A2, dramatic improvements in fuel economy have been studied and demonstrated on the test bed. Also, through project 1A2, a study for the feasibility for engine downsizing utilizing hydraulic hybrid architectures proved that a significant reduction in engine size is possible while equaling or exceeding the performance capability of the standard version of the machine.

After February 2012

The primary focus for the future is to determine what are the technological barriers, what solutions must be developed, and what is the potential for displacement controlled actuation and hydraulic hybrid technologies to drastically improve fuel consumption in multi-actuator mobile machines.

Key goals are reducing engine size by 50% compared to a standard excavator while meeting the current non-road diesel emission standards and maintaining standard machine performance.

2. Test Bed Role in Support of Strategic Plan

Test Bed 1 supports the Center's first goal to achieve a drastic improvement in efficiency of existing fluid power applications and to reduce fuel consumption and pollution. The test bed will be used to demonstrate fuel savings by more efficient fluid power actuator technology and effective machine power management, especially for large, high power equipment. The actuator technology will open new applications in both large scale heavy duty machinery and robots and in human-scaled applications such as surgery robots or other portable devices where efficient and compact actuator technology is needed.

3. Test Bed Description

A. Description and explanation of research approach

Test Bed 1, the excavator, was selected primarily to demonstrate potential energy savings, which could be achieved for multi-actuator mobile machines through innovative system designs and advanced control strategies. However, the system is also suitable for demonstrating the capabilities and performance of individual components developed by other projects across CCEFP.

The core of the test bed will be based upon the theoretical results from Project 1A2 although technologies developed within the scope of several projects throughout the CCEFP will be integrated onto the test bed for demonstration. Project leaders have been contacted and agreed to the milestone and deliverables timeline listed later in this report. The contributions are:

- Project 1A2 (Prof. Ivantysynova, Purdue)
  - Controls for optimal power management of multi-actuator DC hydraulic system
  - Controls for energy based trajectory optimization
  - Design and installation of hybrid hydraulic system and downsizing of excavator engine
  - Reduction of hydraulic cooling power due to improved system efficiency
  - Design and installation of smart pump with integrated electronic pump controls
- Project 1B1 (Prof. Ivantysynova, Purdue)
  - Next generation of highly efficient and smart variable displacement pumps
- Project 1E2 (Prof. Lumkes, Purdue)
  - Virtually variable displacement pump for the excavator's low pressure hydraulic system
- Project 1E3 (Prof. Lumkes, Purdue)
  - High efficiency, high bandwidth, actively controlled variable displacement pump/motor
- Project 1G1 (Prof. Michael, Milwaukee School of Engineering)
  - Energy efficient hydraulic fluids
- Project 3A1 (Prof. Book, Georgia Tech)
  - Tele-operation of the test bed using haptics controls and the Phantom controller
- Project 3D3 (Prof. Klamecki, University of Minnesota)
  - Improved seal design based on adaptive materials

B. Achievements

Achievements prior to the reporting period

- Four variable displacement pumps were installed on TB1 (compact excavator) along with associated sensors and electronic control hardware. All 8 functions (swing, boom, stick, bucket, track drives, boom offset, and blade) are now displacement controlled.
- Control laws for pump displacement, actuator position and actuator velocity were designed and implemented on TB1.
- The DC hydraulic system is operational and was demonstrated by video at the CCEFP annual meeting on October 7, 2009 and in person to a delegation from Caterpillar on November 4, 2009.
- Performance measurements made on the test bed indicated 50% energy savings compared to original LS valve-controlled hydraulic system for soil digging duty cycle.
- Measurement and simulation results have determined that at least 50% of the cooling power requirement in the system could be reduced
- Testing of TB1 with DC hydraulics was conducted in cooperation with Caterpillar. TB 1 consumed 40% less fuel on average than the standard machine while moving the same amount of dirt and productivity was increased by 16.6%, providing a fuel efficiency (tons/kg) improvement of 69%
- The proposed optimal power management algorithm from Project 1A2 showed a 56.4% fuel efficiency improvement for a cycle similar to a pipe laying.
- Through project 1A2, a feasibility study predicted that a parallel hybrid system could be limited to half of the maximum engine power, suggesting that the engine size could be reduced without sacrificing the productivity of the machine for the truck loading cycle

Achievements during the reporting period

Transition to Hybrid DC excavator system

A new hybrid technology combining the advantages of secondary control (a series hybrid solution) in parallel with DC actuators has been designed for TB1 (see Figure 1). A provisional patent was filed and the full patent application process is underway. A static sizing methodology for the energy storage system, consisting of the pump size (V_1), the motor size (V_2), and the accumulator size (V_0). Equations were derived to size each of these parameters as a function of the minimum operating pressure of the accumulator. This sizing assumes a given energy requirement for the accumulator, a given power requirement for the pump and a given torque requirement for the motor and the resulting sizing for each of these parameters is shown in Figure 2 as a function of the minimum operating pressure of the accumulator. The multi-body dynamic simulation model developed for the test bed was used to simulate the hybrid system [22]. These simulations predict the engine power can be reduced by as much as 50% without loss of productivity for a truck loading cycle and reducing the fuel consumption from the non-hybrid by 20% (52% savings from LS).

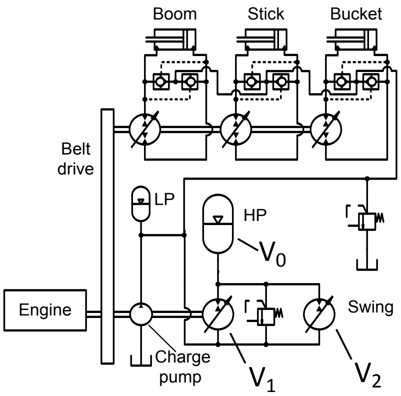


Figure 1: Series-Parallel Hybrid DC System

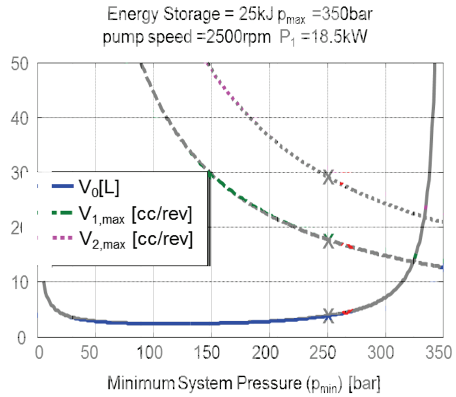


Figure 2: Static Sizing Map

For implementation on TB1, the existing swing motor must be replaced with a variable displacement motor for secondary control. In secondary control, a variable displacement motor is directly connected to a high pressure supply and the motor displacement is regulated to control its torque output. Currently, pump (V_1), which will provide the high pressure for secondary control, is 18 cc/rev. The sizing map (Figure 2) shows that this corresponds to 30 cc/rev for V_2 and a 5 L accumulator for V_0. Unfortunately, the 30 cc unit with the required controls for secondary control was not available, so a 45 cc/rev unit was requested. Simulations have shown that this would not have a significant impact on system performance.

The parts required have been sized and selected, and CCEFP members Sauer-Danfoss and Bobcat have agreed to donate them. The current fixed displacement radial piston swing motor will be replaced by a variable displacement, over-centre and bi-directional axial piston pump/motor. The Sauer H1-B Series 45 cc/rev pump was selected. Bobcat also donated a gear-box from their latest series of compact excavators (M-series) that allows higher operating speeds for the swing unit required for secondary control.

Cooling Power Reduction

Extensive study and testing was performed to determine the machine cooling power requirement. The thermal hydraulic behavior of the machine was simulated and measurements were gathered using TB1. Two different cycles were simulated, one with 100% cooling capacity installed in the machine and a one with no cooling capacity (Figure 3). Both cycles were performed under the same conditions. Due to precautionary measures, the second cycle is shorter to ensure machine integrity.

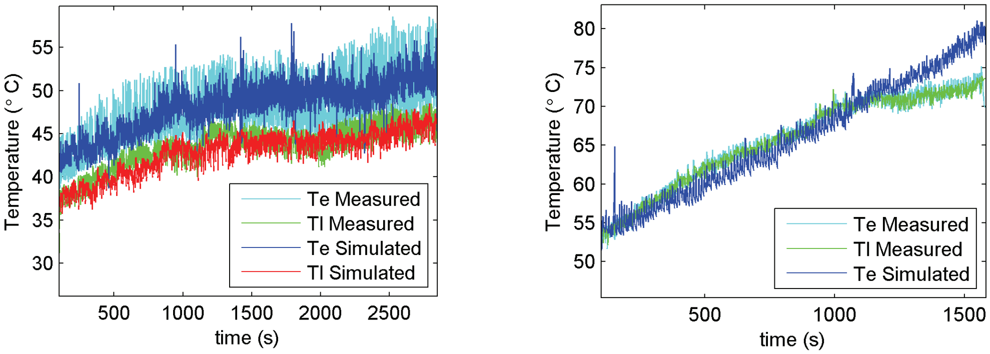


Figure 3: Cooler measured and simulated temperatures. (Left) Full cooling capacity (Right) No cooling capacity

Because the cycle for no cooling capacity is too short to accurately determine where the temperature stabilizes, the measurement data from both cycles was replicated multiple times to form a 15,000 s cycle. The simulation of such cycle allows for the determination of an accurate steady state temperature and finally of an accurate cooling power requirement. Figure 4 shows the results for such simulation.

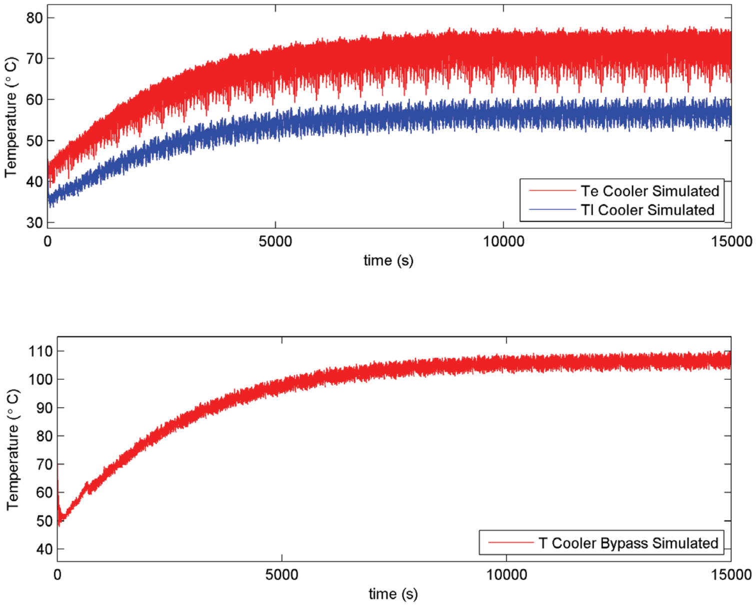


Figure 4: Simulated cooler temperature for 15,000 s cycles (Top) Full cooling capacity (Bottom) No cooling capacity

Based on these results it has been determined that at least 50% of the current machines' cooling capacity can be removed while maintaining allowable working temperatures for hydraulic multi actuator machines.

National Instruments Central Control and Data Acquisition

TB1 has been using xPC-target, a real time controller by MathWorks. When installed, this system was state of the art technology and superior to alternative controllers. However, new systems offer improved reliability, functionality, and advantages in terms of real-time data acquisition and control. The implementation of such a system has started on TB1 and it is expected to be completed by March 2012.

Preliminary Fault Detection

A preliminary fault detection system with the following goals was implemented in TB1 as part of the summer undergraduate research program. The system detects faults in sensors and actuators, faults for ground, and display faults to the operator so they can react promptly and appropriately.

Georgia Tech Collaboration

Georgia Tech's Phantom interface resulting from Project 3A1 was successfully tested on TB1 in August, 2011. This interface allowed for tele-operation of the excavator.

Demonstration of Fine Actuator Control

TB1 was demonstrated for fine actuator control at a Bobcat facility. Several expert operators, systems and test engineers, and marketing personnel tested the excavator to their satisfaction on April 22, 2011.

<u>Planned Achievements following the reporting period</u>

- Conduct on-vehicle experiments
  - Installation of hybrid hydraulics and smaller engine (04/01/2012)
  - Measurements of fuel and performance of hybrid system (06/01/2012)
  - Implementation of optimal controls onto test-bed (04/01/2013)
  - Measurements of fuel and performance of hybrid test-bed (04/01/2013)
  - Demonstration of pump-switching technology on test-bed (01/06/2014)
  - Incorporation of system prognostics schemes (01/06/2014)

- Demonstration of technologies from associated projects
  - Integration of high speed valves from project 1E2 to create a virtual variable displacement pump for low pressure system and measurements or resulting energy savings (2012)
  - Comparison of energy consumption of the test bed using standard hydraulic oil and energy efficient fluids developed in project 1G1 (2012)
  - Integration of next generation of efficient pumps for control of a single actuator (2013)
  - Demonstration of adaptive material for seals from project 3D3 (2013)
  - Installation of next generation smart pump (integrated electronic pump control system from continuation of project 1A2 and demonstration of control of a single actuator (2013)
  - Demonstration and energy measurements for digital pump control of a single actuator using a prototype high efficiency, high bandwidth, actively controlled variable displacement pump/motor from project 1E3 (2013-2014)

C. Member company benefits

The results of the work on TB1 is directly transferable to industry and have already offered benefits to member companies. Some of these benefits include:

- TB1 provides a displacement controlled actuator prototype that can be evaluated and tested by industry members. This saves them time and money compared to building prototypes themselves to evaluate the potential of displacement controlled actuation hydraulic systems.
- The test bed has shown that up to 40% fuel savings can be achieved. This would clearly be a benefit to OEM companies within the Center.
- The improved efficiencies and potential for reduced engine power made possible by the technologies being developed in this project will help OEMs meet upcoming emission regulations under the Tier IV nonroad diesel emissions standards.

Test Bed 3: Hydraulic Hybrid Passenger Vehicle

1. Statement of Test Bed Goals

The goal of Test Bed 3 (TB3) is to create hydraulic hybrid powertrains for the passenger vehicle segment that provide drastic improvements in fuel economy and good performance. The test bed also drives and integrates associated projects by identifying the technological barriers to achieving that goal. The design goals for the test bed vehicle include: (i) 70 mpg under the federal drive cycles; (ii) 0-60 mph in 8 seconds; (iii) the ability to climb a continuous slope of 8%; (iv) emissions levels that meet California standards; and (v) size, weight, noise, vibration and harshness comparable to similar passenger vehicles on the market. The powertrains must demonstrate advantages over electric hybrids to be competitive.

2. Test Bed Role in Support of CCEFP's Strategic Plan

Test Bed 3 directly supports goal 2: improving the efficiency of transportation. Efficiency is achieved by using fluid power to create novel hybrid power trains for passenger vehicles. The powertrains integrate high efficiency components and hydraulic fluids (Thrust 1), compact energy storage (Thrust 2) and methodologies for achieving quiet operation (Thrust 3) from related CCEFP projects.

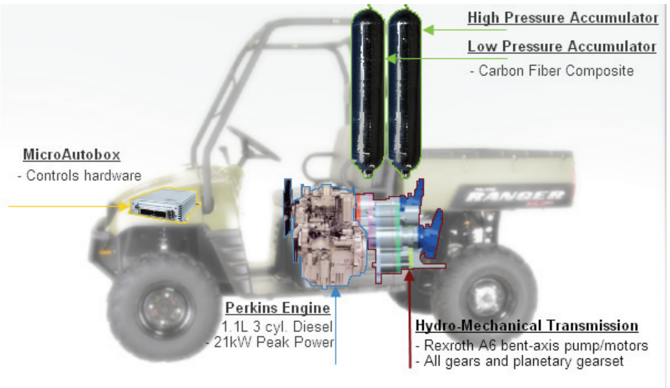


Figure 1: Overview of Test Bed 3 HHPV Generation 1

3. Project Description

A. Description and explanation of research approach

The high power density of hydraulics makes it an attractive technology for hybrid vehicles since they should be able to provide both high mileage and high performance. Hydraulic hybrid vehicles are commercially available for heavy, frequent stop-and-go applications such as refuse or delivery trucks. However, hydraulic hybrids are not available and there is little research and development to bring them to the much larger passenger vehicle market. To succeed in this demanding market, hydraulic hybrid drivetrains must overcome limitations in component efficiency, energy storage, and noise. These barriers represent substantial challenges to existing fluid power technologies.

Hybrid electric vehicles are the closest competition to hydraulic hybrids. While hydraulic hybrids have much lower energy density than electric batteries, they have much higher power density. This is particularly valuable for regenerating braking energy since typical braking events are short in duration, but high in power. Furthermore, hydraulic hybrids eliminate the need for batteries thereby eliminating the cost, life and environmental concerns associated with them.

The three main types of architectures for hybrid drivetrains are series, parallel and power split. A series hydraulic hybrid transmits all power from the engine to the wheel with hydraulic pumps and motors. This architecture enables running the engine at its most efficient combination of torque and speed. However, this architecture requires very high efficiency hydraulic pumps and motors. A parallel architecture augments the traditional drivetrain with a pump/motor. It transmits power to the wheels through the efficient mechanical shaft, but it has less ability to keep the engine at its best operating point. TB3 focuses on power split architectures which are not as well studied as other hydraulic hybrid architectures. A power split hydraulic hybrid provides both a mechanical and a fluid-linked path for power to the wheels.

TB3 is currently developing two hydraulic hybrid passenger vehicles, each of which offers unique research benefits. The “Generation 1” (Gen 1) vehicle (Figure 1) was built in-house using the platform of a utility vehicle (a Polaris “Ranger”). A modular powertrain has been installed on the vehicle. This enables experimenting with different pump, motor and energy storage technologies, including those developed in complementary CCEFP projects. One drawback of the Gen 1 vehicle, however, is that it cannot be driven at speeds higher than about 25 mph due to concerns about vehicle stability.

The “Generation 2” (Gen 2) vehicle is being developed in partnership with Folsom Technologies International (FTI). It is built on the platform of a Ford F150 pickup truck and will be capable of highway speeds. Its powertrain includes a custom-built continuously variable power split hydromechanical transmission (HMT) developed by FTI which will be complemented with hydraulic accumulators to enable hybrid operation. The powertrain is built as a compact, integrated, self-contained package. However, this integrated package has some drawbacks and prevents changing the hydraulic pump/motors or instrumenting them individually. Also, the transmission is not optimally sized for hybrid operation and presents some control restrictions when operated in hybrid modes. Therefore, the Gen 1 vehicle is being continued despite the pending availability of the roadworthy Gen 2 vehicle.

B. Achievements

Energy Management Strategy

An energy management strategy that can be applied to the control of either vehicle has been developed [8]. The strategy is based on the three level hierarchical control approach that was developed in previous years [5]. Specifically, [5] describes a Lagrange multiplier approach, which is a computationally efficient method for solving the optimal control problem of energy management for hydraulic hybrid vehicles. It has been shown to be effective for use in power train design optimization [2, 10]. However, this method is limited by two restrictions: (1) the accumulator is assumed to remain at a constant pressure, which is equivalent to assuming that it is infinitely large, and (2) the drive cycle must be known beforehand.

The new strategy, explained in detail in reference [8], overcomes the first restriction. It relates the power loss from using the accumulator to power lost through the drive train for a specific drive cycle. The Lagrange multiplier can be interpreted as the normalized equivalent loss associated with charging and discharging the accumulator. Two alternative implementations of the new strategy are possible. In the first, the Lagrange multiplier is applied to a short time window to continuously optimize operation of the drive train. In the second, the Lagrange multiplier is made a function of the state of charge of the accumulator. The first approach is more computationally intensive in real time, but the second must be optimized in advance before it can be applied in real time. Both alternatives are able to maintain the state of charge of the accumulator within its physical limits with only a 3-5% penalty on fuel economy compared dynamic programming, which is the best, but most computationally expensive, optimization method.

Future work will consider estimating the drive cycle based on statistics to alleviate the need for deterministic drive cycle information.

Achievements and Plans for the Generation 1 Vehicle

Drive Train Redesign: The original Gen 1 vehicle drivetrain, which was capable of independent wheel torque control, suffered from several limitations that restricted its usefulness. The vehicle's frame would flex during driving and the chains in the system would sometimes skip teeth. In addition, the planetary gear trains, which combine power from hydraulic pump/motors with engine power at the rear wheels, were undersized, so they were not capable of carrying the full wheel torque specification.

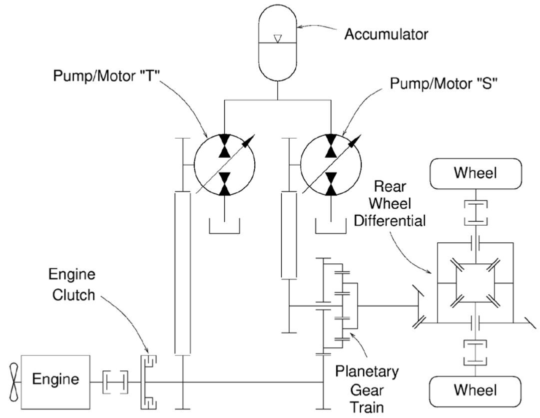


Figure 2: Schematic representation of redesigned Generation 1 HHPV powertrain

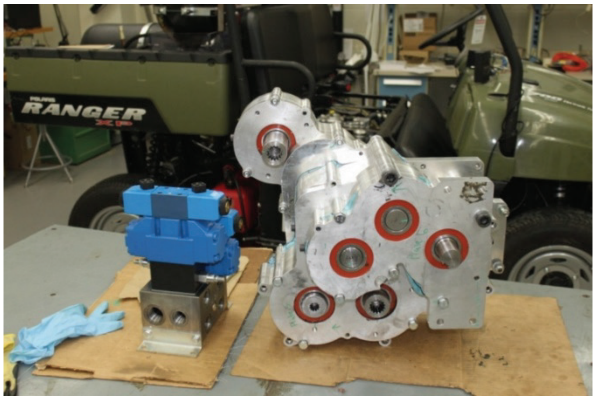


Figure 3: Assembled transmission and valve block

The Gen 1 drivetrain was completely redesigned in 2010. Figure 2 shows schematic of the revised system. The problems experienced in the original drivetrain have been eliminated by using only gears. The drivetrain has been simplified by replacing dual rear wheel "speeder" pump/motors and planetary gear trains with a single "speeder" pump/motor and a stock automotive rear wheel differential. The original axial piston type pump/motors have been replaced with a set of 28cc high efficiency bent axis piston units. Gear ratios and pump/motor sizes have been chosen to optimize fuel economy under EPA driving cycles and to satisfy the acceleration specification.

The transmission assembly was completed in August 2011 (Figure 3) and it was installed in the vehicle in November 2011. Vehicle plumbing was done in collaboration with the Fluid Power Group at Hennepin Technical College (completed February 2012). The vehicle should be ready for testing in Spring 2012.

In parallel with the installation of the transmission, the controls firmware has been upgraded from MATLAB xPC Target to a popular automotive industrial standard system, MicroAutobox, from dSpace. The upgrade will improve robustness and computational power of the controller.

Hydrostatic Dynamometer System: A hydrostatic dynamometer was designed in 2011. Its main purpose is to provide testing capabilities for rapid experimental validation of the hybrid powertrain's performance. The dynamometer is capable of both absorbing and motoring. Other advantages include lower cost than an electrical dynamometer and a high bandwidth due to its low inertia. It is not intended to achieve industrial standard accuracy, but it is targeted to be repeatable. The goal is to conduct dynamometer tests on a mid-size vehicle using EPA's Urban Dynamometer Driving Schedule and Highway Schedule. The new dynamometer eliminates the need for a test track or third-party dynamometer access costs. It allows year-round access and is also more repeatable than outdoor testing, thereby alleviating weather-related delays. It is expected to significantly accelerate the design and tuning of the vehicle controller.

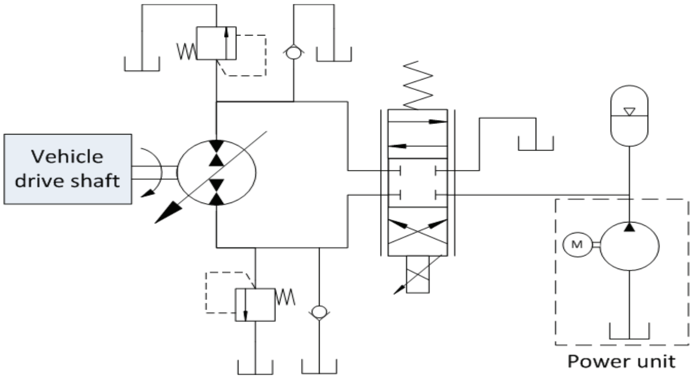


Figure 4: Hydrostatic Dynamometer Schematic

The hydrostatic dynamometer is shown schematically in Figure 4. The assembly of the dynamometer system is complete. It will first undergo constant load testing to ensure proper hardware operation. Then, computer control will be added to both the hybrid vehicle and the dynamometer. Computer control will enable a "virtual driver" to operate the test vehicle through any desired speed trajectory with the dynamometer exerting the required load to produce the specified speeds.

Pump/Motor Performance Characterization: Performance maps for the bent axis pump/motors used in the rebuilt transmission of the Gen 1 vehicle were generated by gathering 2000 data points under a variety of operating conditions with a test stand built previously [6]. These maps were needed to design controllers to optimize vehicle efficiency. Results show significant deviation from manufacturer's data.

Future Plans for the Generation 1 Vehicle: Plans for the Gen 1 vehicle include: testing the redesigned transmission in continuously variable transmission (CVT) mode, integrating the Project 1A.1 high level control strategies, testing the efficiency of advanced hydraulic fluids, determining the efficiency of a virtually variable displacement pump/motor created in Project 1E.1, and testing two novel accumulators. These plans are described in order below.

Initially, the Gen 1 transmission will be operated in a degenerate CVT mode rather than as a full hydraulic hybrid. These experiments have two purposes. First, operation as a CVT serves to prove the effectiveness of the low level control strategy. Second, the fuel economy obtained from operation as a CVT provides a benchmark for comparing improved energy management strategies.

Hybrid operation will be tested next with the implementation of various energy management strategies. Both the modified Lagrange multiplier strategy and Project 1A.1's rule-based control strategy will be implemented. The more complex Stochastic Dynamic Programming (SPD) and Model Predictive Control (MPC) algorithms developed in Project 1A.1 will be implemented and tested in Summer 2012.

A new project which utilizes the Gen I vehicle as a test bed for Project 1G.1 is planned. A synthetic biodegradable ester will be utilized as the hydraulic fluid, which is expected to exhibit higher efficiency at low speeds [11]. The new oil will be compared with a shear stable high viscosity index hydraulic fluid that serves as the baseline oil for the vehicle. The new vehicle dynamometer will be utilized for these tests.

Two new accumulator designs will be tested during the 2012-2013 period. Discussions are underay for testing an efficient accumulator developed by an outside corporation that operates at near isothermal conditions. Also, a prototype of the strain energy accumulator being developed by Project 2C.2 is expected to be ready for testing next year. The strain energy accumulator will have the advantage of constant pressure operation, thereby improving the energy density of the hydraulic powertrain. The modular architecture of the redesigned transmission enables the pump/motors to be changed out.

The bent axis pump/motor used as pump/motor “S” will be replaced with a pulse width modulated fixed displacement pump/motor designed in Project 1E.1 during summer 2013. Simulations have been performed to optimize the gear ratios for the pulse width modulated pump/motor [9]. The actual efficiency using the new pump/motor will be experimentally determined and compared to the baseline efficiency.

Achievements and Plans for the Generation 2 Vehicle

Effort on the Generation 2 vehicle in 2011 has focused on returning the FTI transmission to service, and creating a test plan for generating the efficiency map of the transmission. Each of these efforts is described below. Continuing plans for 2012 are described at the end of this report.

Returning FTI Transmission to Service: Ford has donated an F150 truck for the project. The FTI transmission, hybridized with hydraulic accumulators, will replace the original transmission of the truck. FTI transmission will characterize the efficiency of the transmissions before it is sent to UMN. Problems with the controls on the FTI dynamometer in early 2010 resulted in the transmission being driven at high speed in reverse. Since no lubricant is supplied in this configuration, extensive damage occurred to both mechanical and hydraulic components in the transmission. While the transmission has now been repaired, residual problems have arisen repeatedly, causing several delays.

Efficiency Map Test Results: The dynamometer tests have produced some results (see Figure 5). The input speed of the transmission is set to 1000 rpm, the transmission ratio is set to a specified value, and then the output load is varied. The results show an improvement in efficiency by using a shear-stable high viscosity index (VI) hydraulic fluid. Standard Automatic Transmission Fluid (ATF) with 5 cSt viscosity is used as a baseline for this test (blue lines in Fig. 5). The high VI hydraulic fluid (15 cSt), provided by Evonik Rohmax (Magenta lines in Fig. 5), reduces volumetric losses within the hydraulic units [11]. The improvement is especially significant at higher transmission ratios as shown in Fig. 5(a). Performance of the transmission is similar with both fluids at overdrive transmission ratios (Fig. 5(b)). These results are consistent with those of Project 1G.1 [12]. The highest efficiency achieved was 92%. A full range of dynamometer tests are essential for fuel economy prediction and the design an optimal controller.

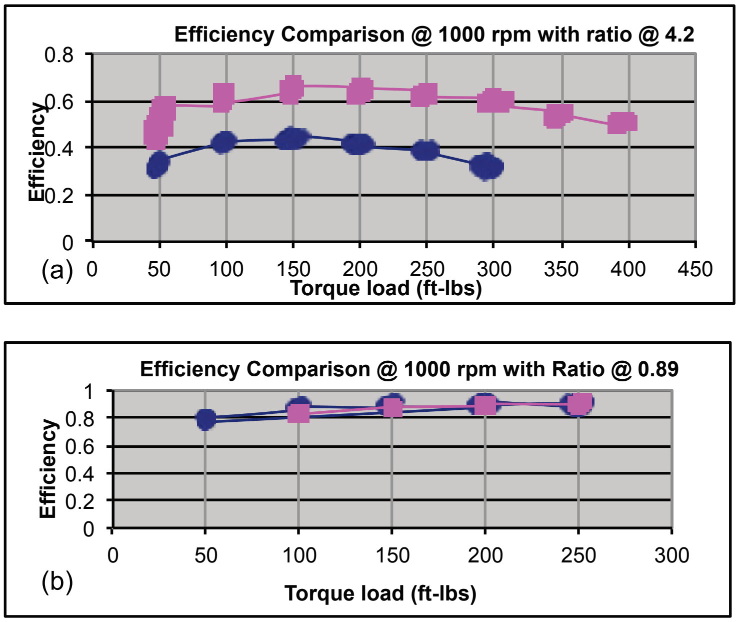


Figure 5: Dynamometer efficiency test results with different fluid comparison (Blue: Standard ATF, Magenta: Rohmax Hydraulic Fluid)

Future Plans for the Generation 2 Vehicle: A new mechanical problem in the FTI transmission is currently being repaired. Following that, the dynamometer tests described above will be completed. The transmission and accumulators will then be installed in the truck. A basic controller will be developed to make the truck operational at FTI. The truck is expected to be delivered to the University of Minnesota in Summer 2012. Development of the full controller can then begin. Much of the controller development that has been completed for the Generation 1 vehicle will be adaptable to the Generation 2 vehicle.

<u>Milestones and Deliverables</u>

- Hydrostatic dynamometer system operational (2/12)
- Test drive of Generation 1 vehicle completed (3/12)
- Efficiency evaluated in CVT mode using Energy Management Strategies (4/12)
- Project 1A.1 integrated by implementing Stochastic Dynamic Programming (SDP) and Model Predictive Control (MPC) (7/12)
- Efficiency of alternative hydraulic oils compared (12/12)
- Performance of alternative hydraulic accumulators compared (3/13)
- Project 1E.1 pump/motor installed as Pump/Motor “S” in Generation 1 vehicle (8/13)
- Project 2C.2 Strain energy hydraulic storage integrated on Gen 1 vehicle (6/14)
- Transmission efficiency characterized with Folsom dynamometer facility (6/12)
- Generation 2 vehicle operational (8/12)
- Controller demonstrated in Generation 2 vehicle (12/12)
- EPA cycle fuel economy evaluation (3/13)
- Initiation of Generation 3 transmission design for mid-size sedan vehicle (1/14)

C. Member company benefits

Practical hydraulic hybrid passenger vehicles would create a new and potentially lucrative market for hydraulic products. Also, development of the HHPV enables member companies to gain experience in a non-traditional potential market segment which requires very high efficiency at relatively low power.

Test Bed 4: Compact Rescue Robot

1. Statement of Project Goals

The goal of Test Bed 4 (TB4) is to demonstrate a compact rescue robot, an example of a portable, untethered human scale fluid power application. Current rescue robots are electric. They can navigate and observe, but do not have the force or power needed to perform rescue operations. The test bed goal is to develop a mobile fluid-power robot that can operate for a reasonable length of time (2 hours minimum), navigate in difficult terrain (urban disaster site), produce a required force (500 lb of lift) with precision control and resulting dexterity (sufficient to apply medical test and treatment devices) and transport a specified weight (250 lb).

2. Project Role in Support of Strategic Plan

TB4 occupies the power range from 100W to 1KW in the Center's efforts to apply to the full power range of applications. This range is poorly addressed by fluid power today due to barriers, including a lack of compact power supplies, lack of miniature components and difficulty in tele-operation and control.

3. Project Description

A. Description and explanation of research approach

The existing applications at the human scale are simple one degree-of-freedom devices and generally dependent on large external power supplies. Examples are log splitters and the "jaws of life" for extracting victims of accidents. While the technology is very successful and indicates the potential of fluid power, their applications are limited. Expansion to more degrees of freedom will require untethered power, miniaturized components and remote or autonomous operation. Addressing these issues in the context of fluid power requires an imaginative leap into devices with this collection of requirements. Rescue in disaster scenarios is the leap we have taken. Advances will be relevant to scenarios in the military, construction, agriculture, personal service and assistance to the handicapped and aged. The state of the art in rescue robots has been reviewed by NIST in its periodic examination published in the Rescue Robotics Handbook.[1] All entries are electrically powered, although a few extremely heavy ones have hydraulic manipulators attached. Some have been exercised on a few disaster sites, but have not been capable of an actual rescue. The military (DARPA) is pursuing rescue on the battlefield with a battlefield extraction assist robot (BEAR [2]) and a quadriped field transportation robot (Big Dog [3]), both employing hydraulics. Neither would meet the specifications for TB4.

TB4, residing at the top of the three plane chart, will require inputs from several projects to be successful. Possible compact power supplies are a free piston engine compressor or pump, or a hot gas vane motor. Safe and intuitive tele-operation will be accomplished through multi-modal haptic user interfaces. The current incarnation of TB4 uses pneumatics, and the free piston engine-compressor is the current project that will be able to provide power in a suitable package.

B. Achievements

In the past years, TB4 has advanced most through the development of two separate platforms. At Vanderbilt, a four-legged crawler actuated by custom miniature high-pressure valves coupled with a Bimba cylinder and linear damper, has been designed and constructed (Figure 1). The robot is controlled via CANbus communication to local microcontrollers at the three joints on each leg. In the past years, the Vanderbilt hardware has been pre-programmed with several low-level gaits for motion across relatively predictable surfaces, including a crawl, a walk, and a trot. The Vanderbilt technology has been intended for use with hardware designed at Georgia Tech: An operator workstation with two Sensable Phantom™ haptic joysticks and an A/V headset provides feedback to the operator (Figure 2). The workstation maps the two joysticks to the four legs of the robot, granting the operator intuitive control of gait and manipulation motions. A two-legged platform for manipulation testing and interim functionality has also been developed at Georgia Tech. These platforms are interfaced using xPC Target real-time software.

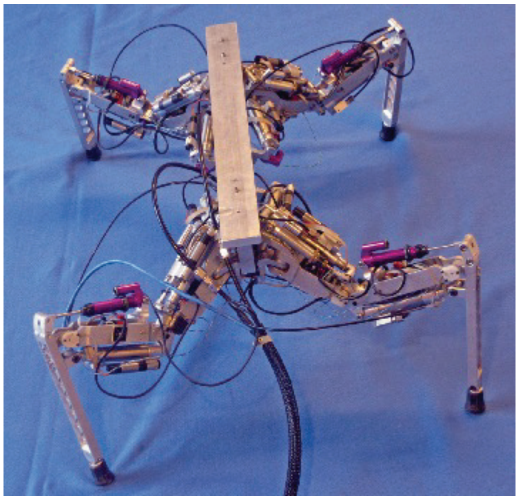


Figure 1: The four legged robot at Vanderbilt.

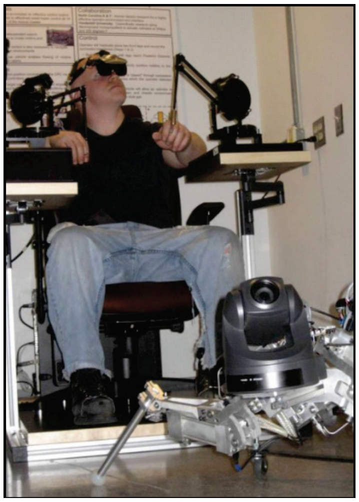


Figure 2: Operator workstation and surrogate robot at Georgia Tech.

Quantifiable Performance Advantages: A study at Vanderbilt used the mass and performance of the TB4 hardware in combination with properties of Center-developed power sources to point out the substantial improvements in energy efficiency that TB4 can bring to mobile human-scale platforms capable of significant manipulation. These studies, shown in Table 1, demonstrate that using fluid-power can greatly reduced the mass of the system, especially as longer run-times are expected. This reduction in weight in turn allows the system to carry larger loads and last for longer periods of time on less energy, thereby validating many of the efforts of TB4 and associate CCEFP projects.

System	Run Time (hrs)	Mass (kg)	Extra Weight (relative to lightest version)
Electric	3	21	10.9
IC Engine Hydraulic	3	23.1	13.0
HGVP Hydraulic	3	17.7	7.6
Free Piston Compressor	3	10.1	0
Electric	10	36.5	24.0
IC Engine Hydraulic	10	25.9	13.4
HGVP Hydraulic	10	25.2	12.7
Free Piston Compressor	10	12.5	0

Table 1: Quantitative Analysis of Rescue Robot Mass for Fluid Power and Electric (Battery) Energy Sources

Hardware Advances: The Vanderbilt robot has been completed, revised for functionality, documented, and brought to Georgia Tech. Because it had originally been developed in a non-real time environment, changes were needed to ensure that the hardware functioned with the operator interface created at Georgia Tech. An undergraduate researcher successfully converted several programs developed at Vanderbilt from non-real time Simulink to xPC Target compatible Simulink. Thus far several of the key components needed for control of the motions have been converted and work is ongoing to apply these to the pre-programmed gait software that had been developed at Vanderbilt.

Georgia Tech has also improved the two-legged test bed, which is used as simulation verification and as a platform for actuator control improvements. Whereas the four-legged test bed couples a damper with a cylinder to make control of the position control joints simpler on a mechanical level, the two-legged test bed employs pressure sensors and Bimba™ cylinders with position feedback. This allows testing of alternate control strategies, such as passive control. In the last year, substantial improvements have been made to this platform. Control was achieved via the operator workstation, using commands from the haptic joysticks to direct motion of the legs. Electronics were reconfigured for a cleaner, more effective and robust design. The previous custom cylinders were replaced with Bimba hardware, as noted above, actuated by Festo proportional directional valves. An undergraduate researcher, Michael Valente, redesigned the legs to accommodate the different, more compact cylinders and increase leg motion. The revised design was used in an extensive study for an MS thesis which explored the modeling of pneumatic systems of this type.

In the future, the Georgia Tech revised design will be completed and implemented with the new cylinders and improved range of motion. This will be used to test control techniques targeted at precise movement of large loads by pneumatically actuated manipulators. University of Minnesota researchers are exploring improved controllers following a passivity based design approach using this version of the test bed.

The Vanderbilt hardware will be completely integrated into the Georgia Tech platform, allowing use of both the low-level, pre-programmed gaits and the semi-autonomous operator-guided gaits to control the robot. Control techniques similar to the ones used on the two-legged Georgia Tech test bed will also be implemented. The robot will be further equipped with A/V feedback using a pan-and-tilt camera that moves together with operator motions of an associated headset, previously developed at Georgia Tech on the interim test bed. Alternative vision displays have been studied. This display provides a trailing view of the robot as if the operator were actually following behind the rescue robot. Such a display has been shown to give the operator a better understanding of the robot's situation in the environment. It places a computer generated drawing of the robot with current limb angles and orientation in an image taken from the robot a few steps earlier. Technical difficulties with the robot made a complete demonstration of the technique possible, but the concept applied to legged robots was presented.[4]

Testing Environment: While the low-level gaits used on the four-legged crawler have been tested in several outdoor environments, a necessary component to proving the versatility of the designed hardware is the usage of standardized "challenging" terrains. Using the NIST [1] environments as a guide, a modular terrain block was created that can be configured to illustrate several difficult scenarios. This terrain will be used as a way of verifying the capabilities of the robot and simulation.

Advances in Simulation: Another key component of TB4 is the hardware simulation. The simulation was created in 2008/09, and uses an open source robotics library, courtesy of Seoul National University, known as SrLib. This library lets the user select from a variety of joints and links to create kinematic representations of the desired hardware. These are then placed in a simulated dynamic environment, where joints can be controlled either by actuated forces (representative of the actual hardware), or desired positions (representative of the ideal circumstance). This serves several key functions: First, it enables the testing of higher level control and operator interface features that would otherwise not be possible without a complete and functional robot, control scheme, and environment. Similarly, it allows design of the operator interface in parallel with robot design, which can be tested within the safe and efficient bounds of the simulation.

Other work has provided a better understanding of joint dynamics and allows simulated testing of new control techniques. This is made possible by coupling the dynamic simulation of the robot with a low-level model of an actuator, consisting of the valve, cylinder, and associated controller. This model, which has been discussed in two papers [4, 5] published/accepted for publication this year, has been designed in Simulink and uses a simple proportional valve model, internal cylinder dynamics, and a friction model to generate a force output. The model has been verified within Simulink to show near equivalent position and pressure behavior as physical systems, using a simple test setup as a measurable comparison. These models have also been implemented together with the simulation, where they have demonstrated similar behavior and drawn conclusions on the effect of naturally occurring time delays in multi-platform simulations on the behavior of pneumatic models.[5]

The dynamic actuator models were then applied to the joints and improved upon to ensure equivalence not only in single-platform simulations, but also when combining multiple software tools for a comprehensive dynamic simulation.[6] The model developed is being used as a basis for advanced controls approaches, starting with establish pneumatic control techniques such as sliding mode control and LQR-derived control. The simulation itself will continue to be used as a guide for interface design and operator control strategies.

Operator Interface and Robot Control: The final key component of the TB4 platform is the operator interface. This interface uses two Phantom haptic joysticks to control the legs of the robot, using a strategy known as the Follow-the-Leader gait to map the user to the robot for gait motions. This strategy allows the user to place the front legs, while to computer decides where to place the rear ones based on knowledge of variables such as stability, safe footholds, and desired direction.[7] Several changes have been made in this interface in the past year. Haptic guidance has been enabled, granting the user a better sense of telepresence through feedback from the joysticks. The interface has also been redefined on a software level, using several modes of operation and internal state machines to provide clarity and ease of use to both the operator and the designer. Several new gaits were added, including haptically guided ones developed at Georgia Tech and the pre-programmed low level gaits provided by Vanderbilt.

The operator interface has also benefited from a higher level controller developed at Georgia Tech that places a penalty on stability (with respect to balance, not actuator performance) of the robot and relates it back to the user in the form of haptic feedback. Thus, the user is guided to move in such a way that the stability of the robot is never compromised. This operator-in-the-loop controller results in more effective overall motion without impeding too heavily on the user's level and sense of control.

Future plans for the operator interface are primarily focused on applying it to the four-legged crawler and ensuring complete functionality. This entails coupling higher level control approaches that related robot balance and user desired motion with lower level actuator motion control to ensure that the user is able to effectively guide the robot across difficult terrain, as well as move the legs to lift items when necessary.

TB4 has also supported several undergraduate researchers, as noted throughout the summary of achievements. Their work contributed towards control and dynamic modeling of the two-legged testbed, integrating the Vanderbilt model with the Georgia Tech system, constructing terrain obstacles, and designing and constructing a revised manipulator design for the two-legged platform working with the newly acquired Bimba cylinders.

Finally, work on TB4 has resulted in several additional papers [8, 9] on modeling, simulation, and interfaces of fluid-powered technologies, presented or accepted to be presented at conferences both within and outside the fluid power community.

Future Plans for the Test Bed

The priority focus of TB4 in the coming months is integration with the Free Piston Engine Compressor (FPEC), Project 2B1. In order to demonstrate the viability of this development, the robot must operate without power tethers, meaning the FPEC must ride on the robot. This guides modification of the robot in several ways. First, the entire operation must be made more reliable. Second, we must contend with the possibility that pressures will be lower than the 300 psi value originally conceived as provided by a monopropellant (H2O2) power source. We also may need to develop strategies for consuming a smaller volume of compressed gas. In order to stress the utility of a legged vehicle, a means of using two legs for manipulation is being developed. In order to free up the front legs for this purpose, outriggers are being fitted to the robot. When extended, the outriggers will hold up the front of the robot at a height suitable for the manipulation task at hand. Representative of these tasks are administering aid to a victim, positioning a pneumatic jack for lifting a fallen timber, or testing the stability of damaged structures.

Since originally conceived as a test bed for fluid powered devices, both pneumatic and hydraulic, of human scale, alternatives to the current rescue scenario are being considered. The opportunity to work with another Engineering Research Center, the Quality of Life Technology (QoLT) Center at Carnegie Mellon University and the University of Pittsburgh, recently emerged with an appropriate application. The need to transfer patients who are unable to move themselves is very pervasive. Movement from bed to chair, chair to toilet, and back again occurs many times a day for each patient. Multiple people are typically involved in each move and every time the patient and the care giver is prone to injury. The concept is a device that can function as a member of a team which includes one or more human caregiver. In their studies to date, electrical drives have proven inadequate because of the low force density, where hydraulics excels. Initial contact has been made and a general strategy for cooperation between centers has been devised. The challenges of this application are within the scope of the CCEFP, including the need for quiet, leak free, safe operation in close proximity to people. Compactness is also a priority. In the coming round of funding it is anticipated that hydraulics at the human scale will be directed in this manner, to rescue individuals from the confines of a hospital bed.

C. Member company benefits

Festo, Bimba, and Enfield are the companies most closely related to TB4 in its present incarnation. Hydraulics component and fluid companies stand to gain from future advances. The end users and integrators for this power range of devices do not generally exist, but could include John Deere, Toro, Caterpillar and Bobcat.

Test Bed 6: Human Assist Devices (Fluid Powered Ankle-Foot-Orthoses)

1. Statement of Project Goals

The goal of this test bed is to drive the development of enabling fluid power technologies to:

- Miniaturize fluid power systems for use in novel, human-scale, untethered devices that operate in the 10 to 100 W range.
- Determine whether the energy/weight and power/weight advantages of fluid power continue to hold for very small systems operating in the low power range, with the added constraint that the system must be acceptable for use near the body.

Human assist devices developed in Test Bed 6 (TB6) provide functional assistance while meeting these additional requirements: (1) operate in the 10 to 100 W target power range, (2) add less than 1 kg of weight to a given segment of the body, excluding the power supply, and be designed to minimize physical interference during use, and (3) provide assistance from 1 to 8 hours. The focus of this test bed is the development of novel ankle-foot-orthoses (AFOs) to assist gait. An AFO with its stringent packaging constraints was selected because the ankle joint undergoes cyclic motion with known dynamic profiles, and requires angle, torque, and power ranges that fit within the test bed goals.

2. Project Role in Support of Strategic Plan

TB6 facilitates the creation of miniature fluid power systems by pushing the practical limits of weight, power and duration for compact, untethered, wearable fluid power systems. The test bed benefits society by creating human-scaled fluid power devices to assist people with daily activities and is creating new market opportunities for fluid power, including opportunities in medical devices.

3. Test Bed Description

A. Description and explanation of research approach

Problem Statement: In the US alone, individuals who suffer from or have been affected by stroke (4.7M), polio (1M), multiple sclerosis (400K), cerebral palsy (100K) or acute trauma could benefit from a portable, powered, daily wear AFO [1]. For individuals with impaired ankle function, current solutions are passive braces that provide only motion control and joint stability. These designs often fail to restore normal ankle function because they lack the ability to actively modulate motion control during gait and cannot produce propulsion torque and power.

The ideal AFO should be adaptable to accommodate a variety of functional deficits created by injury or pathology, while simultaneously being compact and light weight to minimize energetic impact to the wearer. These requirements illustrate the great technological challenges facing the development of non-tethered, powered AFOs. The core challenges that must be met to realize such a device are: (A) a compact power source capable of day scale operation, (B) compact and efficient actuators and transmission lines capable of providing desired assistive force, (C) component integration for reduced size and weight, and (D) control schemes that accomplish functional tasks during gait and effectively manage the human machine interface (HMI). Therefore, the development of light, compact, efficient, powered, un-tethered AFO systems has the potential to yield significant advancements in orthotic control mechanisms and clinical treatment strategies.

State-of-the-Art: Passive AFO designs are successfully used as daily wear devices because of the simplicity, compactness, and durability of the designs, but lack adaptability due to limited functionality. To date, powered AFOs have not been commercialized and exist as research laboratory devices constructed from mostly off-the-shelf components [2, 3]. The size and power requirements of these components have resulted in systems that require tethered power supplies, control electronics, or both [4, 5].

Research Approach: Work in the test bed is following a roadmap for developing portable fluid powered AFO devices with increasing complexity and performance requirements. In 2008, the design and construction of an energy-harvesting AFO that selectively restricted joint motion using a pneumatically-driven locking mechanism was completed [6]. The lessons learned during this design process were used to accelerate the design of a portable fluid powered AFO. Using a systems engineering approach, the fluid powered AFO system has been divided into four subsystems that align with our core system challenges: power supply, actuator/valving, structural shell, and control system (electronics, sensors, and HMI). The subsystems have target specifications that must be met to realize a fully functional device. The power supply must weigh < 500 g, produce at least 20 W of power, run continuously for ~ 1 hour, and be acceptable for use near the human body. The actuator and valving must weigh < 400g and provide a minimum of 10 Nm of assistive torque at a reasonable efficiency. The structural shell must weigh < 500 g, be wearable within a standard pair of slacks (fit inside a cylinder with 18 cm OD), and operate in direct contact with the body. The control system must control the deceleration of the foot at the start of stance, permit free ankle plantarflexion up to mid stance, generate a propulsive torque at terminal stance, and block plantarflexion during swing to prevent foot drop; all in a robust and user friendly manner. In 2008, the test bed team added University of Minnesota students to examine opportunities to increase propulsion torque and power through high pressure hydraulics. Over subsequent years, Illinois and Minnesota teams have been using the portable fluid powered AFO platform to explore lower pressure pneumatics and higher pressure hydraulics, respectively, as promising technology paths for tiny fluid power systems suitable for untethered human assist devices.

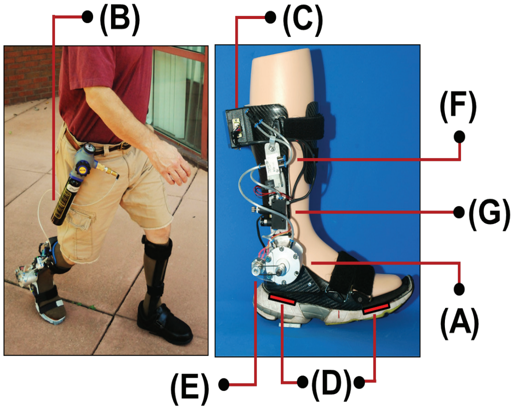


Figure 1: Portable powered ankle foot orthosis (PPAFO) shown assisting an impaired walker. The rotary actuator (A) is powered by a compressed CO_2 bottle (B) worn on the waist. Onboard electronics (C), force sensors (D), and an angle sensor (E) control the solenoid valves (F). A pressure regulator (G) is used to modulate the magnitude of the dorsiflexor assistance.

B. Achievements

Portable Pneumatic AFO (PPAFO) UIUC

In 2010, we constructed our first generation portable, powered, ankle-foot orthosis (PPAFO) using off-the-shelf commercially available components to demonstrate device feasibility (Figure 1). The Gen1.0 PPAFO is an improvement over state-of-the-art passive and active systems [4, 5] because it provides subject-specific motion control and torque assistance without tethered power supply or electronics. A U.S. patent covering the technology embodied by the PPAFO is being filed [7]. Descriptions of the PPAFO system hardware, characterization of system performance, and preliminary results from both healthy and impaired walkers were formally detailed [8]. The Gen 1.0 PPAFO can generate up to 12 Nm at 115 psig and run continuously for about 40 min at 30 psig for both plantarflexor and dorsiflexor assistance, falling short of the more than 1 hour of use requirement. Preliminary component and operational efficiencies of the Gen1.0 PPAFO system were examined [9]. An overall system efficiency of 19% was calculated from the product of the two efficiencies (component: 50% and operational: 39%).

In 2011, in a continued effort to improve the overall efficiency of the PPAFO, we investigated the thermal impact of the gas intake and possible means to save fuel by thermal regulation. These efforts were started by a summer REU student and continued in our collaboration with a CCEFP E&O sponsored yearlong capstone senior design team in Mechanical Engineering at Bradley University in Peoria, Illinois. Due to the thermal cooling nature of liquid CO_2, gas temperature and output pressure decrease over time, which result in reduced thermal efficiency of the system. We hypothesized that gas intake at a higher temperature can decrease fuel consumption and increase run duration. The summer REU study determined that utilizing longer tubing submerged in room temperature water resulted in fuel savings up to 7%. The capstone team has studied the thermal impact on the CO_2 bottle during continuous use in two extreme cases (isothermal and isentropic). They have determined that 17% of the CO_2 in the bottle $_{\text{is}}$ wasted by being converted to dry ice in an isentropic scenario. Preliminary results suggest that sufficient heat exchange to maintain the bottle at room temperature will increase fuel savings. Solutions to improve the overall system efficiency will continue to be investigated in 2012, e.g., warming gas intake, heat exchanger on the bottle, recycling compressed exhaust gas, and harvesting of human energy during gait.

During the beginning of 2011, we realized that the compact integrated rotary actuator developed by MSOE in 2010 would not be a viable design. Therefore, in efforts to continue to driving a technology pull for a compact rotary pneumatic actuator, we have pursued three avenues. (1) MSOE has been tasked to improve their design – they are exploring improving the original design and also have proposed a new design based on bellow technology. (2) The UIUC TB6 team has been collaborating with CCEFP industry partner Parker Hannifin to utilize their expertise in pneumatic rotary actuators to design a custom product. (3) The Bradley University capstone design team is also exploring the development of a rotary actuator that incorporates a gear system. In 2012, we expect to see prototypes from each of these efforts and will be incorporated into a new (Gen 1.1) PPAFO prototype.

One of the challenges in making the PPAFO a portable gait assistance device is its ability to provide assistance accordingly at various scenarios (level ground walking, ascending and descending stairs). In 2011, we began work in gait mode recognition. There are two critical aspects of this problem: first, the original sensor array on the PPAFO has limited sensing ability (only heel and toe contact forces and ankle joint angle), which do not contain enough information to reliably detect gait mode. Second, the gait mode has to be recognized at the earliest possible time to prevent potential misfiring and loss of balance risk to the wearer. To address these limitations, we used a 6DOF inertial measurement unit (IMU). Preliminary results successfully estimate the 3D motion of the PPAFO, and recognize different gait modes at the very beginning of the mode change (Figure 2). Future work includes proper actuation scheme implementation to assist functional gait and use of IMU data to track the foot during seating therapy.

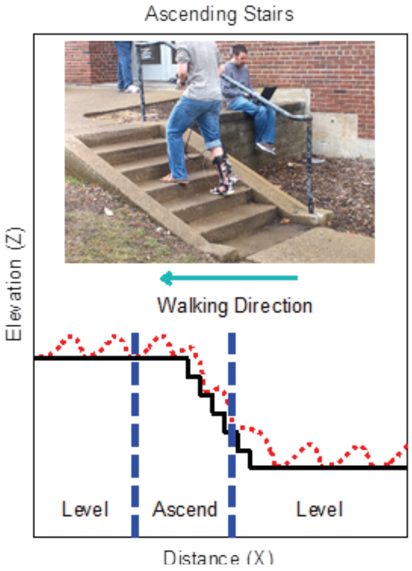


Figure 2: Stair ascending gait mode recognition. Real-time 3D PPAFO position was tracked using a 6DOF IMU at the toe.

We have targeted the PPAFO to be a portable device, which can operate outside of the laboratory or clinic for at-home assistance or therapy. During 2011, we have refined potential applications for the PPAFO. Along with CCEFP faculty and students at NCAT on Project 3A3, we are pursuing the development of a computerized clinician user interface that can be used to track the patient's medical history, therapy progression, and ultimately allow for recording and monitoring of the PPAFO performance while on the patient and also clinician programming of the PPAFO attributes. Additionally, we now seek to investigate the efficacy of the PPAFO as an integrated and portable rehabilitation robot in a seated ankle rehabilitation therapy for acute post-stroke patients. Recent studies using a powered, but tethered, AFO have been found to successfully improve ankle function and gait performance in post-stroke patients (Roy 2011). NCAT is also assisting with the development of an interactive game (using a serious gaming approach) to be used by the patient while using the PPAFO as a joy stick to navigate the game.

We continue to work with several CCEFP projects, which are contributing to the test bed to improve subsystem performance given target specifications. Center technologies are being used to address subsystem limitations, including the miniature HCCI air compressor power supply (Project 2B2), an integrated shell with thermal management abatement (Project 2D), and the pneumatic MEMS proportional valves to improve compactness (Project 2F).

Hydraulic AFO (HAFO) activity at Minnesota:

In 2009, high pressure hydraulics was identified as a promising technology path for tiny fluid power systems suitable for applications such as the untethered AFO. In 2010, theoretical analysis of tiny hydraulic systems was conducted to understand their limits [15]. Additionally, a compact fluid power EHA system was assembled with LiPoly battery, Maxxon motor, Oildyne cartridge pump and Bimba hydraulic cylinder, to demonstrate the capabilities and limits of using off-the-shelf components.

During 2011, theoretical analysis of tiny hydraulic systems was continued to identify the design guidelines.

- Efficiency models for the piston and vane pump were built and verified, which enabled us to compare these two types of pumps in a complete system. The analysis showed that a piston pump gives a lighter AFO weight due to its higher efficiency, so it was decided to use a piston pump as the pumping component of the hydraulic AFO system.
- Further analysis showed that the power unit of the hydraulic AFO must be separated from the actuator unit to achieve better performance than the equivalent electromechanical system. This suggests an AFO architecture that is similar to a miniature hydraulic excavator.
- The design of a complete hydraulic AFO system that was targeted to recover the full ankle joint function is underway. Analysis results showed that a gearhead was mandatory to minimize the weight of the system. The efficiency of the system, which is determined by the efficiency of two hydraulic cylinders, two hydraulic hoses, a hydraulic pump, a planetary gearhead, a brushless electric motor and a LiPo battery, was modeled, as shown in Figure 3.

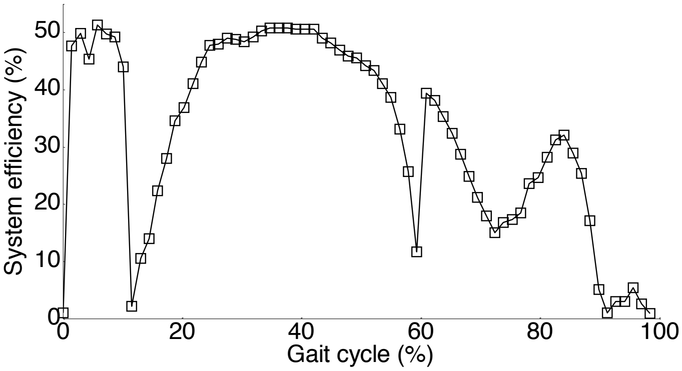


Figure 3: Hydraulic AFO system efficiency

During 2011, work associated with TB6 has resulted in 6 peer-reviewed publications in scholarly journals, 8 conference proceedings, and 1 trade journal article.

Plans, Milestones and Deliverables for Next Year

PPAFO:

- Gait mode recognition testing for different scenarios (level ground, ramp, stairs ascending/ descending); PPAFO pneumatic system component efficiency analysis and design guidelines; Subject testing for energy recycling scheme. (Spring 2012)
- Construction of Gen 1.1 PPAFO with enhanced shell, wireless microcontroller, OTS proportional valves; Demonstration of HCCI engine prototype and thermal management structure, clinician user interface, and MSOE, Bradley, and Parker rotary actuators on PPAFO; Explore pressure & air flow control for torque & rotational velocity control. (Summer 2012)
- Investigate iterative learning control of the PPAFO actuation. (Winter 2012)
- Demonstration of MEMS proportional valves on PPAFO; Preliminary integration of rehabilitation application interface with serious gaming. (Spring 2013)

HAFO:

- Full system efficiency analysis of ver2 HAFO, for dynamic load application; Finish customizing piston pump (modified from Oildyne pump) and cylinders. (Spring 2012)
- Fully functional and integrated ver2 HAFO; Design a control strategy for ver2 HAFO. (Summer 2013)

Plans, Milestones and Deliverables for Next Five Years

Over the next five years, the test bed will further develop the current technologies and explore new ones to continue driving new technology needs.

Continued work:

- Pneumatics: Push development of compact proportional valves, actuators, power sources; energy harvesting through recycling and human power harvesting.
- Hydraulics: Push development of compact fluid power EHA system; Improve actuation speed
- Clinical applications of portable powered AFO: computerized clinician user interface; seated ankle therapy for post-stroke rehabilitation

New areas:

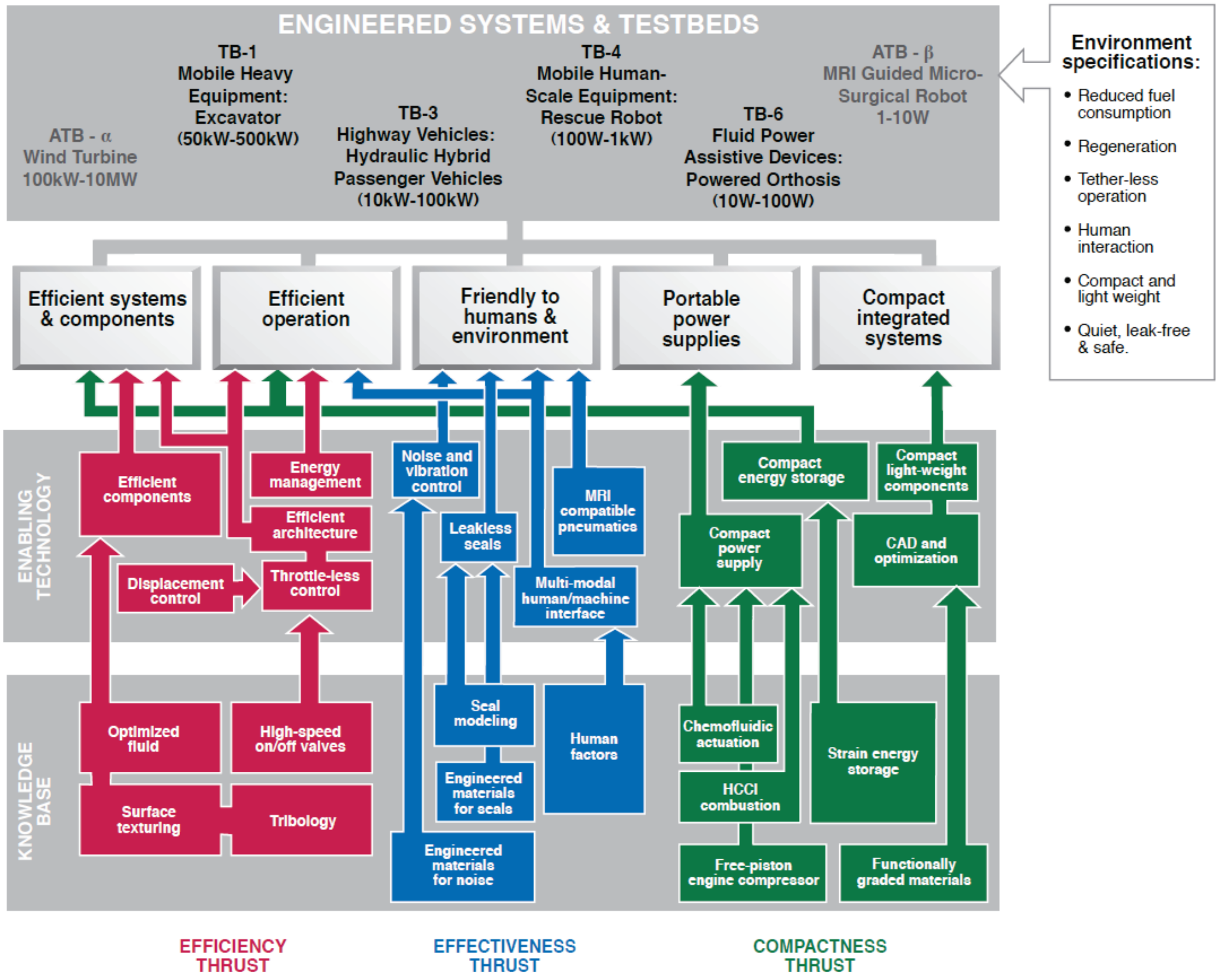
- Develop comprehensive and accurate mathematical model of complete pneumatic AFO system. Use model to create pneumatic AFO devices that optimize efficiency with the goal of increasing run-time and decreasing weight.
- Create new knowledge on a high pressure pneumatic AFO device where "high pressure" means around 500 psi. First assess this technology with comprehensive mathematical models, then validate the models by designing, constructing and evaluating physical devices.
- Continue to research tiny hydraulic devices operating at about 2,000 psi. Critical needs include (1) validated, comprehensive mathematical models that can be used to predict behavior of hardware, (2) concepts for generating pressurized fluid from either battery or hydrocarbon fuel stored energy sources, (3) comprehensive assessment of safety when high pressure tiny hydraulic devices are used in close proximity to humans.

C. Member company benefits

New technologies that miniaturize components such as power sources, actuators, and valves will be developed. The availability of these components could spawn new markets for miniature fluid power systems. During 2011, we have had discussions with a CCEFP industry partner regarding licensing the PPAFO technology.

Three-Plane Research Chart

The three-plane chart of the CCEFP shown below has been modified over the past year to reflect changes in research strategy and research portfolio. Most significant are addition of the two associated test beds (ATB) not directly funded by the Center. They are ATB-alpha: Wind Turbine at the University of Minnesota, and ATB-beta: MRI guided micro-surgical robot at Vanderbilt University. These reflect new applications of fluid power at very high power level (100kW-10MW) and at very low power level (1-10W). Other changes to the three-plane diagram include the elimination of the "open accumulator" in the compactness thrust as a strategy for energy storage for mobile applications, and the focus on "safety oriented control" and "cavitation and noise prediction" in the effectiveness thrust. Added to the effectiveness thrust is the focus to develop MRI compatible pneumatics to address the need of the new associated test bed.

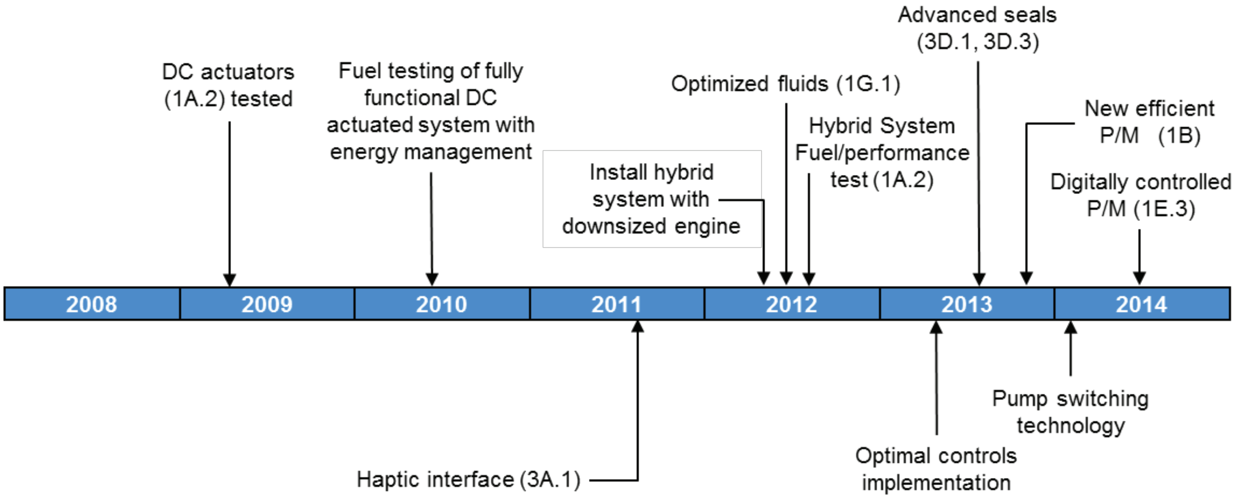


CCEFP Three-Plane Research Chart

Each thrust is led by a senior faculty member from a different core university of CCEFP. The thrust leaders are members of both the CCEFP Management Committee and the CCEFP Executive Committee where they participate in determining the strategic direction of the Center and the allocation of its resources.

Test Bed Future Milestone Charts

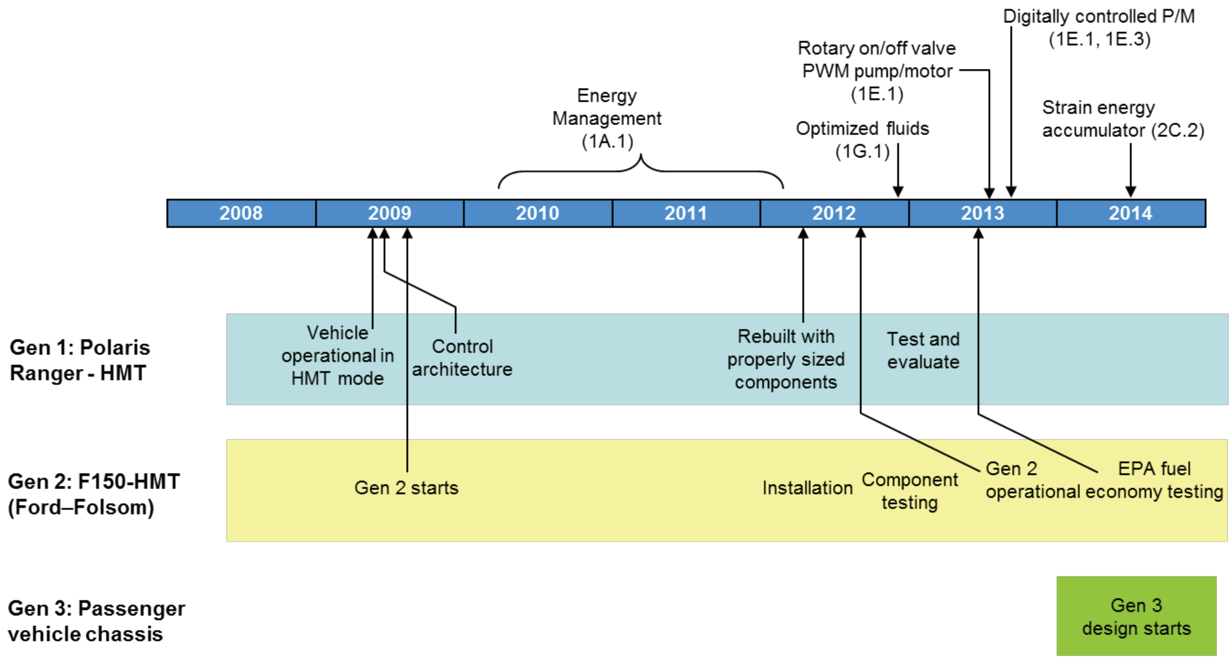
The milestone charts for each test bed are given below. These test beds realize the future engineered systems vision of the Center. The milestone charts have been simplified to highlight the most important system aspects of our research. Further details are available in the strategic action maps (SAMs), which have been placed in a password protected location on the Center's website (www.ccefp.org); the thrust milestone charts in section 2.2; and in the individual project summaries in Volume 2.



Test Bed 1 Milestone Chart

Test Bed 1: Heavy Mobile Equipment - Excavator

The time line for test bed 1 above indicates displacement control, energy management, new pump/motor design, and human machine interfaces being integrated and tested in various points in time. Haptic interface was integrated onto the test bed in August 2011. The next phase of test bed 1 will focus on a hybrid displacement control architecture that involves energy storage and engine downsizing for further fuel reduction. The integration of these new systems, controls optimization, and the investigation od optimized fluids will take place in the Spring and Summer of 2012. A comprehensive test program is planned for Fall 2012.

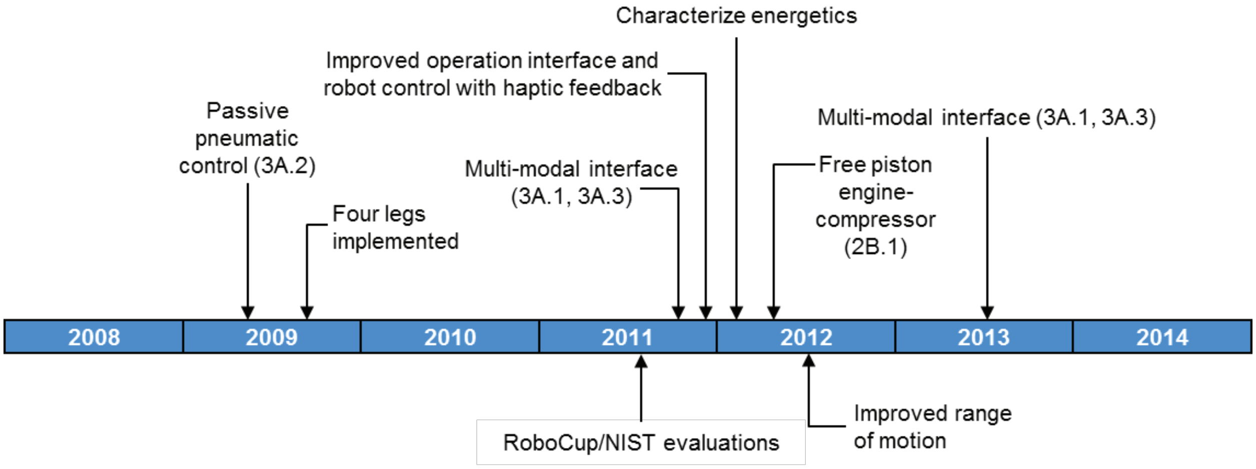


Test Bed 3 Milestone Chart

Test Bed 3: Hydraulic Hybrid Passenger Vehicle

The time line above shows that the test bed is continuing to focus on the Generation 1 Polaris Ranger utility vehicle chassis. Work on Gen 1 will ramp down following the arrival and commissioning of the Ford F150 pick-up truck chassis (Generation 2) this summer. Design work on the Generation 3 system for the passenger vehicle chassis will begin in 2014.

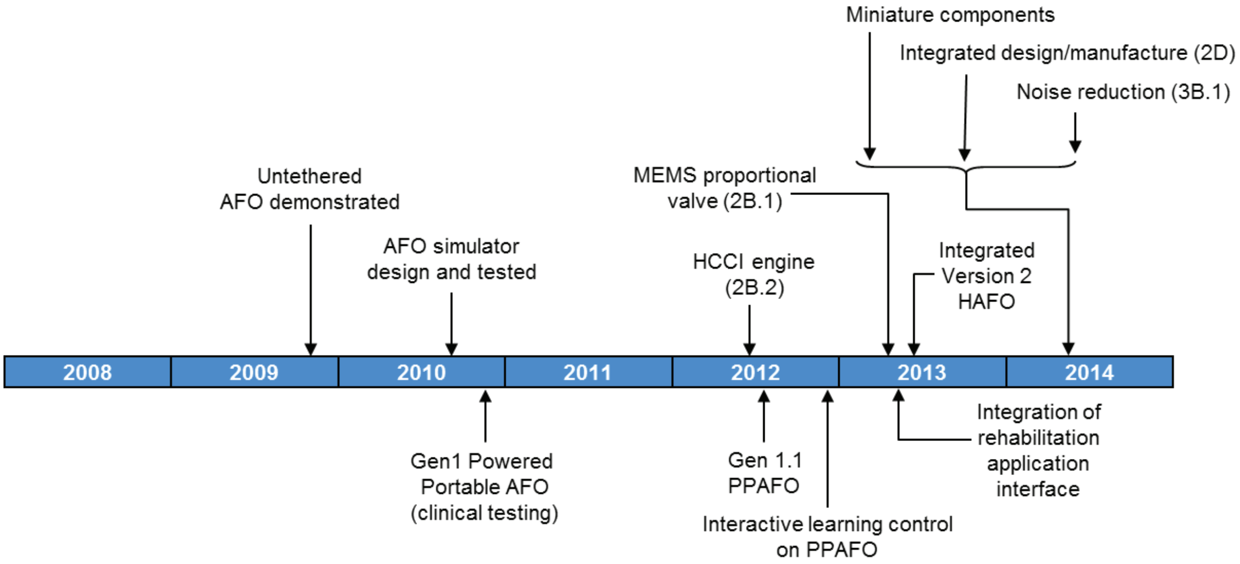
While the hydromechanical architecture is planned for all three generations, there will be differences in terms of design freedom, ruggedness and space constraints. The Gen 1 vehicle is currently has been rebuilt with a new in-house transmission and “right sized” components. Testing of hardware and construction of the Gen 2 vehicle is underway. It is expected to be functional and will undergo standardized efficiency testing in 2012. Integration of associated CCEFP research is continuing. In 2012, the integration of various energy management approaches into the test bed control algorithm (1A.1) and testing with more efficient fluids (1G.1) is planned. In the longer term, the rotary on/off valve controlled pump/motor (1E.1) and high efficiency pump/motors (1E.3) are planned for integration in 2013, and the strain energy accumulators (2C.2) in 2014.



Test Bed 4 Milestone Chart

Test Bed 4: Compact Rescue Robot

The time line above shows that the free-piston engine compressor (2B.1) is the first power supply implemented on test bed 4. This is scheduled to occur in Spring 2012. Various human-machine interfaces are also being tested on this test bed (3A.1, 3A.2, 3A.3). Changes to the operator interface, which include haptic feedback, have improved the robot control. The replacement of the actuation cylinders in the Summer of 2012 will improve the robot's range of motion.



Test Bed 6 Milestone Chart

Test Bed 6: Human Assist Devices (Fluid Powered Ankle-Foot-Orthoses)

The time line for test bed 6 is shown above. An untethered version of an assistive AFO was demonstrated in 2009, and first generation powered portable AFO (PPAFO) underwent clinical testing in 2010. The Generation 1.1 PPAFO with improved pneumatic rotary actuator will be available in summer of 2012. The first prototype of the micro HCCI engine compressor (2B.2) will be integrated into the PPAFO and tested in the second half of 2012. The demonstration of a first MEMS proportional valve will take place in April 2013. Iterative learning control on the PPAFO will be integrated in 2013 and beyond.

REU Program

The CCEFP summer REU program continues to involve undergraduate students in significant CCEFP research projects. REU participants are paired with a CCEFP faculty mentor who constructs a summer research project related to the CCEFP research of the faculty. Participants work on core, test bed or associated projects. Participants become members of the faculty's research group and interact with other graduate and undergraduate students working on the project. Participants attend the REU Fluid Power Bootcamp at the outset of the program, the bi-weekly webcasts and, when possible in person at other center-wide events to connect with other projects. Participants complete a pre- and post-experience survey that probes the quality of their research experience. Eighteen students participated in summer 2011, nearly 100 students to date since 2007. Among the participants, 39% were women and an additional 28% of students were racially or ethnically underrepresented. The CCEFP continues to expand it recruiting database by identifying key institutions that focus on fluid power education or minority-servings institutions with an emphasis in STEM. The importance of undergraduate researchers to the success of the Center was solidified by the decision to require all research projects and test beds to hire at least one academic year undergraduate research assistant.

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2.2 TRANSLATIONAL RESEARCH

Wind energy storage

A team of faculty and students from the University of Minnesota and the University of Virginia together with industry partner, Lightsail Energy, are investigating a novel compressed air energy storage approach for wind power. The research is funded by a four year grant from the NSF *Emerging Frontiers in Research and Innovations* Program (EFRI). The partnership is investigating components and systems designs and control strategies that enhance overall system efficiency and effectiveness.

The investigators of the research are: Perry Li (PI), Terry Simon (Co-PI) and James Van de Ven at the University of Minnesota and Eric Loth at the University of Virginia and industry partner Lightsail Energy which is located in Oakland, CA. The research proposes to develop a localized method for storing off-shore wind energy in high pressure compressed air vessels for later conversion to electricity. In addition to allowing the storage of wind energy during periods of low demand, the concept will achieve load leveling so that components can be down-sized for average rather than peak power. The concept makes use of the comparative advantages of hydraulics and pneumatics in a so-called "Open Accumulator" architecture coupled with an isothermal air compressor/expander design. The interdisciplinary research involves fluid flow, heat transfer, machine design and systems and control.

Efficient, low cost and robust drivetrains for wind turbines

Researchers at the University of Minnesota are collaborating with industry partners on research to develop a hydrostatic drivetrain for large (6 MW+) off-shore wind turbines. The research is funded by a Department of Energy grant targeted at lowering the cost of electricity from off-shore wind turbines. DOE has a goal of generating 20% of the country’s electricity from wind by 2020. In order to achieve that goal, significant off-shore generating capacity will need to be installed. The cost of electricity from off-shore wind turbines today is more than double that of the average land based wind turbine. The hydrostatic drivetrain project is focusing on improvements in system efficiency, cost (capital, operation and maintenance, and replacement cost), availability (robustness) plus the addition of energy storage to reduce the cost of electricity from an off-shore wind turbine using a hydrostatic drivetrain.

Eaton Corporation (Lead) and Clipper Windpower are the University of Minnesota’s industry partners on the project. Kim Stelson is the principal investigator at UMN. The project also includes UMN researchers from the University’s Eolos wind turbine team. Eolos is a 2.5 MW DOE funded research wind turbine located at UMN’s UMore Park in Rosemount, MN (www.eolos.umn.edu). It provides a unique resource for industry and academic researchers to have access to a utility scale wind turbine and all associated data in a real world environment.

While the project with Eaton and Clipper is focused on very large, off-shore wind turbines, UMN researchers believe that a hydrostatic drivetrain could create a significant opportunity in the “mid wind” wind turbine market (100 kW to 1 MW). Wind turbine owners in this market niche don’t have a large wind farm with scores of turbines and on-site personnel for maintenance and repairs, so they are looking for low cost and robust systems. Wind turbines with hydrostatic drivetrains appear to be very well suited for mid wind.

Table 2: Estimated Budgets by Research Thrust and Cluster

Thrust	Cluster Title	Cluster Leader	Project Name	Organizational Sponsor	Project Leader	Investigators	University and Department	Current Year Budget	Est. Next Year Budget
1: Efficiency (Monika M. Ivantysynova)	1: Efficiency	Monika M. Ivantysynova	1A.1: Integrated Algorithms for Optimal Energy Use in Mobile Fluid Power Systems (Center Controlled Project - translational research)	NSF ERC Program	Kim A. Stelson	Andrew G. Alleyne Monika M. Ivantysynova Perry Y. Li	University of Illinois at Urbana-Champaign Purdue University University of Minnesota	$134,359	$2,547,076
			1A.2: Multi-Actuator Hydraulic Hybrid Machine Systems (Center Controlled Project - translational research)	NSF ERC Program	Monika M. Ivantysynova			$90,014	
			1B.1: New material combinations and surface shapes for the main tribological systems of piston machines (Center Controlled Project - translational research)	NSF ERC Program	Monika M. Ivantysynova			$87,721	
			1B.2: Surface Effects on Motor Start-Up Friction (Center Controlled Project - translational research)	NSF ERC Program	Ashlie Martini	John H. Lumkes	Purdue University	$58,608	
			1D: Micro- and Nano-Texturing for Low Friction Fluid Power Systems (Center Controlled Project - translational research)	NSF ERC Program	William King			$113,638	
			1E.1: Helical Ring On/Off Valve Based 4-quadrant Virtually Variable Displacement Pump/Motor (Center Controlled Project)	NSF ERC Program	Perry Y. Li	Thomas R. Chase	University of Minnesota	$76,635	
			1E.2: High Speed On/Off Valves to Enable Efficient and Effective Fluid Power Systems (Center Controlled Project - translational research)	NSF ERC Program	John H. Lumkes	Monika M. Ivantysynova Perry Y. Li	Purdue University University of Minnesota	$75,298	
			1E.3: High Efficiency, High Bandwidth, Actively Controlled Variable Displacement Pump/Motor (Center Controlled Project - translational research)	NSF ERC Program	John H. Lumkes	Monika M. Ivantysynova Perry Y. Li	Purdue University University of Minnesota	$75,738	
			1E.4: Piston-by-piston control of pumps and motors using mechanical methods (Center Controlled Project - translational research)	NSF ERC Program	Perry Y. Li	Thomas R. Chase	University of Minnesota	$77,220	
			1G.1: Tribofilm Structure and Chemistry in Hydraulic Motors (Center Controlled Project - translational research)	NSF ERC Program	Paul W. Michael	Scott S. Bair William King Ashlie Martini	Georgia Institute of Technology-School of Mechanical Engineering University of Illinois at Urbana-Champaign-Mechanical Science and Engineering Purdue University	$73,354	
			Advanced Energy Saving Hydraulic System Architecture for a Wheel Loader (Associated Project - translational research)	Confidential Organization (optional use for associated or sponsored projects only)	Monika M. Ivantysynova			$167,788	
			Advances in External Gear Machines Modeling (Associated Project - translational research)	Casappa S.p.A.	Andrea Vacca			$82,000	
			Design of low noise emission internal gear machines (Associated Project - translational research)	Confidential Organization (optional use for associated or sponsored projects only)	Andrea Vacca			$100,000	
			Design of positive displacement machines for SCR automotive applications (Associated Project - translational research)	MGI Coutier	Andrea Vacca			$58,000	
			Efficiency Measurement on special axial piston pump (Associated Project - translational research)	Confidential Organization (optional use for associated or sponsored projects only)	Monika M. Ivantysynova			$28,808	
			EFRI-RESTOR: Novel Compressed Air Approach for Off-shore Wind Energy Storage (Associated Project - NSF)		Perry Y. Li	James Van De Ven	University of Minnesota	$500,000	
			Fluid Efficiency (Associated Project - translational research)	Confidential Organization (optional use for associated or sponsored projects only)	Paul W. Michael			$195,250	
			Hydrostatic Transmission for Wind Power Generation (Associated Project - translational research)	Bosch Rexroth Corporation, Eaton Corporation, Racine Federated Inc. (formerly Hedland Flow Meters), Sauer-Danfoss	Kim A. Stelson	Bradley F. Bohlmann	University of Minnesota	$9,868	
			Mechanical Implementation of Waved Surface and Waved Piston Technologies (Associated Project - translational research)		Monika M. Ivantysynova			$26,040	
			Modeling and Analysis of Swash Plate Type Axial Piston Pump (Interface) (Associated Project - translational research)	Confidential Organization (optional use for associated or sponsored projects only)	Monika M. Ivantysynova			$107,692	
			Optimization Environment for the Architecting of Micro-grids in Ultra Low Energy Communities (Associated Project - translational research)	United Technologies Research Center	Christiaan J. Paredis			$9,688	

Thrust	Cluster Title	Cluster Leader	Project Name	Organizational Sponsor	Project Leader	Investigators	University and Department	Current Year Budget	Est. Next Year Budget
			PCA Mule- System Implementation and Testing (Associated Project - translational research)	Confidential Organization (optional use for associated or sponsored projects only)	Monika M. Ivantysynova			$281,465	
			Performance Prediction and System Control through Coupled Multi-domain Models: A Comparison Study (Associated Project - translational research)	Confidential Organization (optional use for associated or sponsored projects only)	Monika M. Ivantysynova			$16,423	
			Pump Dynamic Model Development (Associated Project - translational research)	Confidential Organization (optional use for associated or sponsored projects only)	Monika M. Ivantysynova			$115,138	
			Reliable Lightweight Transmission of Off-shore Utility Scale Wind Turbines (Associated Project - translational research)	Eaton Corporation	Kim A. Stelson	Bradley F. Bohlmann	University of Minnesota	$124,502	
							Subtotal for Cluster Within Thrust	$2,685,247	$2,547,076
							Translational Research Projects Within Thrust	$2,108,612	
							Subtotal (all projects) for Thrust	$2,685,247	$2,547,076
							Total Number of Undergraduate Students in Thrust	8	
							Total Number of Graduate Students (M.S. and Ph.D.) in Thrust	32	
							Total Number of Postdocs in Thrust	2	
							Total Number of Personnel in Thrust	61	
2: Compactness (Andrew G. Alleyne)	2: Compactness	Andrew G. Alleyne	2B.1: Free-Piston Engine Compressor (Center Controlled Project - translational research)	NSF ERC Program	Eric J. Barth			$88,190	$816,879
			2B.2 Miniature HCCI Free-Piston Engine Compressor (Center Controlled Project - translational research)	NSF ERC Program	David B. Kittelson	William K. Durfee	University of Minnesota-Mechanical Engineering	$70,638	
			2B.3: Free Piston Engine Hydraulic Pump (Center Controlled Project - translational research)	NSF ERC Program	Zongxuan Sun			$70,181	
			2C.2: Advanced Strain Energy Accumulator (Center Controlled Project - translational research)	NSF ERC Program	Eric J. Barth			$94,524	
			2D: Multifunctional Fluid Power Components Using Engineered Structures and Materials (Center Controlled Project)	NSF ERC Program	Douglas L. Cook			$72,347	
			2E: Model-Based Systems Engineering for Efficient Fluid Power (Center Controlled Project - translational research)	NSF ERC Program	Christiaan J. Paredis			$75,169	
			2F: MEMS Proportional Pneumatic Valve (Center Controlled Project - translational research)	NSF ERC Program	Thomas R. Chase			$58,181	
			2G: Fluid Powered Surgery and Rehabilitation via Compact, Integrated Systems (Center Controlled Project - translational research)	NSF ERC Program	Robert J. Webster	Eric J. Barth Vito R. Gervasi Jun Ueda	Vanderbilt University Milwaukee School of Engineering Georgia Institute of Technology	$136,007	
			Functionally Graded Metallic Lattice Components for Advanced Propulsion Components (Associated Project - translational research)	DARPA	Vito R. Gervasi			$182,000	
			Open Accumulator Compressed Air Storage Concept for Wind Power (Associated Project)		Perry Y. Li			$38,286	
			Precision Pneumatic MRI Compatible Robotic Surgery (Associated Project - translational research)	The Martin Company	Eric J. Barth			$12,692	
			Single-Channel Hybrid FES Gait System (Associated Project - translational research - NSF)	National Institutes of Health (NIH)	William K. Durfee			$5,208	
							Subtotal for Cluster Within Thrust	$903,423	$816,879
							Translational Research Projects Within Thrust	$792,790	
							Subtotal (all projects) for Thrust	$903,423	$816,879
							Total Number of Undergraduate Students in Thrust	12	
							Total Number of Graduate Students (M.S. and Ph.D.) in Thrust	14	
							Total Number of Postdocs in Thrust	1	
							Total Number of Personnel in Thrust	39	
			3A.1: Multimodal Human Machine Interfaces - The impact of operator interface on fuel efficiency (Center Controlled Project - translational research)	NSF ERC Program	Wayne J. Book	Steven X. Jiang Zongliang Jiang Perry Y. Li Eui H. Park	North Carolina Agriculture and Technical State University-Industrial and Systems Engineering North Carolina Agriculture and Technical State University University of Minnesota North Carolina Agriculture and Technical State University	$97,578	
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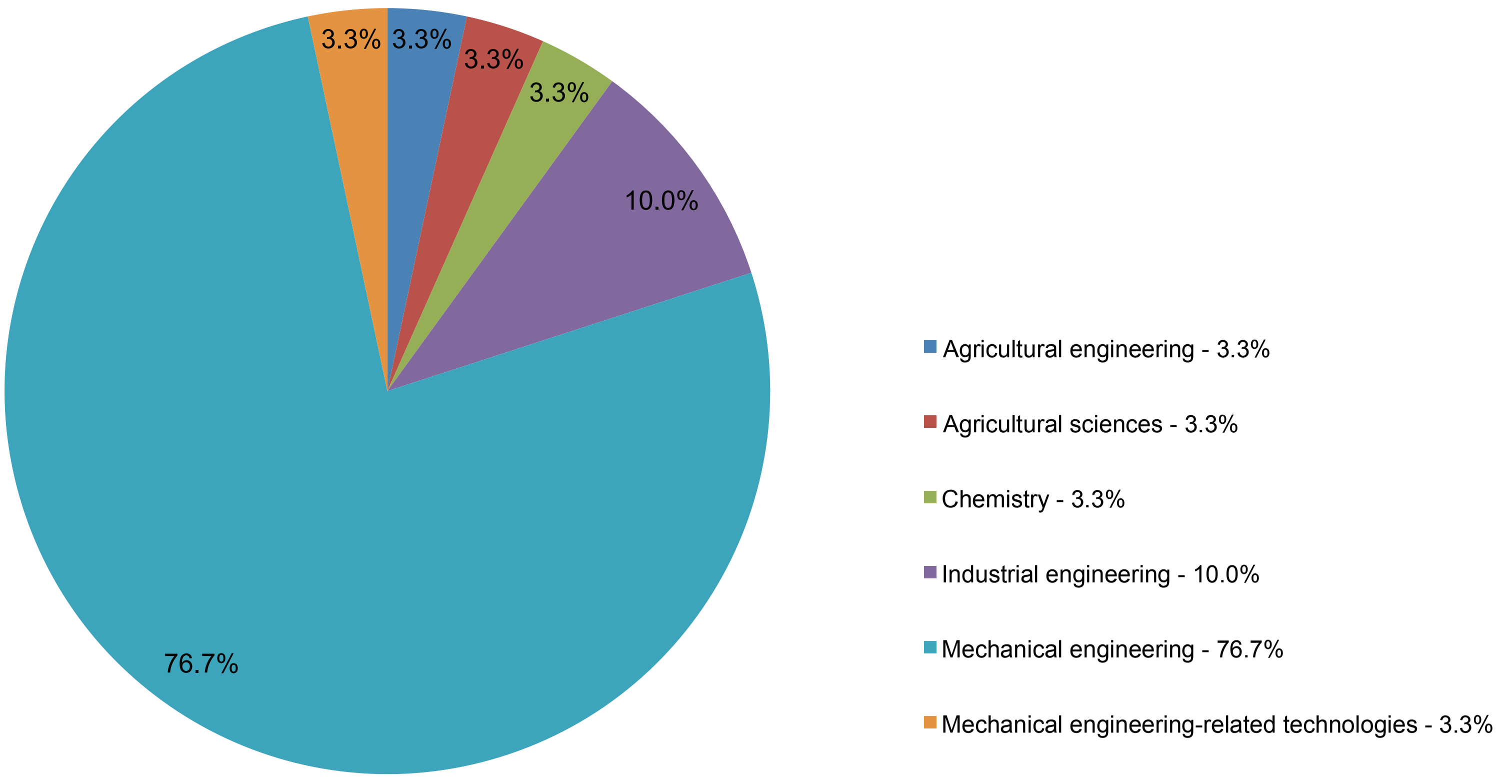
Thrust	Cluster Title	Cluster Leader	Project Name	Organizational Sponsor	Project Leader	Investigators	University and Department	Current Year Budget	Est. Next Year Budget
3: Effectiveness (Wayne J. Book)	3: Effectiveness	Wayne J. Book	3A.3: Human Performance Modeling and User Centered Design (Center Controlled Project - translational research)	NSF ERC Program	Steven X. Jiang	Zongliang Jiang	North Carolina Agriculture and Technical State University	$98,798	$622,625
						Eui H. Park	North Carolina Agriculture and Technical State University		
			3B.1: Passive Noise Control in Fluid Power (Center Controlled Project - translational research)	NSF ERC Program	Kenneth A. Cunefare			$90,573	
			3D.1: Leakage Reduction in Fluid Power Systems (Center Controlled Project - translational research)	NSF ERC Program	Richard F. Salant			$66,817	
			3D.2: New Directions in Elastohydrodynamic Lubrication to Solve Fluid Power Problems (Center Controlled Project)	NSF ERC Program	Scott S. Bair			$72,260	
			Adaptive Control for Oscillation Damping (Associated Project - translational research)	CNH America, Inc.	Andrea Vacca			$17,231	
			Analysis of transmission noise sources (Associated Project - translational research)	Confidential Organization (optional use for associated or sponsored projects only)	Monika M. Ivantysynova			$53,931	
			Development of an Experimental Pressurized Thin-film Couette Viscometer and Consultation (Associated Project)	Total Oil Company	Scott S. Bair			$20,000	
			Evaluation of the High Pressure, High Shear Stress Capability at Georgia Tech (Associated Project)	The Lubrizol Corporation	Scott S. Bair			$7,917	
			MRI-R2: Development of a Precise and High Speed Hydrostatic Dynamometer System for Research and Education in Automotive Propulsion Systems (Associated Project - translational research - NSF)		Zongxuan Sun	David B. Kittelson	University of Minnesota-Mechanical Engineering	$91,183	
						Kim A. Stelson	University of Minnesota-Mechanical Engineering		
			Multimodal Human-Machine Interface Design with Augmented Reality and Ergonomics (Associated Project - translational research - NSF)	Confidential Organization (optional use for associated or sponsored projects only)	Silvanus J. Udoka			$27,176	
			Shaft Pumping by Laser Structured Shafts with Rotary Lip Seals (Associated Project - translational research)		Richard F. Salant			$13,714	
			Understanding and Reducing the Adverse Effects of Biodynamic Feedthrough (Associated Project - translational research)	National Defense Science and Engineering Fellowship Grant (NDSEG)	Wayne J. Book			$13,320	
			Water-removing filters and relative humidity sensors (Associated Project - translational research)	Confidential Organization (optional use for associated or sponsored projects only)	Paul W. Michael			$6,250	
	Subtotal for Cluster Within Thrust							$676,748	$622,625
Translational Research Projects Within Thrust								$576,571	
Subtotal (all projects) for Thrust								$676,748	$622,625
Total Number of Undergraduate Students in Thrust								3	
Total Number of Graduate Students (M.S. and Ph.D.) in Thrust								15	
Total Number of Postdocs in Thrust								0	
Total Number of Personnel in Thrust								34	
Test Beds (Kim A. Stelson)	Test Beds	Kim A. Stelson	Highway Vehicles -- Hydraulic Hybrid Passenger Vehicle (Test Bed 3) (Center Controlled Project)	NSF ERC Program	Perry Y. Li	Thomas R. Chase	University of Minnesota	$111,325	$412,173
			Human Assist Devices -- Fluid Power Ankle-Foot Orthosis (Test Bed 6) (Center Controlled Project)	NSF ERC Program	Elizabeth T. Hsiao-Wecksler	Wayne J. Book	Georgia Institute of Technology	$168,223	
						Vito R. Gervasi	Milwaukee School of Engineering		
						Zongliang Jiang	North Carolina Agriculture and Technical State University		
			Human Scale Mobile Equipment -- Compact Rescue Robot (Test Bed 4) (Center Controlled Project)	NSF ERC Program	Wayne J. Book			$94,622	
			Mobile Heavy Equipment - High Efficiency Excavator (Test Bed 1) (Center Controlled Project)	NSF ERC Program	Monika M. Ivantysynova			$100,036	
	Subtotal for Cluster Within Thrust							$474,206	$412,173
Translational Research Projects Within Thrust								$0	
Subtotal (all projects) for Thrust								$474,206	$412,173
Total Number of Undergraduate Students in Thrust								0	
Total Number of Graduate Students (M.S. and Ph.D.) in Thrust								10	
Total Number of Postdocs in Thrust								1	
Total Number of Personnel in Thrust								19	

[1] - The sum of personnel for all thrusts may be greater than the total number of personnel associated with the ERC if personnel are associated with projects under multiple thrusts.

Figure 2a: Research Project Investigators by Discipline



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2.3 RESEARCH PROGRAM BY THRUST

BACKGROUND

In order to better align with the requirements for multi-year funding to support graduate students, CCEFP extended its funding cycle from one to two years starting in Year 5. A total of 24 projects and 4 test beds were funded by the Center in the Year 5-6 budget cycle. All except Project 2A continued as active projects into Year 6. The Principal Investigator on Project 2A, Chemofluidic Hot Gas Vane Motor, chose to stop work on the project at the end of Year 5. The reasons will be explained later in this report section.

CCEFP recently completed the selection of its Year 7-8 projects. The Center's Industrial Advisory Board was engaged and very actively involved in the call for proposals and the project selection process. A total of 32 proposals were received and 21 were awarded funding. Details on the projects and the selection process can be found in Section 5.3 of this report.

The following pages provide an overview of the Center's Year 5-6 projects from the perspective of the thrust they support.

EFFICIENCY

Efficiency is the first of the Center's transformational goals: *Doubling fluid power efficiency in current applications and in new transportation applications*. The technical barriers to achieving this goal include lack of efficient components, efficient systems, energy management and optimized control. Projects range from improving fluids and components at the microstructure level, to innovative component design, to increasing overall system functionality through the use of novel system architectures and control algorithms.

The table below summarizes the Year 5-6 Thrust 1 projects and the barriers they address. Further project details can be found in the following pages and in Volume II.

Thrust 1: EFFICIENCY	Technical Barriers								
	Efficient Components	Efficient Systems	Control and Energy Management	Compact Power Supply	Compact Energy Storage	Compact Integration	Safe and Easy to Use	Leak-free	Quiet
1A.1: Integrated Algorithms for Optimal Energy Use for Mobile Fluid Power Systems		●	●						
1A.2: Multi-Actuator Hydraulic Hybrid Machine Systems	●	●	●						
1B.1: New Material Combinations and Surface Shapes for the Main Tribo-systems of Piston Machines	●								●
1B.2: Surface Effects on Start-up Friction	●								
1.D: Micro-Textured Low-Friction Surfaces	●								
1E.1: Helical Ring On/Off 4-quadrant Pump/Motor	●	●							
1E.2: High Speed On/Off Valves to Enable Efficient and Effective Fluid Power Systems	●	●							
1E.3: High Efficiency, High Bandwidth, Actively Controlled Variable Displacement Pump/Motor	●	●							
1E.4: Piston-by-Piston Control of Pumps and Motors using Mechanical Methods	●	●							
1G.1: Energy Efficient Fluids	●								

Efficiency Thrust Technical Barriers

Efficiency Projects

1A.1: Integrated Algorithms for Optimal Energy Use for Mobile Fluid Power Systems

The goal of this project is to identify methods of regulating power generation and distribution in mobile fluid power systems that maximize the overall system efficiency and to demonstrate them on Center test beds. From previous Center-funded work in the study of energy management strategies (EMS), it was concluded that there is no single strategy that is optimal for all applications. Therefore, the planned approach is to develop a toolbox of EMS design methods and decision algorithms that will identify the best design method for a chosen application. These algorithms will select the optimal design from the EMS toolbox based on a number of system attributes such as knowledge of duty cycle, ability to store energy, and problem constraints. In this way, the energy efficiency of mobile fluid power applications can be improved without compromising performance. The first Center test bed that will be targeted is the Hydraulic Hybrid Passenger Vehicle, Test Bed 3 (TB3), where the goal is to demonstrate a 100% improvement in fuel economy over a non-hybrid vehicle.

1A.2: Multi-Actuator Hydraulic Hybrid Machine Systems

The original goal of project 1A2 was to develop system architectures and control methods for optimal power management in multi-actuator mobile hydraulic machines using displacement-controlled linear and rotary actuators. The target was at least 40% energy consumption reduction for typical working cycles of multi-actuator machines compared to the state of the art of machines. This level of improvement was met. In fact, energy efficiency was doubled by implementing displacement controlled actuator circuits and demonstrated on Test Bed 1 (TB1), the excavator.

In June 2010, the project goals were redefined to investigate hydraulic hybrid architectures for multi-actuator machines and the potential for further fuel savings from these systems. A target of at least 50% fuel savings over the standard Bobcat excavator system is targeted for TB1. The research includes investigation of hybrid architectures and control methodologies for optimal hybrid power management through efficient engine operation which includes energy storage and engine load-leveling. The new system hybrid design will also allow cost savings by downsizing the combustion engine. The hydraulic and electrical systems will be simplified by the development of methodologies for variable displacement “smart pumps” with improved swash plate controls and integrated electronics.

Starting in 2012, the project will focus on investigating reducing production costs by pump switching between actuators, thus reducing the number of pumps installed in the hydraulic system and their sizes. This is especially important for large machines where the current design approach requires the installation of large pumps. Another goal is the developing effective machine prognostics concepts to allow the prediction of impending failures to avoid expensive machine breakdowns.

1B.1: New Material Combinations and Surface Shapes for the Main Tribo-systems of Piston Machines

The project goal is to discover the impact of material combinations and advanced surface shaping on the reduction of energy dissipation and the increase of load carrying ability of the lubricating gaps of axial piston machines. By studying the role of material properties in combination with gap microgeometry through a fully-coupled fluid-structure-thermal and multi-body dynamics simulation model for the piston cylinder interface, a better understanding of the complex physical phenomena of lubricating gaps performance will be realized. This knowledge will be used to propose new design solutions for the main tribological systems of axial piston machines.

1B.2: Surface Effects on Motor Start-up Friction

A hydraulic motor used to propel construction equipment is routinely oversized for normal operation. This is because while the efficiency is reasonably good during operation it is veryy low during motor starting. This inefficiency is primarily due to the high static friction between metal surfaces. The goal of this project is to develop and experimentally validate a model for static friction to improve the start-up efficiency of hydraulic components. A successful project will result in a fundamental understanding of the relationship between characteristics of a component’s interfaces and the friction it must overcome at start-up. A mathematical model was developed to estimate the static friction coefficient between two surfaces and a test rig was developed and used to measure static friction with various surface profile characteristics and lubricants to validate the model. The modeling tools and corresponding experimental test rig developed for the project are being used to evaluate the start-up efficiency of existing and novel (e.g. textured) surfaces developed in associated CCEFP projects.

The PI for this project has taken a faculty position at the University of California at Merced and the project will be ending in May 2012.

1D: Micro-Textured Low-Friction Surfaces

Friction losses are one of the biggest impediments to energy efficient fluid power. It is well known that during lubricated sliding, microtextured surfaces have lower coefficient of friction than smooth surfaces of the same material. While this effect has been observed on small, laboratory-scale samples, very little work has been done on scaling up microtextured surfaces to sizes, shapes, and materials relevant for fluid power applications, owing to the cost and relative immaturity of the manufacturing technology. Even if the manufacturing technology were suitable for industrial application, there are no rigorous design rules for these textures that lead to optimum performance for various applications. The goal of this project is to develop low-cost microstructured surfaces with significantly reduced coefficient of friction compared to surfaces with conventional surface finish. It aims to design, fabricate and characterize the effect of micro-textures on lubricated surfaces that are suitable for real world fluid power applications. The focus is to enhance the performance of lubricated contacts by using micro-textures that lead to a significant reduction in the sliding friction between the surfaces compared to non-textured ones. The focus is also on low-cost scaling of these surfaces to sizes and shapes appropriate to the industrial applications. The project is working with several CCEFP projects to provide micro-textured components.

1E.1: Helical Ring On/Off Valve Based 4-Quadrant Pump/Motor

Novel high-speed rotary on/off valves are being developed at CCEFP to address shortcomings in current valve technology that prevent the use of digital control techniques in hydraulic systems. The goal of the project is to demonstrate high performance, efficient control of hydraulic power using on/off valves in a throttle-less manner. This goal will be met through the development of critical enabling technologies such as novel high speed rotary on/off valves that will be integrated into virtually variable displacement pump/motors (VVDPM) for demonstration on CCEFP test beds. In addition to the self-spinning rotary spool valve approach studied in previous years, a newly proposed rotary valve based on a ring control element will be developed. This new ring valve addresses the objective of improving valve efficiency at high pressure and high bandwidth operation by simplifying the valve flow path while simultaneously reducing the internal compressible volume. Preliminary analysis indicates that the ring valve has the potential to reduce flow independent losses by approximately 40% in some applications. By pairing the on/off valve with a fixed displacement pump or motor, the effective displacement of the system can be varied by pulse-width-modulating the on/off valve. These “virtually variable displacement” pumps (VVDP) and pump/motors (VVDPM) have the potential to combine the compactness and cost effectiveness of valve control with the efficiency benefits of traditional variable displacement devices.

1E.2: High Speed On/Off Valves to Enable Efficient and Effective Fluid Power Systems

High-speed on/off valves are a critical component in digital hydraulic systems. The goals of the project are to research and develop advanced multi-domain models and increase the theoretical understanding of high speed digital hydraulic valves, experimentally validate the models, and apply the results to design valves in support of CCEFP projects and related digital fluid power applications. Digital valves will be implemented into several CCEFP projects and test beds to facilitate and validate the use of high speed on/off valves as enablers of efficient and effective fluid power systems.

A simulation tool was created to accurately and quickly model the dynamic characteristics of a pilot operated, high speed on/off valve. The modeling technique used in this work couples the fluid domain and the mechanical domain of the valves into a seamless simulation. The developed model was used to investigate pressure drop across the valve, valve timing, and valve transition time in order to design and fabricate a working prototype. Initial experimental results of a prototype pilot operated, high speed on/off main stage valve are presented and compared to the developed valve model for validation.

1E.3: High Efficiency, High Bandwidth, Actively Controlled Variable Displacement Pump/Motor

The goal of the project is to develop a hydraulic pump/motor that replaces the valve plate with actively controlled high speed on/off valves connected to each cylinder of the pump/motor to replace the valve plate. The coupled dynamic model of the hydraulic pump/motor developed during this project is crucial to facilitate the development of the pump/motor. Unit displacement is electronically controlled by on/off valve timing, not by a swash plate or other typical means. Pump/motors of this design can have increased efficiency due to reduction of friction, leakage, and compressibility losses as well as increased displacement control bandwidth. Supporting tasks include using the model to characterize and predict pump/motor efficiency, define the dynamic response and flow requirements of on/off valves required to provide significant improvements in efficiency and dynamic response over traditional pump/motors, simulate different operating strategies and characterize the effects on pump/motor efficiency (valve timing effects, partial fill methods, etc.), and to experimentally validate the model, design, and operating strategies. For experimental validation a prototype pump/motor will be built and tested.

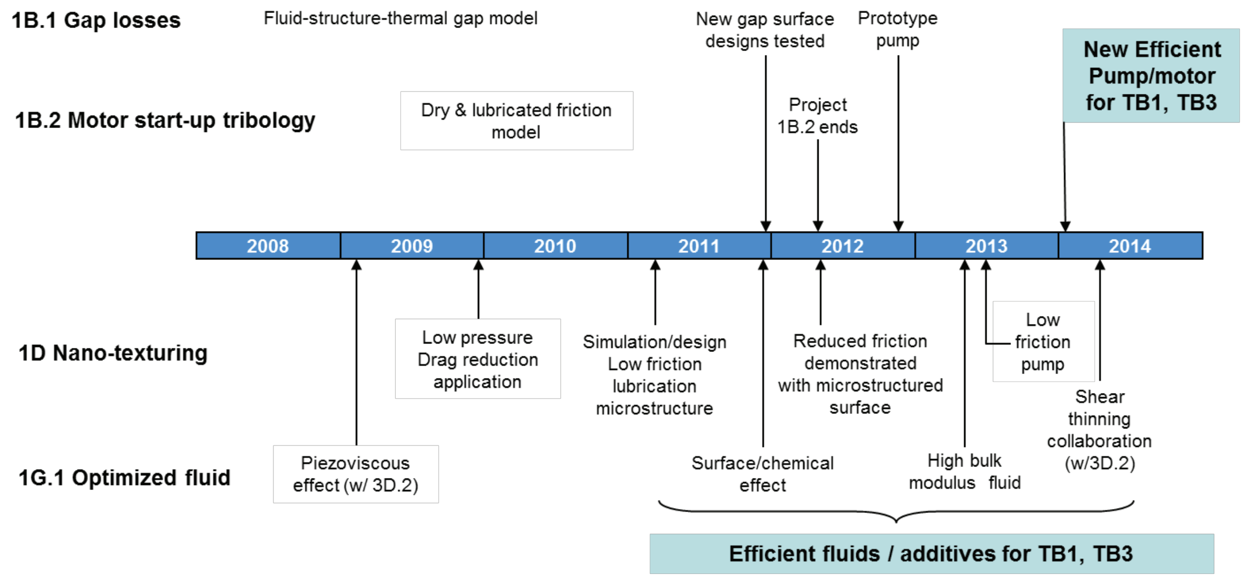
1E.4: Piston-by-piston control of pumps and motors using mechanical methods

The goal of this project is to develop simple and efficient strategies for controlling hydraulic units (e.g., pumps, motors) on a piston-by-piston basis. Piston-by-piston control of pumps and motors is being researched to improve their efficiency, particularly at low displacements. The drop in efficiency is caused by the fact that the dominant power losses, primarily leakage and friction, do not decrease as the output power is decreased in conventional pumps and motors that use fixed valve plates to phase flow into and out of the piston bores. Thus, in conventional pumps and motors high pressure is applied to all pumping pistons regardless of the displacement and, as a result, some of the leakage paths and friction losses remain constant. This project will focus on creating a variable displacement pump/motor that can meet or exceed existing designs in peak efficiency, and demonstrate a smaller drop off in efficiency as the displacement is decreased. With separate valves controlling the fluid in and out of each piston, the near constant losses associated with the fixed valve plate are eliminated. By utilizing a two degree of freedom rotary valve, the expected efficiency benefits of piston-by-piston control will be achieved with a control mechanism that is simpler and more cost effective than alternative research approaches.

1G.1: Energy Efficient Fluids

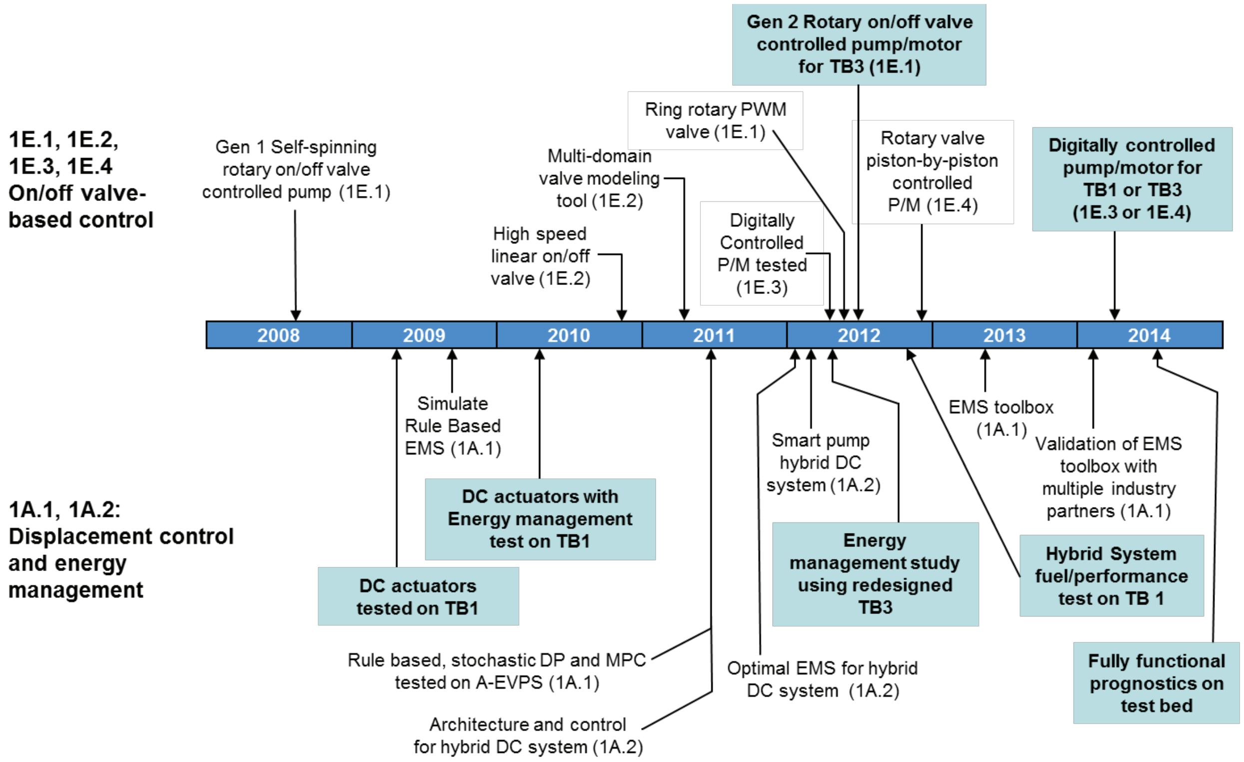
Motor starting efficiency is an important design consideration because friction is high and efficiency is low when a motor starts from zero rpm. In mobile hydraulic systems this means that the pump and motor are often larger than necessary for normal operation in order to meet the motor starting requirements. The goal of this project is to improve fluid power efficiency by systematically investigating tribofilm structure and chemistry in hydraulic motors. From our previous investigations we have concluded that hydraulic motor efficiency can be improved by enhancing boundary lubrication conditions. This conclusion is based upon correlations between motor efficiency tests and friction measurements in simple bench-top tribometers. We propose to bridge the gap between the performance of fluid power components of complex geometry and the fundamental understanding of tribology by studying the structure and chemistry of boundary films formed in motors. Improvements in boundary lubrication conditions are expected increase the minimum hydraulic motor starting efficiency by 10-20% without compromising the efficiency of other fluid power components.

Efficiency Thrust Milestone Charts



Efficient Components Milestone Chart

Efficient components: The timeline for major component-focused activities to break through the efficiency barrier is shown above. In this and the timelines that follow, the colored boxes indicate integration and demonstration on a test bed. Current activities in these projects are focusing on studying the fundamental sciences of tribological gaps, effect of micro-structured surfaces on friction and fluid properties on lubrication. Results are being integrated into development and testing subcomponents, and ultimately into efficient pump/motors that utilize these principle and demonstrated on test beds.



Efficient Systems, Control and Energy Management Milestone Chart

Efficient systems, control and energy management: Timeline for major activities in the areas of efficient systems, control and energy management is shown above. In the area of on/off valve based control, new and improved digital valves of different designs are being pursued. They are also being applied in the development of efficient digitally controlled pump/motors.

In the area of displacement control of mutli-actuator systems, a non-hybridized version has recently been demonstrated on test bed 1 (excavator). Hybrid versions (i.e. with accumulator and reduced engine size) with even greater potential for fuel saving will be demonstrated in the 2nd five years of the center's existence.

Various high level energy management schemes are being developed for the test bed 3 (on-highway vehicle). They will be tested on the vehicle at various stages and refined starting from 2011.

Efficiency Thrust Publications

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Campanella, G; and Vacca, A; "Modellazione numerica di un distributore Flow Sensing," Oleodinamica e Pneumatica, Tecniche Nuove, Milano, Italy (2011).

Casoli, P; Greco, M; Vacca, A; and Lettini, A; "Sistema telemetrico per acquisizione della pressione nel vano," Oleodinamica e Pneumatica, Tecniche Nuove, Milano, Italy (2011).

Chase, T; and Fikru, N; "A Review of MEMS Based Pneumatic Valves," Proceedings of the 52nd National Conference on Fluid Power, Las Vegas, NV; 11.2 (2011)

Cristofori, D; Vacca, A; “Electro-Hydraulic Proportional Valve Modeling Comprehending Magnetic Hysteresis,” Proceedings of the 52nd National Conference on Fluid Power, Las Vegas, NV; 28.1 (2011)

Cross, M; and Ivantysynova, M; “Practical Considerations for Pump / Motor Selection in Hydraulic Hybrid Vehicles,” Proceedings of the 52nd National Conference on Fluid Power, Las Vegas, NV; 11-2.3 (2011).

Deppen, T; Alleyne, A; Stelson, K; and Meyer, J; “A Model Predictive Control Approach for a Parallel Hydraulic,” Proceedings of the American Control Conference, ACC (2011).

Deppen, T; Alleyne, A; Stelson, K; and Meyer, J; “Model Predictive Control of An Electro-Hydraulic Powertrain with Energy Storage,” Proceedings of the ASME Dynamic Systems and Control Conference, DSCC (2011).

Ganesh, K; Minming, Z; and Ivantysynova, M; “Effect of Combining Precompression Grooves, PCFV and DCFV on Pump Noise Generation,” International Journal of Fluid Power, 12 (3):53-64 (2011)

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Garcia, J; Lumkes, J; and Martini, A; “Static friction characterization of metallic contacts with hydraulic fluids,” Proceedings of the 52nd National Conference on Fluid Power, Las Vegas, NV; 39.2 (2011)

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Ivantysynova, M; and Seeniraj, G; “A Multi-Parameter Multi-Objective Approach to Reduce Pump Noise Generation,” International Journal of Fluid Power, 12(1):7-17 (2011)

Klop, R; and Ivantysynova, M; “Investigation of Noise Sources on a Series Hybrid Transmission,” International Journal of Fluid Power, 12(3):17-30 (2011)

Kumar, R; and Ivantysynova, M; “Instantaneous Optimization Based Power Management Strategy to Reduce Fuel Consumption in Hydraulic Hybrids,” International Journal of Fluid Power, 12 (2):15-25 (2011)

Li, P; Loth, E; Simon, T; and Van de Ven, J; “Compressed Air Energy Storage for Offshore Wind Turbines,” 2011 International Fluid Power Exhibition (IFPE) (2011)

Merrill, K; Holland, M; and Lumkes, J; “Analysis of Digital Pump/Motor Operating Strategies,” Proceedings of the 52nd National Conference on Fluid Power, Las Vegas, NV; 1.1 (2011)

Meyer, J; Stelson, K; “Developing an Energy Management Strategy for a Four-Mode Hybrid Passenger Vehicle,” Proceedings of the 52nd National Conference on Fluid Power, Las Vegas, NV; 6.2 (2011)

Michael, P; Guevremont, JK; Devlin, M; and Ziemer, C; “Tribological Film Formation in Hydraulic Motors,” Proceedings of the STLE/ASME International Joint Tribology Conference, Paper IJTC2011-61029 (2011)

Pedchencko, A. V.; Barth, E. J.; "Finite Element Model-based Design of a Hyperelastic Strain Energy Hydraulic Accumulator"; Proceedings of the 52nd National Conference on Fluid Power, Las Vegas, NV; 14.3 (2011)

Rice, A; Li, P; “Optimal Efficiency-Power Tradeoff for an Air Motor/Compressor with Volume Varying Heat Transfer Capability,” ASME DSCC 2011/Bath Symposium on PTMC, Arlington, VA, (2011)

Rose, J; and Ivantysynova, M; “A Study of Pump Control Systems for Smart Pumps,” Proceedings of the 52nd National Conference on Fluid Power, Las Vegas, NV; I11-27.1 (2011)

Schenk, A; Ivantysynova, M; “An Investigation of the Impact of Elastohydrodynamic Deformation on Power Loss in the Slipper Swashplate Interface,” Proceedings of 8th JFPS Int Symp on Fluid Power, Okinawa, Japan. (2011)

Schenk, A; Ivantysynova, M; “Design and Optimization of the Slipper-Swashplate Interface Using an Advanced Fluid-Structure-Interaction Model,” Proceedings of the 52nd National Conference on Fluid Power, Las Vegas, NV; 4.2. (2011)

Schweiger, W., Schoefmann, W., and Vacca, A., "Gerotor Pumps for Automotive Drivetrain Applications: A Multi Domain Simulation Approach," SAE Int. J. of Passeng. Cars – Mech. Syst. 4(3):1358-1376, doi:10.4271/2011-01-2272 (2011).

Stelson, K; “Saving Energy by Advancing Fluid Power Technology,” Fluid Power Journal, March/April, 4 (2011)

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Tu, H; Rannow, M; Wang, M; Li, P; Chase, T; “High-speed 4 way rotary on/off valve for virtually variable displacement pump/motor applications,” ASME DSCC 2011/Bath Symposium on PTMC, Arlington, VA (2011)

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Wang, F.; Randan, M.; and Stelson, K.; “Comparison between Hydraulic Hybrid and Electric Hybrid Passenger Vehicle using ADVISOR 2004,” Proceedings of the 52nd National Conference on Fluid Power, Las Vegas, NV; 2.2 (2011)

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Wilfong,G; Holland, M; and Lumkes, J; “Design and Analysis of Pilot Operated High Speed On/Off Valves for Digital Pump/Motors,” Proceedings of the 52nd National Conference on Fluid Power, Las Vegas, NV; 20.1 (2011)

Yong, Chao; Barth, Eric J.; "A Virtual-Cam Control Methodology for Free-Piston Engines", ASME DSCC 2011/Bath Symposium on PTMC, Arlington, VA; TuAT1.2 (2011)

Yong, C.; Willhite, J. A.; Barth, E. J; "A Virtual-Cam Control Methodology for a Novel Free-Liquid-Piston Engine Compressor"; Proceedings of the 52nd National Conference on Fluid Power, Las Vegas, NV; 3.3 (2011)

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COMPACTNESS

The Compactness Thrust is primarily focused on CCEFP's third major goal: *Create portable, un-tethered human-scale fluid power applications*. The Center strategy identifies the technical barriers to achieving these goals. They are the lack of compact power supplies, compact energy storage, and compact integration. The table below summarizes the Thrust 2 projects and the barriers that they address. Further project details can be found in the following pages and in Volume II.

Thrust 2: COMPACTNESS	Technical Barriers								
	Efficient Components	Efficient Systems	Control and Energy Management	Compact Power Supply	Compact Energy Storage	Compact Integration	Safe and Easy to Use	Leak-free	Quiet
2A: Chemo-fluidic Hot Gas Vane Motor				●					
2B.1: Free-Piston Engine Compressor				●					
2B.2: Miniature HCCI Free-Piston Engine-Compressor				●					
2B.3: Free Piston Engine Hydraulic Pump			●	●		●			
2C.2: Advanced Strain Energy Accumulator					●				
2D: Multi-Functional Fluid-Power Components Using Engineered Structures and Materials						●			
2E: Model-Based Systems Engineering for Efficient Fluid Power		●	●			●			
2F: MEMS Proportional Pneumatic Valve			●			●			
2G: Fluid-Powered Surgery and Rehabilitation via Compact, Integrated Systems			●			●			

Compactness Thrust Technical Barriers

Compactness Projects

2A: Chemo-fluidic Hot Gas Vane Motor

The goal of this project is to develop, demonstrate, and characterize the performance of a monopropellant-powered vane motor for use in high bandwidth actuation of a hydraulic pump. The initial research involved the development of the motor, which had a target for continuous power in excess of 1000 W/kg. This is approximately five greater than rare-earth magnet brushless electric motors. The latest research has nfocused on design revisions to the vane motor to enable continuous operation of the motor with 80% peroxide. This is the concentration that previous research has indicated is necessary to acieve the project goals. Three new versions of the motor were fabricated and tested, but after 18 months of work the project tean has not been able to achieve continuous operation with 80% peroxide.

The researchers believe that the geometric requirements of multiple surface close-sliding-fits, together with significant thermal expansion, coupled with the absence of a lubrication system, renders this a research project that is not consistent with the resources of the Center. Therefore, work on Project 2A was stopped at the end of Year 5.

2B.1: Free-Piston Engine Compressor

The project goal is to develop a dynamic model-based design framework for a novel compact high energy density pneumatic power supply applicable to untethered fluid-power applications. This is achieved by modeling, designing, building and testing a free-piston engine utilizing spark-ignited fuel that is specifically load matched to the task of compressing air. Target metrics for the device include 100W average continuous output power in the form of 80 to 150 psig compressed air, a dry weight of 1.5 kg, energy density greater than 1500 kJ/kg, and a small footprint. This device will be integrated into the Compact Rescue Robot, Test Bed 4, by the end of 2012. Fundamental research will result in a generalized design method for the exploitation of free-piston engine dynamics for optimizing the efficiency and power density of the energetic conversion and transduction processes between chemical stored energy, kinetic energy of the free-piston, compression and pumping work, and stored pneumatic potential energy. This model-based design methodology takes a combined system dynamic and thermodynamic perspective that uniquely addresses the role of dynamic elements and effects seen to have a larger role in free-piston engines than more standard kinematic engines. Correspondingly, a generalized control methodology for free-piston engines will be formulated and applied.

2B.2: Miniature HCCI Free-Piston Engine Compressor

The first of the project's two goals is to generate new knowledge about the science and engineering of homogeneous charge compression ignition (HCCI) free piston engine-compressors (FPEC) that are suitable for tiny power supplies for small scale fluid power systems. The research on the FPEC builds on preliminary work which investigated novel small free-piston engine-compressors operating in glow-plug combustion mode. The second goal is to design, build, evaluate and deliver a tiny, high-efficiency air compressor that delivers approximately 10W of cold compressed air and runs on clean-burning dimethyl ether (DME) fuel. This engine compressor package, coupled with a fuel tank, will provide much higher power density and energy density than a battery – electric motor package, thus enabling a more compact design and longer run time of tiny fluid power systems. The engine-compressor will be integrated into Test Bed 6, the Portable Pneumatic Ankle Foot Orthosis.

2B.3: Free Piston Engine Hydraulic Pump

The goal of this project is to provide a compact and efficient fluid power source for mobile applications (10 kW-500 kW). Specifically this project will investigate the design, modeling and control of a free piston engine driven hydraulic pump.

For mobile applications including both highway vehicles and mobile heavy equipment, fluid power is currently generated onboard using a crankshaft based internal combustion engine (ICE) with a rotational hydraulic pump. The main drawbacks of this configuration are the relatively low efficiency and complex design of both the ICE and the hydraulic pumping system due to the dynamic operating requirements. An alternative approach is to supply fluid power using a free piston engine with a linear hydraulic pump. This configuration has the potential to significantly increase the ICE and pump efficiency while increasing system modularity. Specifically, the ICE efficiency can be improved with the variable compression ratio, advanced combustion such as homogeneous charge compression ignition (HCCI) and less fiction due to the elimination of the crankshaft. The pump efficiency can be improved with reduced fiction and leakage due to a simpler design. Previous work on free piston engine has shown limited success mainly due to the complex dynamic interactions between the combustion and the fluid power in real-time. To address the challenge, we propose to investigate the two fundamental technical barriers of the free piston engine driven hydraulic pump. They are the seamless coordination of the combustion and the fluid power and the design optimization of the system. To support the proposed research, our industrial partner Ford Motor Company has donated a free piston engine driven hydraulic pump to the University of Minnesota. A dynamic model for the system that includes HCCI combustion, two zone scavenging, the hydraulic dynamics and the piston dynamics has been built. We have also investigated control strategy for regulating load control, compression ratio control and combustion phasing control.

2C.2: Advanced Strain Energy Accumulator

The research objective of this work is to extend the current state of knowledge in the use of strain energy storing materials for the engineering design of compact energy storage devices. Specifically, this project seeks a low cost, low/no maintenance, high energy density accumulator primarily targeted toward a fluid powered automotive regenerative braking system (hydraulic hybrid). This project will focus on extending the energy storing capabilities of accumulators for the specific purpose not of flow smoothing, but of storing large amounts of hydraulic energy with an energy density appropriate for applications such as regenerative braking in passenger vehicles. The envisioned high energy density accumulator will be appropriate for either series or parallel hydraulic hybrid vehicles. The metric for success of the project will be an experimental prototype capable of storing up to 200 kJ of energy (3500 lbs at 35 mph) at a peak power of 90 kW (35 mph to zero in 4.5 second) in a package of acceptable weight and volume for a compact to midsized passenger vehicle (accumulator system energy density >10 kJ/liter). This metric will enable implementation in a passenger vehicle for city driving. Additional significant benefits of this research potentially include solutions to more traditional accumulator problems including cost, pre-charge issues, and fluid contamination from gas diffusion through the bladder.

2D: Multi-Functional Fluid-Power Components Using Engineered Structures and Materials

The goal of Project 2D is to characterize the structural-thermal-acoustic coupling of three of the five unit-lattice structure types identified earlier to allow for the design of passive, noise-reducing, heat-managing, fluid-power components, i.e. multi-functional components using meso-scale meta-materials. Structural-acoustic and thermal-structural couplings will be defined through virtual testing; and, physical, non-destructive testing will be conducted for validation of the couplings. An additional goal is the inclusion of thermal-energy storage, recovery and conversion for improved component and system efficiencies. Much of the work is focused on designing and fabricating structural-thermal-acoustic solutions for CCEFP research. This has included test bed 6, the portable pneumatic ankle-foot orthosis (PPAFO) and Project 2B.2, the micro HCCI free piston engine. Future goals are to apply this multi-functional design methodology to other components and systems, on Center projects and test beds, and those being developed by industry, including aerospace and medical.

2E: Model-Based Systems Engineering for Efficient Fluid Power

The goal of the project is to significantly reduce the time and effort required to formulate and solve systems engineering problems for compact and efficient fluid-power systems. To achieve this, analysis knowledge about fluid-power components from multiple disciplinary perspectives and multiple levels of abstraction will be captured and organized in a modular, object-oriented knowledge repository using a standardized language (Systems Modeling Language, SysML) and synthesis knowledge about fluid-power systems will be captured in the form of model transformations. A systems engineering method and software framework will be developed in which the synthesis and analysis knowledge from the repository is used to explore efficiently and comprehensively large spaces of system architectures with the goal to improve the compactness and efficiency of fluid-power systems while balancing other system objectives such as effectiveness, cost, and reliability.

Both components of the project (architecture exploration and variable-fidelity optimization) have reached significant milestones – the algorithms developed by the students have been implemented, tested, and compared to competing approaches. Both students are therefore in the final phases of their research and will be defending their PhD theses in April 2012. We have therefore decided to end this project and no research will be done beyond Year 6.

2F: MEMS Proportional Pneumatic Valve

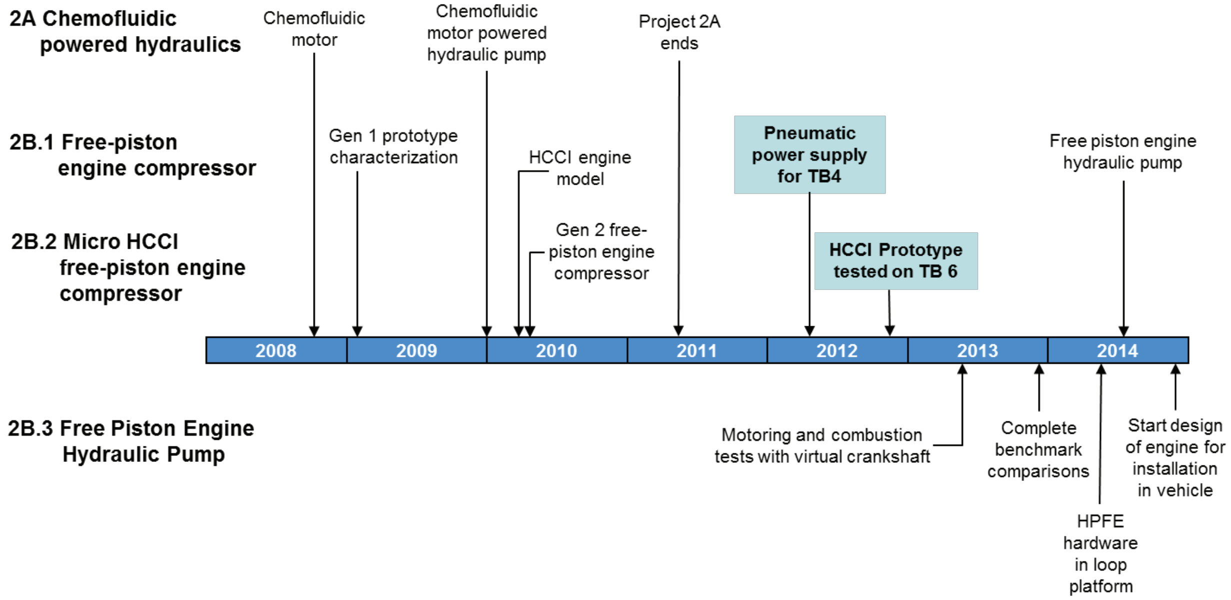
The goal of this project is to create an efficient miniature proportional valve for controlling air flow in pneumatic systems based on Micro-Electrical Mechanical Systems (MEMS) technology. The valve is intended to operate at pressures up to 7 bar (700 kPa / 100 psi) with a flow rate of at least 25 slpm when operated at a pressure of 6 bar venting to 5 bar in the fully open state. Actuation efficiency is equally important to fluidic efficiency and the goal is to be able to hold a normally closed valve in the fully open state with an actuation power of 5 milliwatts. The target envelope of the valve is 4 cm^3.

Microvalves currently available in the marketplace can only deliver flow on the scale of milliliters per minute. The new valve will be able to provide macro scale flow while maintaining compactness, efficiency and low leakage. This will be achieved by a unique parallel architecture. The hardware design will be supported by models that can correctly predict the actuator behavior and fluid flow phenomena. The valve is planned to be integrated into Test Bed 6, the Portable Pneumatic Ankle-Foot Orthosis.

2G: Fluid-Powered Surgery & Rehabilitation via Compact, Integrated Systems

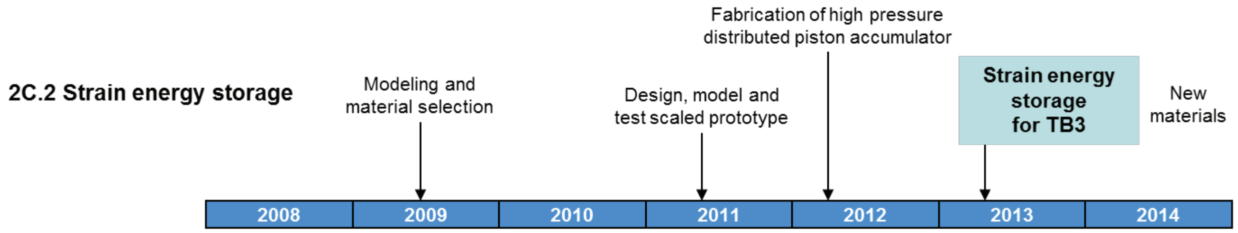
Magnetic resonance imaging (MRI) is one of the most useful methods available to study neuroscience, evaluate rehabilitation therapies, and perform image-guided interventions and surgeries. The research goal is to extend fundamental understanding of the unique characteristics of fluid power that enable precise machines to withstand intense magnetic fields. Toward this end, the project will develop compact systems where cylinders, valves, and sensors are no longer independent entities assembled together, but are a single integrated system that can be manufactured simultaneously. MRI compatible devices are the perfect focusing application for this research. In surgery, MRI provides exquisite soft tissue resolution, but robots are required to effectively make intraoperative use of this information. In rehabilitation, functional MRI (fMRI) offers the unique ability to visualize brain activity during therapy. Fluid power is an essential enabler in both contexts, because traditional electromagnetic actuators fail (or cause artifacts in) intense magnetic fields. This research will help open an entirely new industry to fluid power: Medicine (which represents about one sixth of the Gross Domestic Product of the USA).

Compactness Thrust Milestone Charts



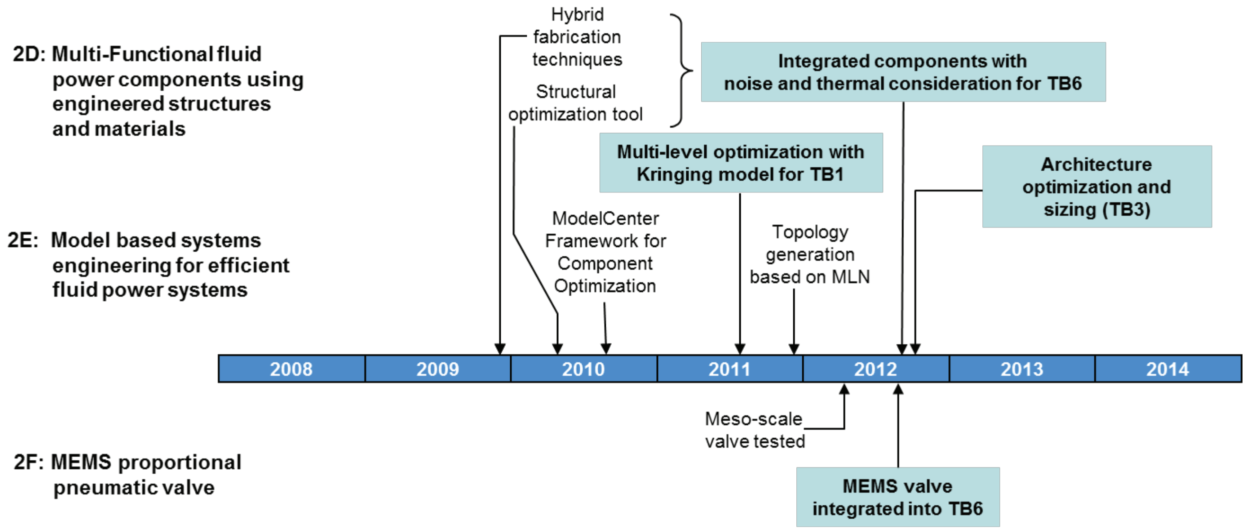
Compact Power Supply Milestone Chart

Compact power supply: Research on Project 2A, the chemofluidic hydraulic pump, was stopped in May 2011 due to challenges to achieving the target performance for the pump. The free-piston engine compressor (2B.1) is targeted for test bed 4 (compact rescue robot): and a are planned for integration with test bed strating in May 2012. The HCCI micro-free piston engine compressor (2B.2) is targeted for test bed 6 (portable pneumatic ankle foot orthosis) and integration is planned for Spring/Summer of 2012.



Compact Energy Storage Milestone Chart

Compact energy storage: The strain energy accumulator approach (2C.2) is being pursued by the CCEFP to significantly increase energy storage density. It has the potential of increasing energy density by 2-3 times and appears to be quite simple to implement and maintain. This project is undergoing various design phases and is planned to be tested on test bed 3 (hydraulic hybrid passenger vehicle) in Spring 2013.



Compact Integration Milestone Chart

Compact integration: Research on engineered structures and materials for multi-functional fluid power components in Project 2D is bearing fruit in the area of compact integration and are being utilized in development of components for test bed 6. Of note is the integrated structure that is optimized for load, thermal and NVH to be implemented in test bed 6 in 2013.

Development of tools and methodology the use of systems engineering to fluid power systems are being carried out in Project 2E. As the tools are developed, they are also being applied to the test bed designs. The researchers have accomplished their initial goals and will not continue the project beyond year 6.

An efficient miniature proportional valve for controlling air flow in pneumatic systems based on Micro-Electrical Mechanical Systems (MEMS) technology is being developed in Project 2F. The new valve will be able to provide macro scale flow while maintaining compactness, efficiency and low leakage. It is targeted for integration into Test Bed 6, the Portable Pneumatic Ankle-Foot Orthosis.

Compactness Thrust Publications

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EFFECTIVENESS

The Effectiveness Thrust is focused on the Center's fourth major goal: ubiquity. The means for achieving this goal are to make fluid power safe, quiet, clean and easy to use so that it can be used anywhere. The CCEFP strategy identifies the technical barriers to achieving these goals. These are safe and easy to use, quiet and leak-free operation. The table below summarizes the Thrust 3 projects and the barriers they address. Further project details can be found in the following pages and in Volume II.

Thrust 3: EFFECTIVENESS	Technical Barriers								
	Efficient Components	Efficient Systems	Control and Energy Management	Compact Power Supply	Compact Energy Storage	Compact Integration	Safe and Easy to Use	Leak-free	Quiet
3A.1: Multimodal Human-Machine Interfaces							●		
3A.3: Human-Machine Interface Design for Fluid Power Systems							●		
3B.1: Passive Noise Control in Fluid Power									●
3D.1: Leakage Reduction in Fluid Power Systems								●	
3D.2: New Directions in Elastohydrodynamic Lubrication to Solve Fluid Power Problems						●			
3E: User-Center Human-Machine Interface for an Excavator							●		

Effectiveness Thrust Technical Barriers

Effectiveness Projects

Project 3A.1: Multimodal Human-Machine Interfaces

In some operator-controlled machines, motion of the controlled machine excites motion of the human operator, which is fed back into the control device, causing unwanted input and sometimes instability; this phenomenon is termed biodynamic feedthrough. In operation of backhoes and excavators, biodynamic feedthrough causes control performance degradation. Backhoe user interface designers and research under the project indicate that biodynamic feedthrough produces undesirable oscillations in output with conventionally controlled backhoes and excavators, and it is even more of a problem with this advanced user interface. Results indicate that the coordinated control provides more intuitive operation, and the haptic feedback relays meaningful information back to the user. But the biodynamic feedthrough problem must be overcome in order for this improved interface to be applicable in industry. For the purposes of reducing model complexity, the system is limited to a single degree of freedom, using fore-aft motion only.

This project will establish the relationship between the user interface and fuel efficiency for a relevant range of dynamic system behaviors. The interfaces used will incorporate both traditional and experimental interface devices and sensory modalities. Prediction of the relative performance of interface approaches will be enabled for a range of applications. Implications for usability will be addressed through collaboration with researchers at NCAT.

3A.3: Human-machine interface design for fluid power systems

The goal of the project is to develop an integrated human performance model that can address both cognitive and physical perspectives simultaneously in complex fluid power (FP) systems where human operators interact with the machines, and to use user centered design approach to develop human machine interface for selected fluid power systems (test beds) that are user-centered, safe, easy and comfortable to use.

To achieve optimal overall system performance, both machine performance and operator performance need to be improved and the effectiveness of any design advancements need to be investigated to better understand the human-machine interaction. Human performance modeling provides a means to simulate these design changes and evaluate their impact on the human operator without developing costly prototypes. The most promising of these changes can then be implemented and tested.

3B.1: Passive Noise Control in Fluid Power

Noise is a significant and pervasive issue with fluid power systems. It needs to be controlled not only to meet regulatory standards, but also to meet the expectations of customers and consumers. Fluid-borne noise is generated by pumps and can couple to structures, causing vibration and air-borne noise. The high speed of sound in hydraulic fluid, coupled with the low fundamental frequencies of pumps results in wavelengths of fluid-borne noise that are much longer than the practical size of common noise control components. The aim of this project is to improve noise control in fluid power systems by passive means. Excess noise is a problem not only for the attractiveness of existing products, but also as a barrier for entry of fluid power into new markets and technologies. This project seeks passive solutions to the reduction of noise and vibration by means of integrating engineered compliant materials into existing components and technologies. The use of compliant materials is expected to help reduce the size of noise control devices for fluid power.

3D.1: Leakage Reduction in Fluid Power Systems

The general goal of this project is the development of realistic numerical models of the seals and seal systems used in fluid power systems, which would be capable of predicting the key seal performance characteristics, especially seal leakage and friction, and serve as design tools. A further aim is to develop a fundamental understanding of the physics of sealing through the model development.

The elastomeric rod seal, which seals the gap between the protruding rod and the housing of a linear hydraulic actuator, is one of the most critical elements in a hydraulic system because it must prevent the leakage of hydraulic fluid directly into the environment. At the CCEFP a numerical viscoelastic model of the rod seal has been developed. It is capable of predicting the key seal performance characteristics, especially seal leakage and friction, and will serve as a design tool. The model simulates the dominant physical processes governing the operation of the seal. It analyzes the behavior of the hydraulic fluid in the interface between the seal and the rod, the contact between asperities on the seal and the rod, and deformation of the seal. Previous models treat the seal material as elastic, reacting instantaneously to changes in the sealed pressure within the actuator. However, the polymeric materials used for seals are viscoelastic and have a delayed reaction to pressure changes. Since they have a memory, the behavior of the seal depends on its past history. Such viscoelastic effects are taken into account in the CCEFP model.

3D.2: New Directions in Elastohydrodynamic Lubrication to Solve Fluid Power Problems

The field of Elastohydrodynamic Lubrication (EHL), a branch of lubrication science specific to the full-films which occur between non-conformal rolling/sliding machine elements, has been lacking a fundamental rheological foundation since its inception. For instance, to predict Newtonian film thickness, a proper pressure-viscosity coefficient definition is still missing to quantify piezoviscous strength regardless of the underlying nature of the piezoviscous function. Additionally, the properties for inclusion to calculate film thickness when Newtonian assumptions fail have not been formalized. Furthermore, the necessary parameters for full-film friction calculation are not all understood. This project is centered on providing the rheological foundation to solve these important problems and to develop engineering design tools for improved film thickness calculations and reduced mechanical losses.

The goal of the project is to develop the tools that may be used by engineers to design more compact, reliable and energy efficient fluid power components by improving the film thickness and reducing mechanical loss in the full-films occurring between non-conforming rolling/sliding machine elements. A fundamental rheological foundation for the field of elastohydrodynamic lubrication (EHL) has been lacking since the inception. For example:

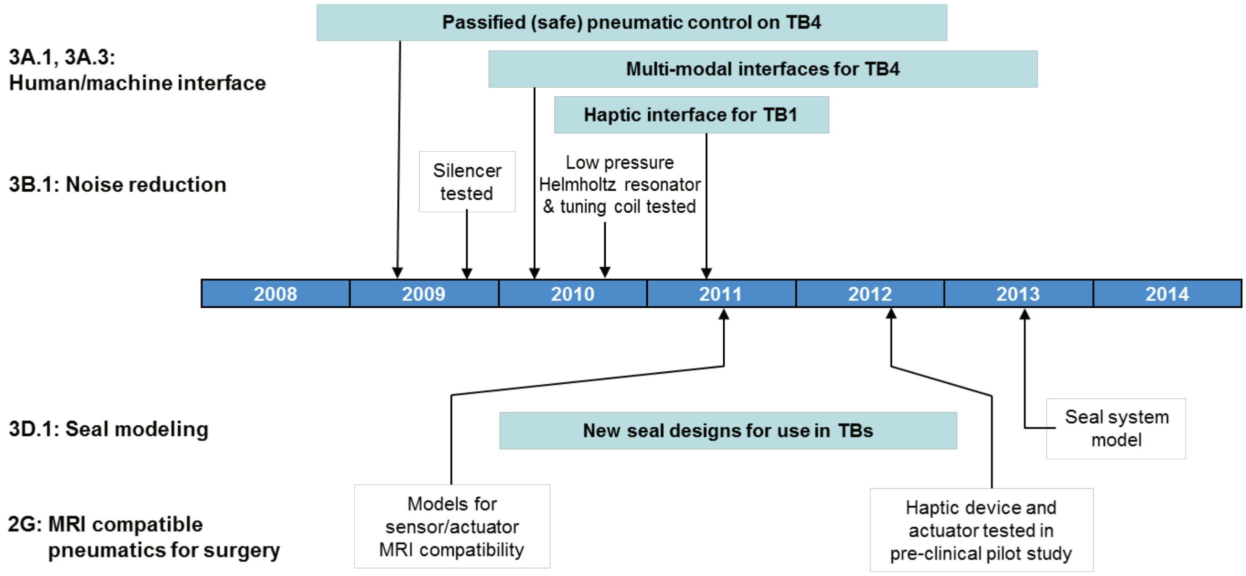
a. The proper definition has not been found for a parameter (a pressure-viscosity coefficient) to quantify the piezoviscous strength of any Newtonian liquid, regardless of the nature of the piezoviscous function, so that Newtonian film thickness may be predicted.

b. The properties of a liquid that must necessarily be included in a film thickness calculation when the Newtonian prediction is inaccurate have not been specified.

c. The properties of a liquid that must necessarily be included in a full-film friction calculation have not been specified.

This project is providing the rheological foundation to solve these important problems.

Effectiveness Thrust Milestone Chart



Effectiveness Thrust Milestone Chart

Quiet, leak-free, safe-and-easy-to-use: The timeline for activities to make fluid power more quiet, leak-free, safe-and-easy-to-use are shown above. Various human-machine interfaces are moving from the development phases and are being tested on test bed 1 and test bed 4. In the area of noise reduction, nonlinear materials are being designed for desirable acoustic properties. Seal modeling and projects that make fluid power quieter are also proceeding. A new research theme of developing MRI compatible pneumatic surgical tools has been added this year. This theme is targeted for the new associated test bed of MRI guided surgical robot.

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Humphreys, H.; Book, W.; Huggins, J.; “Compensation for Biodynamic Feedthrough in Backhoe Operation by Cab Vibration Control,” Proceedings of the IEEE International Conference on Robotics and Automation, Shanghai, China; (2011)

Michael, P; Blazel, B; Reuchel, R; Harville, X; “Hydraulic Fluid Compatibility and Filterability,”; Proceedings of the 52nd National Conference on Fluid Power, Las Vegas, NV; 35.2, (2011)

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3. UNIVERSITY AND PRE-COLLEGE EDUCATION PROGRAM

The mission of the Education and Outreach Program of the NSF Center for Compact and Efficient Fluid Power (CCEFP) is to develop research inspired, industry practice directed education for pre-college, university and practitioner students; to integrate research findings into education; to broaden the general public's awareness of fluid power; and through active recruiting and retention, to increase the diversity of students and practitioners in fluid power research and industry.

The vision of the Education and Outreach Program is a general public that is aware of the importance of fluid power and the impact of fluid power on their lives; students of all ages who are motivated to understand fluid power and who can create new knowledge and innovate; industry that capitalizes on new knowledge to lead the world in fluid power innovation; and participants in all aspects of fluid power who reflect the gender, racial and ethnic composition of this country.

The strategy of the Education and Outreach Program is to develop and deliver high quality projects that wherever possible capitalize on existing, broadly distributed education and outreach networks to maximize program impact; to develop projects that can be replicated and/or adapted by other educators and program leaders for new audiences; and to leverage and coordinate the accomplishments of individual Education and Outreach projects to facilitate the progress and successes of other Education and Outreach projects.

The Center's mission, vision and strategy are the basis for each of its education and outreach projects. The projects are organized around five thrust areas: public outreach, pre-college education, college education, industry, and evaluation. The following figure is a snapshot of the CCEFP education project portfolio showing the target audiences for each project. While most projects are specific to fluid power education, there are some that focus instead on STEM education, with examples drawn from fluid power when appropriate. The project reports in Volume 2 provide detailed information on each project.

Education and Outreach Core Project Portfolio	University Education	Pre-College	Industry Education
Thrust A: Public Outreach Bringing the message of fluid power to the general public			
A.1 Interactive Exhibits Fluid Power	x	x	x
A.3 Multimedia Educational Materials	x	x	x
Thrust B: Pre-College Education Bringing fluid power education to pre-college, with a focus on middle and high school			
B.1 Research Experiences for Teachers (RET)		x	
B.2 Project Lead The Way		x	
B.3 Hands-on Fluid Power Workshops	x	x	x
B.4 gidaa STEM Programs		x	
B.5 BRIDGE Program	x	x	

Thrust C: College Education Bringing fluid power education to undergraduate and graduate students			
C.1 Research Experiences for Undergraduates (REU)	x		
C.2 Fluid Power OpenCourseWare	x		x
C.3 Fluid Power Projects in Capstone Design Courses	x		x
C.4 Fluid Power in Engineering Courses	x		
C.5 giiwed’anang North Star Alliance	x		
C.6 Fluid Power Simulator	x	x	x
C.7 Fluid Power Basic Training (on hold)	x		
C.8 Student Leadership Council (SLC)	x	x	x
C.9 Undergraduate Research Diversity Supplement (URDS)	x		x
C.10 Graduate Research Diversity Supplement (GRDS)	x		x
C.11 Innovative Engineers	x	x	x
Thrust D: Industry Making connections between CCEFP and industry			
D.1 Fluid Power Scholars/Interns	x		x
D.2 Industry Student Networking	x		x
D.3 Advanced Fluid Power Engineering Workshops (on hold)	x		x
D.5 CCEFP Webcasts Series	x		x
D.6 Publications	x	x	x
Thrust E: Evaluation Measuring CCEFP program effectiveness	x	x	x

Recent highlights resulting from the Center’s education and outreach program include:

- A transition in leadership and administration under the Education and Outreach program welcomed Professor Paul Imbertson, (Electrical Engineering, University of Minnesota), to serve as Education Director; Alyssa Burger continues as Education Outreach Director and Linda Western, former Education Co-Director with Professor Will Durfee, now serves as Education Industry Program Coordinator to more efficiently intersect the two entities.

- Former CCEFP Post Doctoral student and current Mechanical Engineering faculty member at the University of Minnesota, Professor Jim Van de Ven, joins the Education and Outreach team as the leader of undergraduate and graduate fluid power curriculum efforts. This effort draws on the expansion of the college education thrust. (Projects C.3 and C.4)
- The CCEFP Education and Outreach program modified existing projects and introduced new projects to its portfolio. Projects modified and expanded in scope include: A.3 Multimedia Educational Materials, D.2 Industry Student Networking. New projects include B.5 BRIDGE Program, C.8 Student Leadership Council [not new to the Center, but newly funded under E&O], C.9 Undergraduate Research Diversity Supplement, C.10 Graduate Research Diversity Supplement and C.11 Innovative Engineers. Proposed projects include a high school research opportunities program, a hydraulic fuel-efficient school bus and a fluid power educational smart-app for mobile devices.
- The Student Leadership Council submitted a project proposal and was subsequently granted $15,000 to launch a travel and project grant program which supports student travel between other research teams and industry partners. (Project C.8)
- A new and deliberate focus of the Education and Outreach program is to foster industry and student connections by leveraging existing meetings and events to build upon networking opportunities, both for employment as well as research collaboration. (Project D.2)
- The CCEFP Education and Outreach team resolved an issue with evaluation and assessment and identified a new partner, Quality Evaluation Designs, to lead evaluation and engineering education research for the CCEFP. (Project E.1)
- New diversity initiatives were launched, including a novel membership interface with the National GEM Consortium, NSF Engineering Research Centers, and undergraduate and graduate research diversity supplements (Projects C.9 and C.10).
- Eighteen enthusiastic REU students conducted research in CCEFP labs at the Center's seven universities during the summer of 2011. REU students participated in the Center's first Fluid Power Bootcamp for REUs at the University of Minnesota, June 2011. To date, 105 REU students have participated in Center research. (Project C.1)
- The Fluid Power Scholars Program is in its third year. To date, 16 high-performing undergraduate engineering students completed a fluid power boot camp followed by a full-time summer internship at a CCEFP member company. Since 2010, 67% of Scholars have been hired into fluid power, 47% have been hired by their host company. (Project D.1)
- Six RET participants conducted research in CCEFP labs. Twenty nine RETs have participated since the Center's launch. The CCEFP is the only ERC to have RET-designed curricula published to the NSF website, TeachEngineering.com, a repository of STEM curriculum. Three fluid power lesson modules are available. (Project B.1)
- The hands-on fluid power workshops continue to be refined and offered to hundreds of high school and younger students. (Project B.3)
- The gidaa robotics program is expanding. Over 60 students (⅔ are Native American, ½ are female) participate in day and after-school robotics activities. A new teacher development program is identifying additional local teachers who are eager to launch similar efforts. (Project B.4b)
- The fluid power exhibits at the Science Museum of Minnesota are now in a special fluid power area of the physical exhibit floor and have educated thousands of museum visitors of all ages about fluid power. (Project A.1)

3.1 UNIVERSITY EDUCATION PROGRAM

The objective of the CCEFP university education program is to train graduate and undergraduate students in fluid power with the expectation that they will become future leaders in the fluid power industry and in university-based fluid power research and teaching. Three methods are used to attain the goal: (1) Attract undergraduate and graduate students and engage them in cutting edge fluid power research, (2) Infuse fluid power into traditional engineering curriculum so that every undergraduate student gains exposure, (3) Provide advanced students with the opportunity to learn cutting edge curricular material based on the latest CCEFP research.

Examples from CCEFP education projects illustrate progress towards the goals:

Integration of Fluid Power into Core Curriculum: The Fluid Power OpenCourseWare (Project C.2) site was launched in 2010 to be a single repository of high quality, college level curriculum related to fluid power. Lecture notes from three courses developed by CCEFP faculty have been posted along with two mini-books. An additional mini-book is in draft form and others are in the planning stages. In Year 6, three new courses were developed and taught by CCEFP faculty, and eight existing courses have been modified based on CCEFP research. Additionally in Year 6, the CCEFP welcomed Professor Jim Van de Ven to lead its efforts ind developing undergraduate and graduate fluid power curriculum. Preliminary plans and actions for fluid power curriculum design and dissemination include:

- Continue to encourage the incorporation of fluid power content into existing courses throughout the Center.
    - The Fluid Power OpenCourseWare project makes it easier for instructors within and outside of the CCEFP network to include college-level fluid power material in their course.
    - Develop problem sets associated with the mini-books to ease course integration. Possibly utilize the Student Leadership Council for assistance in developing these problems and solutions.
    - Encourage competition throughout the Center to develop additional mini-books.
    - Utilize multiple modes to increase the digital repository content of the OpenCourseWare site; various online access points to the products of the Center's research and education impacts.
- Encourage CCEFP faculty to take the lead in developing new lecture and lab courses in fluid power.
- Encourage CCEFP faculty who are teaching core undergraduate classes to write and present papers in the education sections of technical conferences on infusing fluid power modules into existing mechanical engineering classes (e.g., system dynamics, fluid mechanics, and thermodynamics).
- Increase awareness of the Fluid Power OpenCourseWare site among industry members through distribution of literature at meetings.
- Encourage CCEFP member schools to include fluid power in the list of ABET outcome objectives for related core mechanical engineering courses.

REU Program: The Center determined that committing significant funding to its REU program would kindle participants' interests in attending graduate school and would yield undergraduate students with research experience who were knowledgeable in fluid power, a positive outcome from industry's point of view, too. Over 105 REU have participated in the CCEFP program--more than in many REU site programs. Based on responses by 54 undergraduates to a recent longitudinal study, we learned that 22 of them are working with/in/pursuing fluid power in some way, with three of them working for CCEFP member companies. Thirty are/have attended graduate school after their REU experience, and ten are currently PhD candidates. (In other words, 55% of all former CCEFP REU students enter graduate school and 33% eventually serve as PhD candidates.)

Fluid Power Scholars Program:

The Fluid Power Scholars program compliments the REU program. Despite the challenged economy, the program was successfully launched in 2010 with continued support in 2011 and is underway for 2012. Sixteen scholar/interns were named during the program's first two years; plans call for naming nine more in 2012. All scholar/interns participate in an intensive fluid power orientation followed by an exceptional summer internship experience within a fluid power company. Subsequently, seven of these Scholars have been hired full-time by their internship host company (a CCEFP member company), and three Scholars have been hired by companies with interests in fluid power but that are not CCEFP members. Looking at the numbers in another way, 63%of Fluid Power Scholars are working in the fluid power field. The CCEFP's Fluid Power Scholars Program is an outstanding example of an effective industry/university partnership spawned by NSF's ERC program. At every stage and at every level, CCEFP corporate supporters worked enthusiastically in creating environments where scholar/interns could effectively apply what they had learned about fluid power in the classroom to hands-on, real-world applications.

This growing cadre of undergraduate REU and Scholar students with skills in fluid power is precisely the pool that fluid power manufacturers were expecting when they committed to supporting the CCEFP six years ago.

Student Leadership Council Travel and Grant Programs: The Student Leadership Council is an independent board of the CCEFP. The Education and Outreach program sponsors the activities of the SLC. The SLC has launched a successful travel and project grant program used to support student travel between CCEFP institutions and to companies engaged in the fluid power industry. The travel grant program will foster greater communication between the research institutions as well as between students and industry partners. To date, 12 travel grants of $1000 or less have been issued to CCEFP graduate students to work collaboratively with other research teams or companies.

Capstone Design Projects: In 2010, NFPA member companies, who are the most important source of significant fluid power capstone projects, to sponsor capstone design courses at CCEFP institutions, made an important commitment. This year, the CCEFP supported a capstone project between UIUC and Bradley University, advised by Professor Elizabeth Hsiao-Wecksler. Other capstone design projects include: Parker Hannifin Chainless Challenge (UMN, Brad Bohlmann), Open Accumulator Display (UMN, Perry Li), Fluid Systems (VU, Robert Webster) and Hydraulic Fuel Pump Drive (UMN, Brad Bohlmann).

Outstanding CCEFP Graduates: The following recent CCEFP graduates exemplify students who are making an impact in fluid power and related fields:

CCEFP Student **Course of Study, Graduation, Institution**	**Current Employment**	**Contributions to the Field**
Khaliah Hughes PhD 2011 North Carolina A&T State University **Ms. Hughes is the first Female African American PhD graduate of the CCEFP at NCAT.*	Usability Analysist SAS Institute Inc.	Role consists of evaluating and supporting various development teams to provide usability in products. Goal is to apply usability principles to support the software development process.
Matt Lynch BS, ME 2011 Georgia Institute of Technology	Co-Founder & CTO at Bractlet, Chile *Past experience:* 2011 CCEFP Fluid Power Scholar, 2010 CCEFP REU	Provides customers with the ability to easily monitor and control the energy consumption of all their appliances in real time by giving them the power to turn outlets on or off remotely. By giving users the knowledge and control of where energy is going, Bractlet customers will see firsthand the effects of their decisions on energy use in their home and the resulting effect on their energy bill.

James Van de Ven Post Doc 2007 CCEFP University of Minnesota	Assistant Professor University of Minnesota *Past experience:* Assistant Professor Worcester Polytechnic Institute (2007-2011)	Research interests: fluid power, energy conversion and storage, machine design. Current research is based on the foundation created as a post-doc in the CCEFP. His multiple research collaborations/contacts are ongoing. Currently leading the undergraduate and graduate fluid power curriculum thrust in the CCEFP.
Kelly Burgess MSE 2011 Milwaukee School of Engineering	Engineer, General Dynamics	Responsibility in the hardware mechanical engineering division, and primarily works on design for military/defense ships and submarines.
Azam Thatte PhD, ME 2010 Georgia Institute of Technology	Research Scientist, GE Research Headquarters	Research focus includes fluid-structure interaction for aircraft engines, gas turbines, oil and gas applications, multi-physics modeling and experiments, aerodynamic film riding seals, aero-acoustic, thermal and vibration analysis of turbomachinery, bio-mechanics.
Brenen Thul MSME 2011 University of Minnesota	Mechanical Design Engineer, MTS Systems Corporation *Past experience:* Applications Engineer, Donaldson Company	Mechanical design engineer in the custom engineering group working primarily on some sub components of the NTL wind turbine test systems. Applications engineer at Donaldson Company Inc. in the mobile hydraulics group.
Josh Heber MSABE 2011 Purdue University	Application Engineer Cummins, Inc. (Diesel Engines)	Application Engineer at Cummins on the PACCAR (Kenworth and Peterbilt) account. Serves as the technical liaison between Cummins and PACCAR and is responsible for integrating the engine with the rest of the vehicle and for testing the engine and chassis combination.
Paul Kalbfleisch BS 2011 Purdue University	PhD Candidate at Purdue *Past experience:* 2010 CCEFP REU	CCEFP research interests: fluid power noise control.

Priorities for the Future

The college education program continues with its same two priorities: infuse fluid power into the core curriculum and provide high quality research and internship experiences for undergraduates and graduate students. We hope that the opencourseware site will grow in content and use, and in particular that it will be used by universities outside the CCEFP. Through the REU program, the Fluid Power Scholars program, the Undergraduate Research Diversity Supplement (C.9) program, and the requirement of each research project to include at least one non-graduate research student, significant numbers of undergraduate students will gain fluid power experience during the summer and academic yeart.

We are making significant impacts within the fluid power industry and education. Our recent longitudinal survey revealed the following: 61% of all former CCEFP students are working in fluid power in some way, 50% of all former CCEFP students are working in some industry, 11% of all former CCEFP students are employees of CCEFP fluid power industry member companies, 67% of CCEFP fluid power scholars are hired into the fluid power industry, 55% of all former CCEFP undergraduate researchers enter graduate school, and 33% of those are PhD candidates.

3.2 PRE-COLLEGE PROGRAM

A core objective of the CCEFP pre-college outreach program is to expose young students to fluid power with the added objective of increasing the number of students pursuing STEM fields in college. These outcomes are also served by the CCEFP outreach programs that are STEM-oriented but without a core fluid power focus. The Center is of the opinion that increasing interests in STEM fields among young students is an important first step in increasing the number of students later pursuing engineering studies, some of them in fluid power.

Progress in the CCEFP pre-college program is illustrated by the following examples, drawn from our project portfolio:

Research Experiences for Teachers Program: In the recent reporting year, six RET teacher participants conducted research in the CCEFP laboratories of Purdue University, Vanderbilt University and the University of Minnesota. The CCEFP has sponsored 29 RET projects to date; many teachers have been repeat participants. The CCEFP is the only ERC to have RET-designed curriculum published to the NSF website, TeachEngineering.com, a repository of STEM curriculum. Three fluid power teaching modules are available for download from www.ccefp.org. Additionally, the 2011 RET team at Purdue University continued to work on the Fluid Power Demonstrator Kit and Curriculum under the guidance of Professor John Lumkes. (See Project B.2.) Note that Professor Lumkes, along with two teachers and a number of high school students, will visit Bangang in Cameroon, Africa in May 2012. Students will assist local villagers with the task of retrieving fresh water by using fluid power technology and equipment.

gidaa robotics Program: Year 6 saw yet another expansion in the suite of education programs targeted at Native American students of all ages. With support from the CCEFP, South Ridge School has been able to offer its 10-12 grade students a year-long robotics course that is integrated into the school day, as well as an after-school program, tailored to grades 7-12, that meets two nights a week over the course of three months. The robotics after-school program allows students to build a robot to compete in the annual RoboFest Robotics Challenge, a competition designed to promote and support STEM activities. So far, a total of over 60 students have participated in these two programs; 65% of students represent racial or ethnic minorities, and approximately half are female. With the support of the CCEFP, South Ridge School will host its third annual RoboFest Competition in the Spring 2012. South Ridge School is currently the only site in the state of Minnesota to allow students to qualify for the International Robofest Competition, held at Lawrence Technical University. This program also includes a teacher workshop enrichment element to entice other local schools to offer similar educational opportunities.

Zephyr Wind Energy Teacher Training. The Zephyr Wind Project Teacher Training is a one-time teacher enrichment program which seeks to build a brighter future for our communities and our world by empowering teachers to 1) advance students' knowledge of STEM concepts in a world that needs young people's creativity and problem-solving skills; and 2) to inspire the next generation to embrace and advance renewable energy technology as part of a healthy and sustainable energy infrastructure. The CCEFP, along with KidWind and Xcel Energy Center, sponsored the participation of 15 teachers, including those of Native American students. Building these connections also allows the CCEFP to have a solid teacher network across the state of Minnesota.

Priorities for the Future

With the CCEFP now in its sixth year, planning for E&O sustainability is underway. The pre-college programs could be vulnerable and we have identified, as a top priority, development of a long term strategy for receiving federal grants and other funding sources to sustain these important programs. Another priority is to move the hands-on workshops (Project B.3) from development to delivery. Materials and instruction materials for the workshops are reasonably well developed, while dissemination is still in the early stages.

3.3 INDUSTRY EDUCATION PROGRAM

Industry is an essential component of the CCEFP. Approximately fifty fluid power manufacturers and distributors are Center members. Time and time again they have stated that the education outcomes of the Center are as important to them as the outcomes of research. These Center partners share in a common goal--the Center will foster deep understandings of fluid power technology and its applications among its students.Toward that end, the Center is striving to provide students with specialized, research-driven education while striving to implement ways to connect students with industry.

Highlights from projects illustrate progress towards these goals:

IFPE 2011: IFPE is an international exposition and technical conference dedicated to the integration of fluid power and other technologies for power transmission and motion control. It is held once every three years and is co-located with CONEXPO-CON/AGG, another industry trade show, on the Las Vegas exposition grounds. Together the shows draw an audience of over 100,000 attendees from all over the world. The CCEFP participated in IFPE 2011 in several ways. Forty of the 120 papers included in the 52nd National Conference on Fluid Power (NCFP), held at IFPE, were presented by CCEFP faculty and students. The CCEFP held its Annual Meeting in conjunction with IFPE; more than 300 industry representatives attended the meeting's poster show. The meeting also featured a resume exchange where Center students met with industry representatives; it was well attended and well received by all. Further, the CCEFP hosted a large booth on the IFPE show floor that featured demonstrations of selected Center research as well as materials on additional Center projects. CCEFP faculty, students and staff hosted the booth, meeting with hundreds of industry representatives over the show's five day run.

Industry / Student Networking: The CCEFP is responsible for providing its students with opportunities to network with industry representatives through a variety of channels. In doing so, there are multiple benefits: all students will better understand the fluid power industry's needs and its markets; interested students will be able to find internships and later job opportunities upon graduating; companies will be able to meet, interact, and discuss potential employment opportunities with students. Channels utilized in this project include company tours, poster sessions, and resume exchanges as well as additional opportunities that extend the Center's outreach to more students and companies. This program leverages the existing events and activities of the CCEFP and engages students in the fluid power industry, often offering them opportunities to stay in this industry so they can have an impact in fluid power research and applications. This project also provides industry with mechanisms to contact and interact with students (possibly perspective employees) who have become familiar with fluid power through the Center's work. Examples include Fluid Power Capstone Courses, Fluid Power Scholars Program, CCEFP Webcast Series, CCEFP Student Retreats, Industry Advisory Board (IAB) Summits, CCEFP Annual Meetings which include speed-meetings, resume exchanges, poster session presentations, industry kiosks, etc.

Priorities for the Future

Continue to develop networking opportunities for students and industry. Connect industry to the opencourseware project and develop versions of the hands-on workshops suitable for new engineering employees not familiar with fluid power and non-engineering employees. Further engage industry in education initiatives. Expand the content of the CCEFP Webcast Series as a key element of knowledge transfer to increase the participation of the academic and industry audience.

Education Activities Matrix

	REU / Undergraduate	RET / Teacher	Pre-College	College Education	Industry	General Community
University of Minnesota	✓	✓	✓	✓	✓	✓
GeorgiaTech	✓	★	✓	✓	✓	★
MSOE	✓	★	✓	✓	✓	★
NCAT	✓	★	✓	✓	✓	★
Purdue	✓	✓	✓	✓	✓	✓
UIUC	✓	★	✓	✓	✓	★
Vanderbilt	✓	✓	✓	✓	✓	★

✓ = In Place ★ = Future Year

3.4 WEAKNESSES IDENTIFIED BY 2011 SITE REVIEW TEAM

Weakness	Response
Students are concerned they are unclear of the role they are to serve as the Student Leadership Council.	The role of the SLC is important and it will work better if the students define their own role. We have a created a process to do that and this is what the SLC has committed to do: 1) The SLC formed a task force including SLC officers, graduate students, faculty and consultants 2) First task force meeting was held at the IAB Summit at GeorgiaTech in May 2011. 3) A follow-up meeting was held at the CCEFP Student Retreat in August 2011. 4) Action items include a newly defined role, SLC organizational model, an education and outreach funded project proposal and other modifications as determined.
There are imbalances in underrepresented minority students among partner institutions, particularly with regard to Hispanic and African American students.	Addressed in the diversity section of this report.
The public education activities appear to focused at Minnesota, in particular, for the Interactive Exhibits and the Fluid Power Video.	The impact of the videos has already extended far beyond Minnesota, including out-of-state PBS affiliates. The videos are also available in streaming form on the NFPA and CCEFP web sites. A traveling display of the interactive exhibits is in our future plans but successful traveling displays require several years of fund-raising and coordinated planning to be successful.

Weaknesses Identified Internally

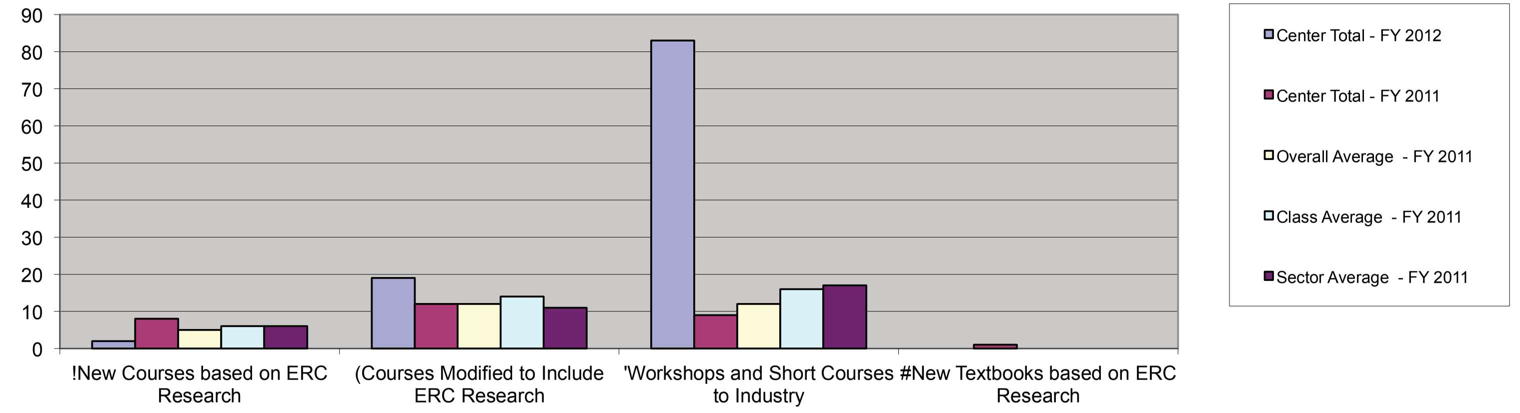
Weakness	Response
Undergraduate participation in research activities still not where it should be.	The Center launched the Undergraduate Research Diversity Supplement (URDS) to increase number of academic year undergraduate research students.
Few publications based on education and outreach programs.	As part of the push to advance fluid power curriculum, inquire with CCEFP faculty who are teaching core undergraduate classes to write and present papers in the education sections of technical conferences on infusing fluid power modules into existing mechanical engineering classes.
Utilization of OpenCourseWare	As part of the push to advance fluid power curriculum, a new leader had been appointed and along with future plans of CCEFP integrated and modified courses, a dissemination plan will be developed and implemented.

Table 3a “Curricular Impact” and Table 3b “Ratio of Graduates to Undergraduates” appear on the following pages.

Table 3a: Educational Impact

	Total from Table 1: Quantifiable Outputs	With Engineered Systems Focus		With Multidisciplinary Content		Team Taught by Faculty From More Than 1 Department		Undergraduate Level		Graduate Level		Used at More Than 1 ERC Institution		Cumulative Total for All Years
		Feb 01, 2011-Jan 31, 2012	Percent	Feb 01, 2011-Jan 31, 2012	Percent	Feb 01, 2011-Jan 31, 2012	Percent	Feb 01, 2011-Jan 31, 2012	Percent	Feb 01, 2011-Jan 31, 2012	Percent	Feb 01, 2011-Jan 31, 2012	Percent	
New Courses Currently Offered [1]	2	2	100%	0	0%	0	0%	1	50%	1	50%	0	0%	16
Currently Offered Ongoing Courses With ERC Content [2]	19	10	53%	9	47%	2	11%	13	68%	6	32%	0	0%	N/A
Workshops, Short Courses, and Webinars	83	65	78%	18	22%	0	0%	0	0%	0	0%	0	0%	132
New textbooks based on ERC research	0	0	0%	0	0%	N/A	N/A	0	0%	0	0%	0	0%	4

Table 3a: Educational Impact - Comparison of Center, ERC Program Overall, Center Class, and Center Sector, FY 2011



[1] New courses currently offered and approved by the curriculum committee are only counted in the first year that they are offered so there is no multiple counting of these courses.

[2] The cumulative totals for "Currently offered, ongoing courses with ERC content" may count the same course more than once.
This is due to the fact that a single course can be modified in multiple years and therefore will be included in the cumulative total multiple times.

Table 3b - Ratio of Graduates to Undergraduates

Center Grouping	Undergraduates	Graduate Students	Ratio Grad/UG	REU Students	Total College Students	Young Scholars	Total Students (Graduate, Undergraduate, Young Scholar, and REU Students)
Average All Active ERCs FY 2011	36	79	2.2	18	133	9	141
Average Advanced Manufacturing Sector FY 2011	45	80	1.8	18	143	8	150
Average for Class of 2006 FY 2011	35	73	2.1	24	132	3	135
Minnesota Twin Cities-CCEFP FY 2011	63	94	1.5	26	183	0	183
Minnesota Twin Cities-CCEFP FY 2012	**123**	**81**	**0.7**	**19**	**223**	**0**	**223**

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4. INDUSTRIAL/PRACTITIONER COLLABORATION, TECHNOLOGY TRANSFER AND NEW BUSINESS DEVELOPMENT

Industry interest in the CCEFP remains high. Total membership in year 6 was 47. Eight new industry members joined this year. They are; CNH America, Freudenberg – NOK, Idemitsu Kosan, Nitta Moore, StorWatts, Walvoil Fluid Power and Woodward Inc. There have been several companies that have been purchased by another member company this reporting period. We are continuing to recruit new members in strategic areas.

4.1 VISION, GOALS, AND STRATEGY

The CCEFP will continue to develop close relationships with Industry. With so many members, the CCEFP has broad industry representation. Our challenge is to more actively engage our members to ensure long term commitment. Current financial strains have caused companies to have a shorter term focus to meet near term financial goals. We need to engage people in our industry member's organizations that understand the value of longer term research. This will be beneficial to the center as well as it will position us to gain greater support from these members as we focus on long term sustainability as is addressed in our sustainability plan.

We will continue to invite all companies to become members of the CCEFP. However, our focus will be on companies that can help sustain the center. Typically this would suggest that we focus on larger companies and work to upgrade them to higher level memberships. It also means that we need to recruit with this goal in mind.

One of the ways that the center gets funding is through its membership dues. We do not have any members at our highest level. This has been evaluated and we have re-written the membership agreement to provide higher value at this level and to address some lessons learned from our NSF ILO Consulting visit in July 2011. Member feedback about how to implement these changes suggest that we do not want to modify the membership agreement for existing members and will likely implement these changes in the by-laws.

Our goal is to increase membership dues income more than $1 million as we migrate to a sustainable organization. This will be a challenge. Ongoing discussions with our members are underway to develop a membership value proposition that will allow us to achieve this. We have learned that providing direct access to technology experts to support such things as problem resolution and technology road-mapping are perceived as very high value. This is being considered in our sustainability planning efforts.

4.2 MEMBERSHIP

As the center matures, it is important to focus on strategic members. In the process of identifying these strategic partners, we have identified gaps that are leading us to develop other relationships. A review of our industrial membership identifies some opportunities:

- Most of our members are in the hydraulics sector of the fluid power market. Yet industry uses significant pneumatic power. We have begun a project to understand that industry base and recruit as appropriate.
- We need to strategically focus on OEMs and system integrators. Examples of these include automotive manufacturers, aerospace, and off-road/ heavy equipment manufacturers. Recruiting the integrators will likely have a secondary effect of creating more interest by their suppliers in the CCEFP.
- Our membership is not well represented by government agencies. We are working to recruit support from the Departments of Defense and Energy.
- We have also begun efforts to understand fluid filtration. In collaboration with the Center for Filtration Research at the University of MN, we are developing a possible research agenda leveraging our existing membership base. This will likely lead to new membership opportunities.

- The wind energy market is another strategic focus for the CCEFP. A critical maintenance concern is the transmission of mechanical power from the turbine to the generator. Fluid power offers some potential advantages over tradition approaches. This market is being actively pursued.
- Aerospace is underrepresented in our center. In the aerospace industry fluid power is used primarily to control flight surfaces and landing gear. Compactness and low weight are certainly important in this market. Wear and sealing are important maintenance issues in the industry. These are aligned with our compactness and effectiveness thrusts. We have an active program underway to better understand this market.

Membership Agreement

All members have signed the Center's standard Membership Agreement shown in Appendix II. The major elements covered include: membership level (Supporter, Principal and Sustaining); escalating dues based on membership level and company sales; terms and conditions regarding patent disclosures; publications; and information concerning access to intellectual property. A tiered royalty rate is used which is tied to membership level at the time of disclosure. The membership dues levels are shown in the table below.

Member's Annual U.S. Fluid Power-Related Revenues	Annual Membership Dues		
	Sustaining Level (Platinum)	Principal Level (Gold)	Supporter Level (Silver)
Less than $25 million	$10,000	$5000	$1,000
$25 - $100 million	$30,000	$15,000	$6,000
$100 - $500 million	$80,000	$40,000	$12,000
Over $500 million	$100,000	$50,000	$15,000

CCEFP Annual Membership Dues Structure

The membership agreement was reviewed and a plan developed to update it for existing members. Feedback from industry indicated the implementing a new contract was not desirable to industry because of the legal effort required to do so. We are pursuing a concept of implementing the changes in a set of by-laws. The proposed by-laws contained in Appendix IV address many of the modifications we intend to make. Legal counsel has suggested that as long as we do not take away from the original agreement, a by-laws modification should be adequate.

Intellectual Property

The process for handling ERC generated intellectual property (IP) is as follows:

- The PI makes an invention disclosure to the technology transfer office (or similar entity) at their respective University.
- The technology transfer office provides the disclosure(s) to the CCEFP Industry Liaison Officer (ILO).
- The ILO works with the PI to create a non-confidential overview of the invention which is distributed to all CCEFP members. With this overview is a notice of a web-meeting in which the PI will provide additional details about the invention. Member companies can attend the web-meeting if they have an interest in pursuing their patent rights as a CCEFP member. The other participants in the web-meeting are the technology transfer officer from the University and the ILO.
- During the web-meeting, the member companies attending are provided a deadline by which they must declare their interest in participating in the pursuit of a patent for the invention and sharing the costs.

- If a Member elects not to exercise its option to participate in the pursuit of a patent, or decides to discontinue the financial support of the prosecution or maintenance of the protection, the Member shall have no rights in the invention.
- If only one Member bears the costs of protection, the Inventing University shall grant that Member the first option to a royalty bearing exclusive license to the invention. If only one Member is interested in a license for a particular field of use, the Inventing University shall grant that Member an option to a royalty bearing exclusive license for that field of use. In either case, if the Member is a Sustaining Member, then the Sustaining Member shall have an option to obtain a royalty-free, non-exclusive license, without a right to sublicense, rather than a royalty bearing exclusive license; further, when a Sustaining Member elects to obtain an exclusive license, the royalty shall be at a reduced rate to be negotiated at a discount from a commercially reasonable royalty. If the Member is either a Supporter Member or a Principal Member, the exclusive license shall bear a full reasonable royalty to be negotiated on commercially reasonable terms. Any exclusive licensee under this Paragraph will have a right to sublicense on terms and conditions to be mutually agreed upon. The option shall extend for a time period of (180) days from the date of filing the first patent application, which period may be extended by mutual agreement.
- If more than one Member bears the costs of prosecution, the Inventing University shall grant to each of those Members options to a license to the invention on terms and conditions to be mutually agreed upon. The license shall be exclusive as to the rest of the world, but non-exclusive as among those Members which bear the cost of prosecution, provided that, where only one Member seeks a license for a particular field of use, the preceding paragraph, and not this paragraph, shall apply. The Inventing University shall grant all Sustaining Members that have borne the cost of prosecution of the patent a royalty-free license. The Inventing University shall grant all Principal Members that have borne the cost of prosecution a royalty-bearing license, but the royalty amount will be a reduced rate. The Inventing University shall grant all Supporter Members that have borne the cost of prosecution a royalty-bearing license, the royalty to be negotiated on commercially reasonable terms, but in any event the royalty amount will be higher than the amount paid by Principal Members. Except in cases of fully exclusive licenses as provided in the preceding paragraph (either for all uses or for particular fields of use), there shall be no right to sublicense; provided, however, that with the consent of the Inventing University and of all Members that have entered into licenses, either the University or a Member may sublicense the invention on such terms as the parties may agree.
- If no members elect to exercise their option, or if all members discontinue their support, then the Inventing University shall be free to file or continue prosecuting or maintaining any such application(s), and to maintain any protection issuing thereon in the U.S. and in any foreign country at that University's sole expense.

Industrial Advisory Board

The Industrial Advisory Board (IAB) is composed of one representative from each member company at the Sustaining or Principal Membership level. The CCEFP has an active communication process with its members. This is especially true with IAB members. There is a monthly IAB Conference call where topics of particular interest are discussed. This meeting is run by the IAB chair. Agenda topics include issues of interest to the IAB. These meeting have cover topics like upcoming meetings, information sharing, sustainability planning, by-law modifications, call for proposal input and the proposal review process. Approximately quarterly, the IAB meetings are held on site at a member university. The meetings held at different member universities on a rotating schedule. The meeting is a 1.5 day event. The first day is dedicated to technical presentations by the researchers and usually includes a tour of the university laboratory facilities. The second day of the meeting is a half day event includes a feedback session on the technical presentations and special topics discussions. The meetings also provide an opportunity for the members to network among themselves and with the research team. They also provide an opportunity for potential members to experience firsthand the value of a membership in the CCEFP. These site meetings have proven to be very successful.

The IAB continues to work within an organizational framework developed with the help of its members during year 1 of the Center. Within this framework, roles and responsibilities for key leadership positions (Chairman, Vice Chairman, subcommittee chairs, etc.) are clearly defined and major IAB goals/objectives are identified on an ongoing basis. Continuity of leadership is assured by a transition policy under which the existing Chairman's role is assumed by the Vice Chairman, whose vacancy is subsequently filled through a nominating and voting procedure involving all IAB members. At the beginning of their term, the Chairman becomes a member of the CCEFP Executive Committee (EC) replacing the person who was Chairman 4 years before their term. Thus, the current IAB Chairman and their 3 immediate predecessors are the members of the CCEFP Executive Committee (EC).

Table 4: Industrial/Practitioner Members, Innovation Partners, Funders of Sponsored Projects, Funders of Associated Projects and Contributing Organizations

Summary:
47 - Industrial/Practitioner Members
1 - Innovation Partner
0 - Funder of Sponsored Projects [1]
8 - Funders of Associated Projects [1]
6 - Contributing Organizations [1]

Section 1: 47 Industrial/Practitioner Members

Organization	Sector	Product Focus (Industry only)	Type of Financial Support	Type of Involvement	Domestic / Foreign	Size (Industry Only)	New Member (Yes/No)	Total # of Sponsored Projects	Total # of Associated Projects
Industrial/Practitioner Members That Have Already Provided Current Award Year Support.									
Afton Chemical Corp.	U.S. Industry	Fluid power components and systems	Unrestricted Cash Donations	Member of Center's Industrial Advisory Board Participates in science/engineering research projects Involvement in Technology Transfer	Domestic	Large (>1000 employees)	No	0	0
Air Logic	U.S. Industry	Fluid power components and systems	Unrestricted Cash Donations	Participates in science/engineering research projects	Domestic	Small (<500 employees)	No	0	0
Bobcat	Foreign Industry	Vehicle OEM	Unrestricted Cash Donations	Participates in science/engineering research projects	Foreign	Large (>1000 employees)	No	0	0
Bosch Rexroth Corporation	Foreign Industry	Fluid power components and systems	Unrestricted Cash Donations Associated Project Support In-Kind Donations	Member of Center's Industrial Advisory Board Participates in science/engineering research projects Involvement in Technology Transfer	Foreign	Large (>1000 employees)	No	0	1
Caterpillar, Inc.	U.S. Industry	Vehicle OEM	Unrestricted Cash Donations	Member of Center's Industrial Advisory Board Participates in science/engineering research projects Participation in education/outreach activities Involvement in Technology Transfer	Domestic	Large (>1000 employees)	No	0	0
CNH America, Inc.	U.S. Industry	Vehicle OEM	Unrestricted Cash Donations Associated Project Support	Member of Center's Industrial Advisory Board Participates in science/engineering research projects Participation in education/outreach activities Involvement in Technology Transfer	Domestic	Large (>1000 employees)	Yes	0	1

Table 4: Industrial/Practitioner Members, Innovation Partners, Funders of Sponsored Projects, Funders of Associated Projects and Contributing Organizations

Concentric AB/Haldex	Foreign Industry	Fluid power components and systems	Unrestricted Cash Donations	Member of Center's Industrial Advisory Board Participates in science/engineering research projects	Foreign	Medium (500-1000 employees)	No	0	0
Eaton Corporation	U.S. Industry	Fluid power components and systems	Unrestricted Cash Donations Associated Project Support In-Kind Donations	Member of Center's Industrial Advisory Board Participates in science/engineering research projects Participation in education/outreach activities Participation in translational research Involvement in Technology Transfer	Domestic	Large (>1000 employees)	No	0	2
Enfield Technologies	U.S. Industry	Fluid power components and systems	Unrestricted Cash Donations In-Kind Donations	Member of Center's Industrial Advisory Board Participates in science/engineering research projects Involvement in Technology Transfer	Domestic	Small (<500 employees)	No	0	0
Evonik Industries	U.S. Industry	Chemical manufacturer	Unrestricted Cash Donations	Member of Center's Industrial Advisory Board Participates in science/engineering research projects Involvement in Technology Transfer	Domestic	Large (>1000 employees)	No	0	0
Exxon Mobil	U.S. Industry	Fluid power components and systems	Unrestricted Cash Donations	Member of Center's Industrial Advisory Board Participates in science/engineering research projects Involvement in Technology Transfer	Domestic	Large (>1000 employees)	No	0	0
Freudenberg - NOK	U.S. Industry	Fluid power components and systems	Unrestricted Cash Donations	Involvement in Technology Transfer	Domestic	Large (>1000 employees)	Yes	0	0
G.W. Lisk Company	U.S. Industry	Fluid power components and systems	Unrestricted Cash Donations	Member of Center's Industrial Advisory Board	Domestic	Medium (500-1000 employees)	No	0	0
Heco Gear, Inc.	U.S. Industry	Fluid power components and systems	Unrestricted Cash Donations	Participates in science/engineering research projects	Domestic	Small (<500 employees)	No	0	0
High Country Tek, Inc.	U.S. Industry	Electronics	Unrestricted Cash Donations	Participates in science/engineering research projects	Domestic	Small (<500 employees)	No	0	0
Hoowaki, LLC	U.S. Industry	Manufacturing Technology	Unrestricted Cash Donations	Participates in science/engineering research projects	Domestic	Small (<500 employees)	No	0	0

Table 4: Industrial/Practitioner Members, Innovation Partners, Funders of Sponsored Projects, Funders of Associated Projects and Contributing Organizations

Husco International, Inc.	U.S. Industry	Fluid power components and systems	Unrestricted Cash Donations	Member of Center's Industrial Advisory Board Participates in science/engineering research projects Involvement in Technology Transfer	Domestic	Large (>1000 employees)	No	0	0
Linde Hydraulics Corp.	Foreign Industry	Fluid power components and systems	Unrestricted Cash Donations	Member of Center's Industrial Advisory Board Involvement in Technology Transfer	Domestic	Small (<500 employees)	No	0	0
Main Manufacturing Products, Inc.	U.S. Industry	Fluid power components and systems	Unrestricted Cash Donations	Participates in science/engineering research projects	Domestic	Small (<500 employees)	No	0	0
Master Pneumatic-Detroit, Inc.	U.S. Industry	Fluid power components and systems	Unrestricted Cash Donations	Participates in science/engineering research projects	Domestic	Small (<500 employees)	No	0	0
Mico, Inc.	U.S. Industry	Fluid power components and systems	Unrestricted Cash Donations	Participates in science/engineering research projects	Domestic	Small (<500 employees)	No	0	0
Moog, Inc.	U.S. Industry	Fluid power components and systems	Unrestricted Cash Donations	Participates in science/engineering research projects	Domestic	Large (>1000 employees)	No	0	0
National Fluid Power Association	Industrial Association	N/A	Unrestricted Cash Donations	Member of Center's Industrial Advisory Board Involvement in Technology Transfer	Domestic	N/A	No	0	0
National Tube Supply Company	U.S. Industry	Fluid power components and systems	Unrestricted Cash Donations	Participates in science/engineering research projects	Domestic	Small (<500 employees)	No	0	0
Netshape Technologies	U.S. Industry	Fluid power components and systems	Unrestricted Cash Donations	Member of Center's Industrial Advisory Board Participates in science/engineering research projects	Domestic	Medium (500-1000 employees)	No	0	0
Nexen Group, Inc.	U.S. Industry	Fluid power components and systems	Unrestricted Cash Donations	Participates in science/engineering research projects	Domestic	Small (<500 employees)	No	0	0
Nitta Corporation	Foreign Industry	Fluid power components and systems	Unrestricted Cash Donations	Participates in science/engineering research projects	Foreign	Large (>1000 employees)	Yes	0	0
Parker Hannifin Corporation	U.S. Industry	Fluid power components and systems	Unrestricted Cash Donations In-Kind Donations	Member of Center's Industrial Advisory Board Participates in science/engineering research projects Involvement in Technology Transfer	Domestic	Large (>1000 employees)	No	0	0
PIAB Vacuum Products	Foreign Industry	Fluid power components and systems	Unrestricted Cash Donations	Participates in science/engineering research projects	Domestic	Small (<500 employees)	No	0	0
Poclain Hydraulics	Foreign Industry	Fluid power components and systems	Unrestricted Cash Donations	Member of Center's Industrial Advisory Board Involvement in Technology Transfer	Foreign	Large (>1000 employees)	No	0	0

Table 4: Industrial/Practitioner Members, Innovation Partners, Funders of Sponsored Projects, Funders of Associated Projects and Contributing Organizations

Quality Control Corporation	U.S. Industry	Fluid power components and systems	Unrestricted Cash Donations	Participates in science/engineering research projects	Domestic	Small (<500 employees)	No	0	0
Racine Federated Inc. (formerly Hedland Flow Meters)	U.S. Industry	Fluid power components and systems	Unrestricted Cash Donations Associated Project Support	Participates in science/engineering research projects	Domestic	Small (<500 employees)	No	0	1
Ross Controls	U.S. Industry	Fluid power components and systems	Unrestricted Cash Donations	Member of Center's Industrial Advisory Board	Domestic	Small (<500 employees)	No	0	0
Sauer-Danfoss	U.S. Industry	Fluid power components and systems	Unrestricted Cash Donations Associated Project Support In-Kind Donations	Member of Center's Industrial Advisory Board Involvement in Technology Transfer	Domestic	Large (>1000 employees)	No	0	1
Shell Global Solutions	Foreign Industry	Petrochemical	Unrestricted Cash Donations	Participates in science/engineering research projects	Domestic	Large (>1000 employees)	No	0	0
Simerics, Inc.	U.S. Industry	Fluid power components and systems	Unrestricted Cash Donations	Participates in science/engineering research projects	Domestic	Small (<500 employees)	No	0	0
StorWatts Inc.	U.S. Industry	Energy solutions	Unrestricted Cash Donations	Participates in science/engineering research projects	Domestic	Small (<500 employees)	Yes	0	0
Sun Hydraulics	U.S. Industry	Fluid power components and systems	Unrestricted Cash Donations In-Kind Donations	Participates in science/engineering research projects	Domestic	Medium (500-1000 employees)	No	0	0
Takako Industries	Foreign Industry	Fluid power components and systems	Unrestricted Cash Donations In-Kind Donations	Participates in science/engineering research projects	Foreign	Small (<500 employees)	No	0	0
Tennant	U.S. Industry	Fluid power components and systems	Unrestricted Cash Donations	Participates in science/engineering research projects	Domestic	Large (>1000 employees)	No	0	0
The Lubrizol Corporation	U.S. Industry	Petrochemical	Unrestricted Cash Donations Associated Project Support	Member of Center's Industrial Advisory Board	Domestic	Large (>1000 employees)	No	0	1
Trelleborg Sealing Solutions	Foreign Industry	Fluid power components and systems	Unrestricted Cash Donations	Member of Center's Industrial Advisory Board Participates in science/engineering research projects	Foreign	Large (>1000 employees)	No	0	0
Woodward, Inc.	U.S. Industry	Aerospace	Unrestricted Cash Donations	Member of Center's Industrial Advisory Board Participates in science/engineering research projects	Domestic	Large (>1000 employees)	Yes	0	0
Industrial/Practitioner Members That Will Provide Support by the End of the Current Award Year.									

Table 4: Industrial/Practitioner Members, Innovation Partners, Funders of Sponsored Projects, Funders of Associated Projects and Contributing Organizations

Deltrol Fluid Products	U.S. Industry	Fluid power components and systems	Unrestricted Cash Donations	Member of Center's Industrial Advisory Board Participates in science/engineering research projects Participation in education/outreach activities Involvement in Technology Transfer	Domestic	Small (<500 employees)	No	0	0
Donaldson Company	U.S. Industry	Fluid power components and systems	Unrestricted Cash Donations	Participates in science/engineering research projects Participation in education/outreach activities	Domestic	Large (>1000 employees)	No	0	0
Gates Corporation	U.S. Industry	Fluid power components and systems	Unrestricted Cash Donations	Member of Center's Industrial Advisory Board Participates in science/engineering research projects	Domestic	Large (>1000 employees)	No	0	0
MTS Systems Corporation	U.S. Industry	Fluid power components and systems	Unrestricted Cash Donations	Member of Center's Industrial Advisory Board	Domestic	Large (>1000 employees)	No	0	0

Section 2: 1 Innovation Partner

Organization	Sector	Product Focus (Industry only)	Type of Involvement	Domestic / Foreign	Size (Industry Only)	New Partner (Yes/No)
Fluid Power Educational Foundation	Private Foundation	N/A	Participates in science/engineering research projects Participation in education/outreach activities	Domestic	N/A	No

Section 3: 0 Funder of Sponsored Projects

Organization	Sector	Product Focus (Industry only)	Type of Financial Support	Type of Involvement	Domestic / Foreign	Size (Industry Only)	New Partner (Yes/No)	Total # of Sponsored Projects
There are no funders of sponsored projects for which support has been received.								

Section 4: 8 Funders of Associated Projects

Organization	Sector	Product Focus (Industry only)	Type of Financial Support	Type of Involvement	Domestic / Foreign	Size (Industry Only)	New Partner (Yes/No)	Total # of Associated Projects
Casappa S.p.A.	Foreign Industry	Fluid power components and systems	Associated Project Support	Participates in science/engineering research projects	Foreign	Large (>1000 employees)	No	1
DARPA	U.S. Government (Not NSF)	N/A	Associated Project Support	Participates in science/engineering research projects	Domestic	N/A	No	1
MGI Coutier	Foreign Industry	Aerospace	Associated Project Support	Participates in science/engineering research projects	Foreign	Small (<500 employees)	Yes	1
National Defense Science and Engineering Fellowship Grant (NDSEG)	U.S. Government (Not NSF)	N/A	Associated Project Support	Participation in education/outreach activities	Domestic	N/A	No	1
National Institutes of Health (NIH)	U.S. Government (Not NSF)	N/A	Associated Project Support	Participates in science/engineering research projects	Domestic	N/A	No	1
The Martin Company	U.S. Industry	Aerospace	Associated Project Support	Participates in science/engineering research projects	Domestic	Small (<500 employees)	No	1
Total Oil Company	Foreign Industry	Petrochemical	Associated Project Support	Participates in science/engineering research projects	Foreign	Large (>1000 employees)	No	1

Table 4: Industrial/Practitioner Members, Innovation Partners, Funders of Sponsored Projects, Funders of Associated Projects and Contributing Organizations

United Technologies Research Center	U.S. Industry	Technology development	Associated Project Support	Participates in science/engineering research projects	Domestic	Small (<500 employees)	No	1

Section 5: 6 Contributing Organizations

Organization	Sector	Product Focus (Industry only)	Type of Financial Support	Type of Involvement	Domestic / Foreign	Size (Industry Only)	New Partner (Yes/No)
Bimba Manufacturing Company	U.S. Industry	Fluid power components and systems	In-Kind Donations	Participates in science/engineering research projects Participation in education/outreach activities Involvement in Technology Transfer	Domestic	Small (<500 employees)	No
Festo Corporation	Foreign Industry	Fluid power components and systems	In-Kind Donations	Participates in science/engineering research projects Involvement in Technology Transfer	Foreign	Large (>1000 employees)	No
International Fluid Power Society	Industrial Association	N/A	Unrestricted Cash Donations	Participates in science/engineering research projects	Domestic	N/A	No
No Magic, Inc.	U.S. Industry	software	In-Kind Donations	Participates in science/engineering research projects	Domestic	Small (<500 employees)	Yes
Phoenix Integration	U.S. Industry	software	In-Kind Donations	Participates in science/engineering research projects Participation in translational research	Domestic	Small (<500 employees)	Yes
The Toro Company	U.S. Industry	Fluid power components and systems	Unrestricted Cash Donations	Participates in science/engineering research projects	Domestic	Large (>1000 employees)	No

Section 6: Summary

Sector	Industrial/Practitioner Members	Percent Foreign	Percent Small	Percent Medium	Percent Large
U.S. Industry	36	0%	44%	8%	47%
Foreign Industry	10	70%	30%	10%	60%
Industrial Association	1	0%	N/A	N/A	N/A
Total	**47**	**15%**	**N/A**	**N/A**	**N/A**

[1] - Funders of sponsored projects, funders of associated projects and contributing organizations are only included if support has been received.

Table 4a: Organization Involvement in Innovation and Entrepreneurship Activities

Organization Name	Innovation/Entrepreneurship Training Activities	Providing Incubation Facilities	Technology Screening Activities	Connections to sources of commercialization funding	Other Activity
No organizations with involvement in innovation and entrepreneurship activities have been entered.					

Table 5: Innovation Ecosystem Partners and Support by Year

	Jun 01, 2008 - May 31, 2009	Jun 01, 2009 - May 31, 2010	Jun 01, 2010 - May 31, 2011	Jun 01, 2011 - May 31, 2012 [1]
Industrial/Practitioner Members	58	54	54	47
Innovation Partners	0	0	0	1
Funders of Sponsored Projects	0	0	0	0
Funders of Associated Projects	6	6	17	9
Contributing Organizations	0	2	5	7
Total Participating Organizations	**64**	**62**	**76**	**64**
Number of Member-Sponsored Projects	0	0	0	0
Number of Non-Member-Sponsored Projects	0	0	0	0
Total Number of Sponsored Projects	**0**	**0**	**0**	**0**
Membership Fees Received - Cash	$741,500	$666,265	$641,250	$628,167
Membership Fees Expected from Prior Year Members [2]	N/A	N/A	N/A	$125,750
Member-Sponsored Projects Total Dollar Amount	$12,000	$0	$0	$0
Member-Associated Projects Total Dollar Amount	$503,806	$121,067	$166,864	$95,295
Member In-Kind Total Dollar Amount [3]	N/A	$18,300	$123,661	$92,150
Total Dollar Amount, Industrial/Practitioner Member Support to Center	**$1,257,306**	**$805,632**	**$931,775**	**$941,362**

[1] Partial Award Year data only.

[2] Only applies for organizatons that were already Industrial/Practitioner Members in a prior year.

[3] Data for this row is from the In-Kind Support reported in the Organizations section. There is no data prior to 2010 since it is a new field that year.

Table 5a - Technology Transfer Activities

Organization Name	Faculty On Site at Organization	Faculty Instruction to Organization	Individual from Organization on Lead Institution Campus	Licensed Software	Licensed Technology (other than software)	Graduate Hired by Organization	Student On Site at Organization	Participation in Test Bed	Other Activities
Afton Chemical Corp.		✓							1B.1: New Material Combinations...,
Air Logic									
Bimba Manufacturing Company			✓						
Bobcat									
Bosch Rexroth Corporation	✓				✓	✓		✓	
Casappa S.p.A.									
Caterpillar, Inc.		✓					✓	✓	Technology Licensing Opportunities Fluid Power Scholars
CNH America, Inc.			✓						
Concentric AB/Haldex									
Confidential Organization (optional use for associated or sponsored projects only)									
DARPA									
Deere and Company									
Deltrol Fluid Products							✓		
Donaldson Company									
Eaton Corporation	✓	✓			✓	✓	✓		
Enfield Technologies									Research project support CEO on Executive Committee
Eolos Wind Energy Research Consortium									
Evonik Industries			✓						
Exxon Mobil			✓						
Festo Corporation			✓						
Fluid Power Educational Foundation									
Freudenberg - NOK									Support Research Projects
G.W. Lisk Company									
Gates Corporation									
Heco Gear, Inc.									
High Country Tek, Inc.									
Hoowaki, LLC									
Husco International, Inc.			✓						
International Fluid Power Society									
Linde Hydraulics Corp.		✓							
Main Manufacturing Products, Inc.									
Master Pneumatic-Detroit, Inc.									
MGI Coutier									
Mico, Inc.									
Moog, Inc.									
MTS Systems Corporation									
National Defense Science and Engineering Fellowship Grant (NDSEG)									
National Fluid Power Association		✓							
National Institutes of Health (NIH)									
National Tube Supply Company									
Netshape Technologies									
Nexen Group, Inc.									
Nitta Corporation									
No Magic, Inc.									
Parker Hannifin Corporation							✓		
Phoenix Integration									
PIAB Vacuum Products									
Poclain Hydraulics		✓							
Quality Control Corporation									
Racine Federated Inc. (formerly Hedland Flow Meters)									
Ross Controls									
Sauer-Danfoss		✓			✓				
Shell Global Solutions									
Simerics, Inc.									
StorWatts Inc.									
Sun Hydraulics									
Takako Industries									
Tennant									
The Lubrizol Corporation									
The Martin Company									
The Toro Company									
Total Oil Company									
Trelleborg Sealing Solutions									
United Technologies Research Center									
Woodward, Inc.									

Figure 5b: Lifetime Industrial/Practitioner Membership History

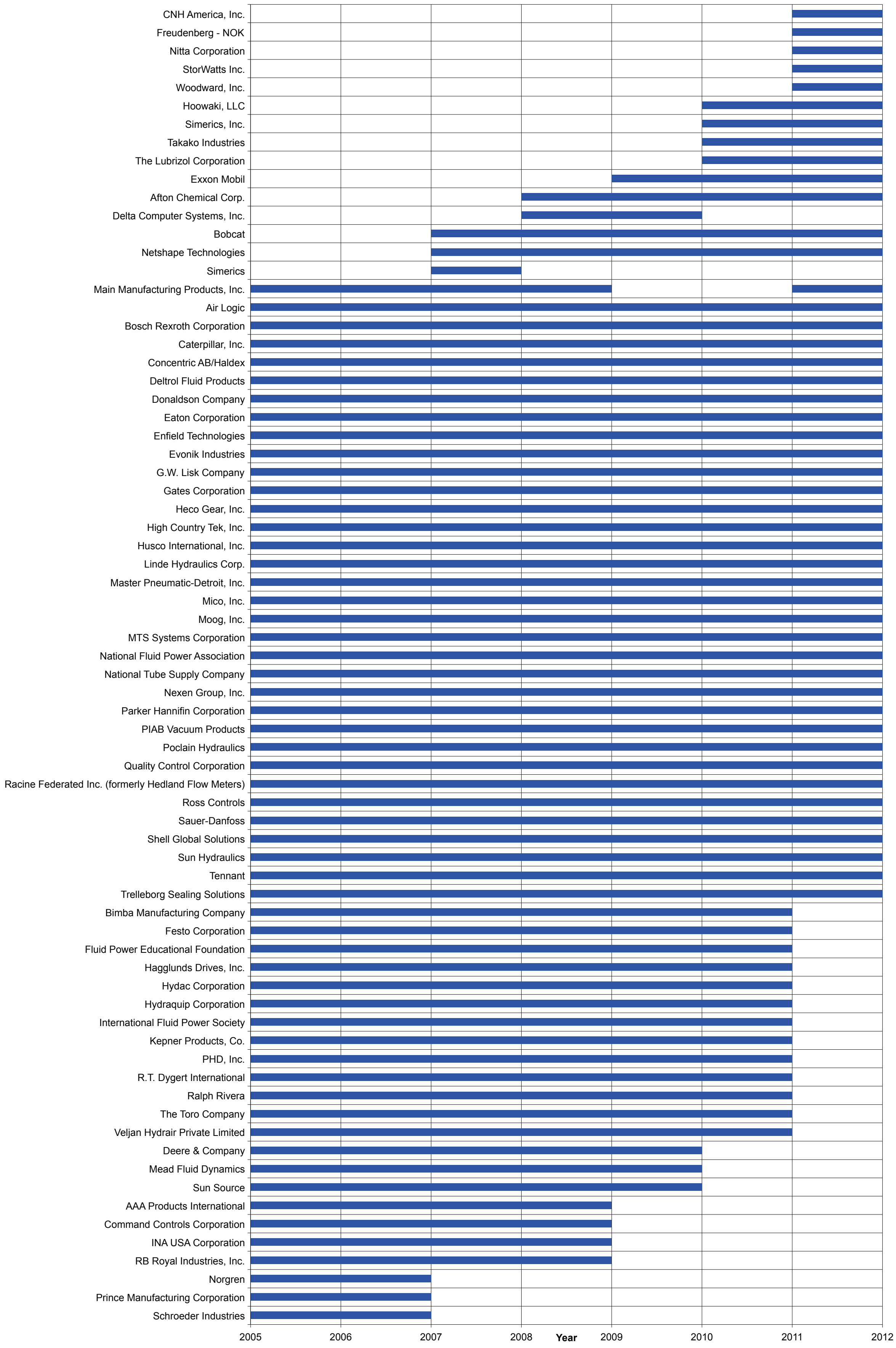


Figure 5c: Total Number of Industrial/Practitioner Members

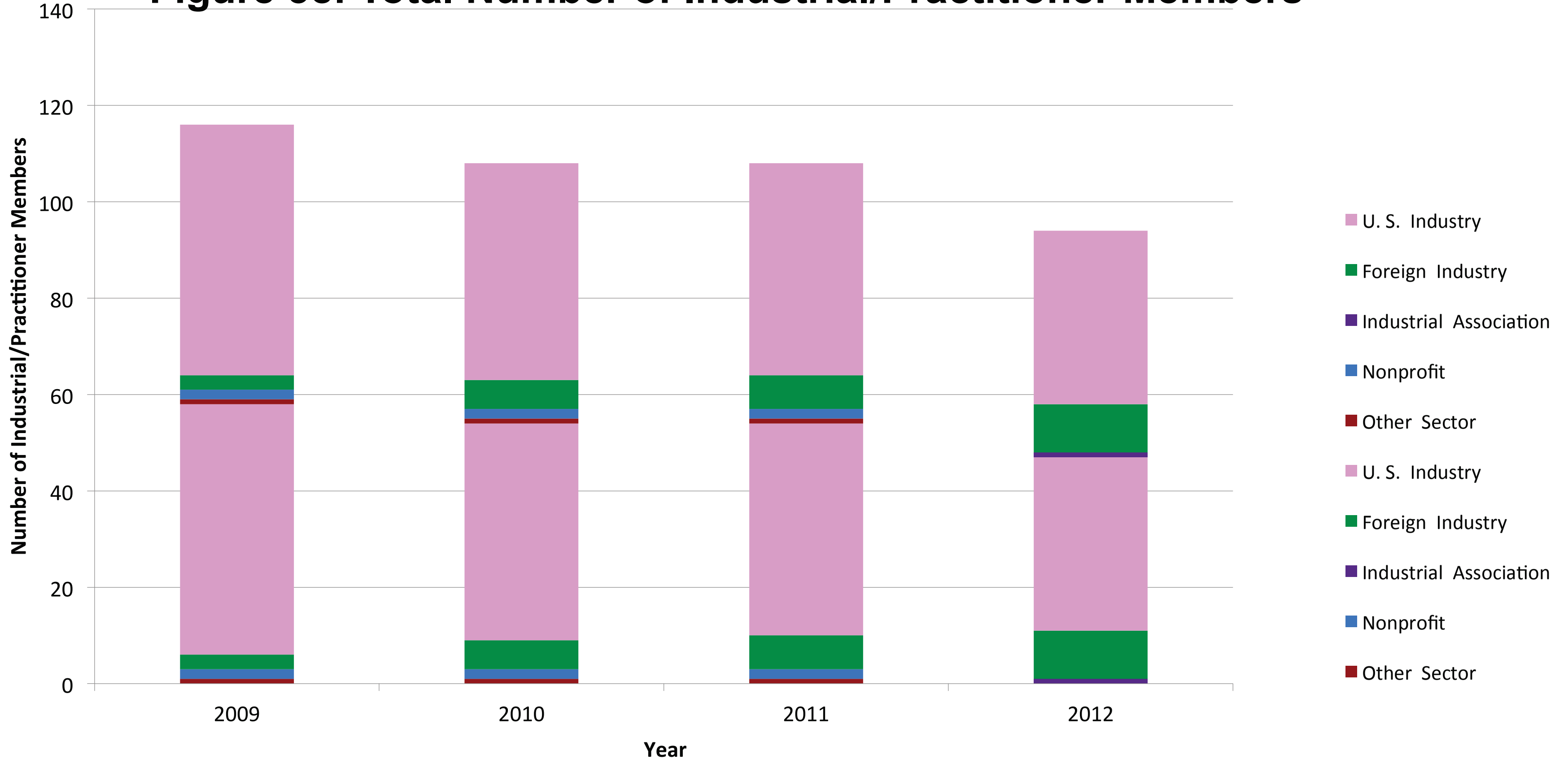
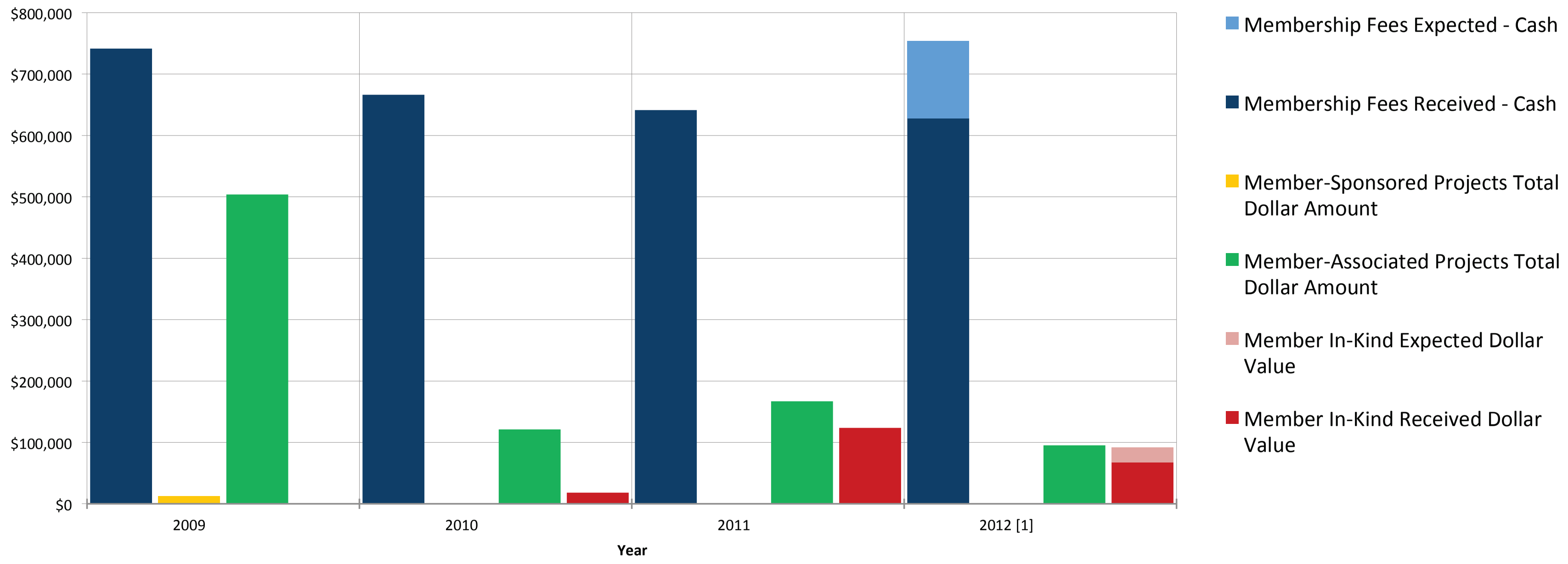


Figure 5d: Industrial/Practitioner Member Support by Year, FY 2012 2012



4.3 TECHNOLOGY TRANSFER AND NEW BUSINESS DEVELOPMENT

The CCEFP participates in many technology transfer efforts. CCEFP Faculty and staff of the CCEFP are encouraged to consult with industry to transfer research knowledge. Many of the lead researchers are active consultants. Two of our faculty members have taken leaves to be on location at the partner organizations and several graduate students have worked on internships with our member companies.

One of our faculty participated in the development of a Systems Modeling Specification to define bi-directional mapping between SysML and Modelica to leverage the benefits from both languages. By integrating SysML and Modelica, SysML's strength in descriptive modeling can be combined with Modelica's DAE solving capability to support analyses and trade studies. The group that developed this was represented by industry, academia (domestic and international) and a government laboratory.

The CCEFP has produced 12 invention disclosures this year. These disclosures were shared with our Industry Members and there is active IP Licensing discussions occurring associated with 11 of these disclosures. The table below summarizes the CCEFP Invention disclosures that have occurred since the Center started in 2006.

ERC Intellectual Property Table:

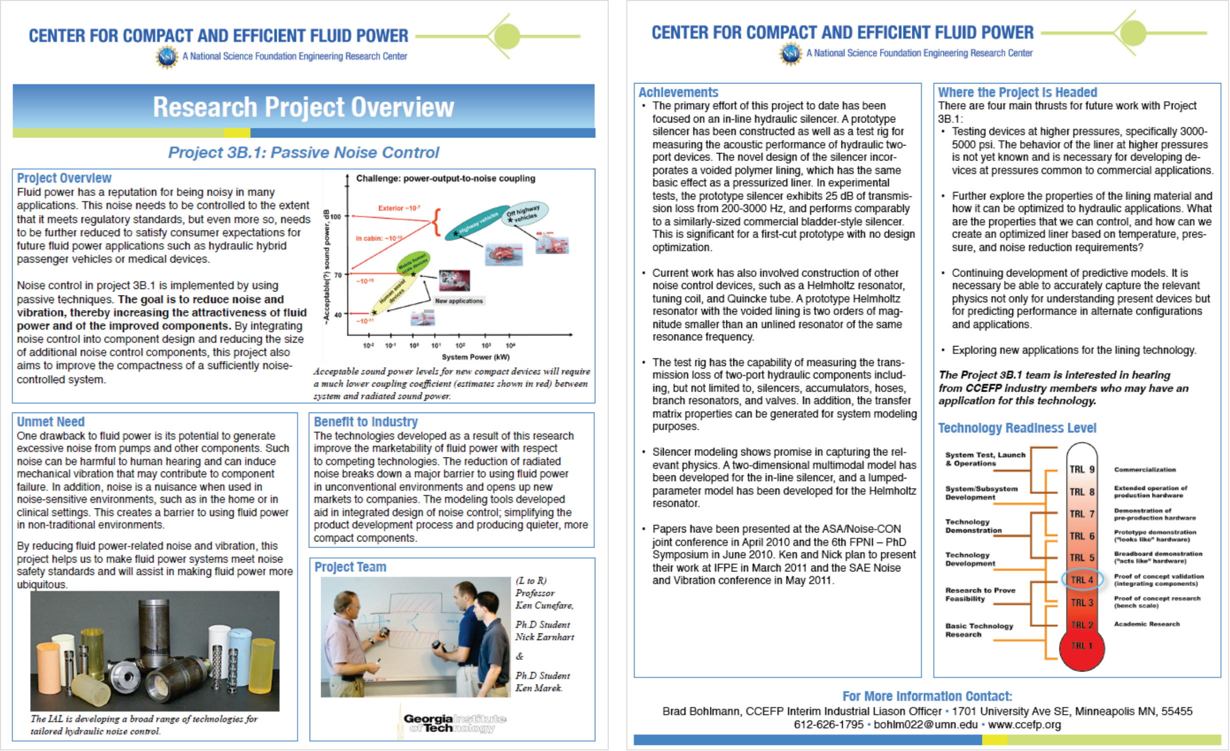
IP File number at the Home University	Home University	IP Title	Provisional Application Date	Patent Application Date	Patent Number	Existing or possible licensing opportunities
Z07054	Minnesota	Open Accumulator Compact Energy Storage for Regenerative Fluid Power Applications	10/10/06	6/30/09	12/445,176	Licensed to SustainX Inc
Z07129	Minnesota	Hydro-mechanical Hybrid Drive Train	4/10/07	4/10/08	PCT/US2008/004618	
Z08013	Minnesota	Hydraulic Actuation of a Spool Using an Actuated Pump	8/20/07	4/9/09	12/444,910	Passively marketed. No licensing negotiations
2008P00304	MSOE	Method for reducing torque ripple in hydraulic motors	12/31/08	7/1/2010 7/8/2010	US 12/347,608 WO 2010/076241 A1	
65083	Purdue University	Axial Sliding Bearing with Structural Sliding Surface	4/1/08	11/16/2010 (US), 10/29/2010 (KR), 4/1/2009 (JP), 4/1/2009 (EP)	None issued yet	Licensed to a CCEFP member
	UIUC	Micro- and Nano-Texturing for Low-Friction Fluid Power Systems		8/10/09	Pending	Nitta-Moore
HyperCube (ID 2)	MSOE	Dynamic, Multi-Functional, Load-Directed, Composite, Lattice Unit Truss and Unit Cell				
Z09145	Minnesota	Rotary On/Off Valve for Virtually Variable 4 Quadrant Pump/Motor Applications	None	None	None	

IP File number at the Home University	Home University	IP Title	Provisional Application Date	Patent Application Date	Patent Number	Existing or possible licensing opportunities
VU09108	VANDERBILT UNIVERSITY	High Energy Density Elastomeric Accumulator	4/6/09	3/31/10	PCT/US10/29361	
VU09107	VANDERBILT UNIVERSITY	High Inertance Liquid Piston	4/6/09	4/5/10	12/753,990	
	UIUC	Ankle-Foot-Orthoses Device	10/5/09	10/5/10	Pending	
65550	Purdue University	Bi-directional Check Valve	1/24/11	1/24/2012 (US)	None issued yet	Available
65293	Purdue University	Piston with Waved Surface for Positive Displacement Pumps and Motors	4/1/09	11/23/2011 (US), 9/28/2011 (EP), no date listed (KR)	None issued yet	Licensed to a CCEFP member
5344	GT	Multiple Disclosures for Acoustic Management	not yet filed	not yet filed		
5345	GT	Multiple Disclosures for Acoustic Management	not yet filed	not yet filed		
5346	GT	Multiple Disclosures for Acoustic Management	not yet filed	not yet filed		
5347	GT	Multiple Disclosures for Acoustic Management	not yet filed	not yet filed		
5348	GT	Multiple Disclosures for Acoustic Management	not yet filed	not yet filed		
5350	GT	Multiple Disclosures for Acoustic Management	not yet filed	not yet filed	NA	
5408	GT	Multiple Disclosures for Acoustic Management	not yet filed	not yet filed		
5480	GT	Piezo-Array Embedded Polymeric Seals for Effective Micro-Control of Sealing	1/28/11			

IP File number at the Home University	Home University	IP Title	Provisional Application Date	Patent Application Date	Patent Number	Existing or possible licensing opportunities
VU1172	VANDERBILT UNIVERSITY	Elastic Hydraulic Accumulator /Reservoir System	N/A	1/31/11	US 13/017,118 AND PCT PCT/US11/23120	
VU1195	VANDERBILT UNIVERSITY	Multiple Accumulator Systems and Methods of Use Thereof	2/3/11	1/30/12	US 13/360,929 AND PCT/US12/23073	
65810	Purdue University	Hydraulic Hybrid Architecture for Systems having Rotary and Linear Actuators	3/16/11	Utility Patent being drafted	None issued yet	Available
5567	GT	Multiple Disclosures for Acoustic Management	not yet filed	not yet filed		
5568	GT	Multiple Disclosures for Acoustic Management	not yet filed	not yet filed		
5569	GT	Multiple Disclosures for Acoustic Management	not yet filed	not yet filed		
20110146	Minnesota	Integrated Portable Pneumatically Powered Ankle-foot Orthosis	3/14/11			
	UIUC	Ankle-Foot-Orthoses Device	3/14/11	3/13/12	Pending	
MSOE Muscle (I0D 1)	MSOE	Fluid Power Actuator (MSOE Muscle)	4/1/12	TBD	N/A	
VU12052	VANDERBILT UNIVERSITY	Continuous Perimeter Clamp	N/A	N/A	N/A	

The Center has created another tool to facilitate technology transfer. These are two page project summaries for the research funded by the Center. These summaries have proven to be valuable tools to communicate to potential members the value of the ongoing research. They have also proven to be a source of new members and projects. An example of this is a company that found a description of our work on the internet. They contacted the center. This company is now a member of the CCEFP and is working with the researcher to develop an associated project.

The project summary sheets are available in printed form on a heavy gauge, glossy paper printed on two sides creating a single leaf document. These hard copies will be mailed to targeted member companies and can also be used by the University to market the technology if no CCEFP members exercise their rights for the IP. In addition, these sheets are available for download in pdf format from the CCEFP website.



CENTER FOR COMPACT AND EFFICIENT FLUID POWER

A National Science Foundation Engineering Research Center

Research Project Overview

Project 3B.1: Passive Noise Control

Project Overview

Fluid power has a reputation for being noisy in many applications. This noise needs to be controlled to the extent that it meets regulatory standards, but even more so, needs to be further reduced to satisfy consumer expectations for future fluid power applications such as hydraulic hybrid passenger vehicles or medical devices.

Noise control in project 3B.1 is implemented by using passive techniques. **The goal is to reduce noise and vibration, thereby increasing the attractiveness of fluid power and of the improved components.** By integrating noise control into component design and reducing the size of additional noise control components, this project also aims to improve the compactness of a sufficiently noise-controlled system.

Acceptable sound power levels for new compact devices will require a much lower coupling coefficient (estimates shown in red) between system and radiated sound power.

Unmet Need

One drawback to fluid power is its potential to generate excessive noise from pumps and other components. Such noise can be harmful to human hearing and can induce mechanical vibration that may contribute to component failure. In addition, noise is a nuisance when used in noise-sensitive environments, such as in the home or in clinical settings. This creates a barrier to using fluid power in non-traditional environments.

By reducing fluid power-related noise and vibration, this project helps us to make fluid power systems meet noise safety standards and will assist in making fluid power more ubiquitous.

The IAL is developing a broad range of technologies for tailored hydraulic noise control.

Benefit to Industry

The technologies developed as a result of this research improve the marketability of fluid power with respect to competing technologies. The reduction of radiated noise breaks down a major barrier to using fluid power in unconventional environments and opens up new markets to companies. The modeling tools developed aid in integrated design of noise control; simplifying the product development process and producing quieter, more compact components.

Project Team

(L to R)
Professor
Ken Cunefare,

Ph.D Student
Nick Earnhart

&

Ph.D Student
Ken Marek.

Georgia Institute of Technology

CENTER FOR COMPACT AND EFFICIENT FLUID POWER

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Achievements

- The primary effort of this project to date has been focused on an in-line hydraulic silencer. A prototype silencer has been constructed as well as a test rig for measuring the acoustic performance of hydraulic two-port devices. The novel design of the silencer incorporates a voided polymer lining, which has the same basic effect as a pressurized liner. In experimental tests, the prototype silencer exhibits 25 dB of transmission loss from 200-3000 Hz, and performs comparably to a similarly-sized commercial bladder-style silencer. This is significant for a first-cut prototype with no design optimization.
- Current work has also involved construction of other noise control devices, such as a Helmholtz resonator, tuning coil, and Quincke tube. A prototype Helmholtz resonator with the voided lining is two orders of magnitude smaller than an unlined resonator of the same resonance frequency.
- The test rig has the capability of measuring the transmission loss of two-port hydraulic components including, but not limited to, silencers, accumulators, hoses, branch resonators, and valves. In addition, the transfer matrix properties can be generated for system modeling purposes.
- Silencer modeling shows promise in capturing the relevant physics. A two-dimensional multimodal model has been developed for the in-line silencer, and a lumped-parameter model has been developed for the Helmholtz resonator.
- Papers have been presented at the ASA/Noise-CON joint conference in April 2010 and the 6th FPNI – PhD Symposium in June 2010. Ken and Nick plan to present their work at IFPE in March 2011 and the SAE Noise and Vibration conference in May 2011.

Where the Project Is Headed

There are four main thrusts for future work with Project 3B.1:

- Testing devices at higher pressures, specifically 3000-5000 psi. The behavior of the liner at higher pressures is not yet known and is necessary for developing devices at pressures common to commercial applications.
- Further explore the properties of the lining material and how it can be optimized to hydraulic applications. What are the properties that we can control, and how can we create an optimized liner based on temperature, pressure, and noise reduction requirements?
- Continuing development of predictive models. It is necessary be able to accurately capture the relevant physics not only for understanding present devices but for predicting performance in alternate configurations and applications.
- Exploring new applications for the lining technology.

The Project 3B.1 team is interested in hearing from CCEFP industry members who may have an application for this technology.

Technology Readiness Level

For More Information Contact:

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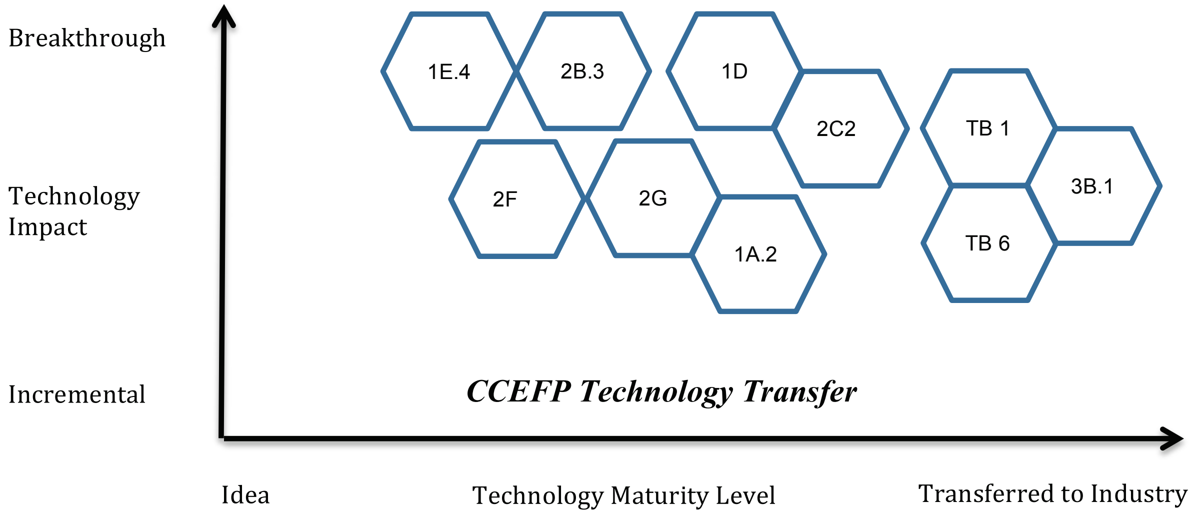
Project Summary Sheet

Technology Impact

Some of the more impactful CCEFO technologies are mapped in the Impact vs. Maturity chart below. The numbers in the markers are the project numbers. A status review for each project appears in Volume II of this report. The projects identified are:

- 1E.4: Piston-by-Piston Control of Pumps and Motors using Mechanical Methods
- 2F: MEMS Proportional Pneumatic Valve
- 2B.3: Free Piston Engine Hydraulic Pump
- 2G: Fluid Powered Surgery and Rehabilitation via Compact, Integrated Systems
- 1D: Micro- and Nano-Texturing for Low-Friction Fluid Power Systems
- 1A.2: Multi Actuator Hydraulic Hybrid Machine Systems
- 2C2: Advanced Strain Energy Accumulator
- Testbed 6: Fluid Power Ankle-Foot Orthosis
- Testbed 1: High Efficiency Excavator
- 3B.1: Passive Noise Control in Fluid Power



4.4 INNOVATION

The fluid power industry is typically very capital intensive. This is not conducive to new business start-up activities. Also, our industry members are the some of the most dominate in their market. Therefore our most promising intellectual property is typically reserved by our members. We believe that the technologies that we bring forward will help our members grow their business. However, we continue to continue encourage start-up activities and will market our new technologies aggressively to promote economic growth.

4.5 FUTURE PLANS

The SWOT developed by the Industrial Advisory Board has been valuable both in working issues this year as well as integrating this input in our sustainability plan. The bullets below address key weaknesses and threats that the IAB identified during the last site visit.

Weaknesses

- **New project management processes not yet proven** – The new project management review process include 2 project reviews each year. These reviews are done by the executive committee. The projects are placed into good, marginal and at risk categories based in individual scoring by executive committee members. Feedback is provided to the project teams. Additional follow-up is done by the Center Director and the Sustainability Director on the high risk projects. This occurs in a meeting with the project team to address specific concerns and to develop a plan bring the project back on track.
- **CCEFP does not proactively use/involve industry advisors** – The CCEFP has addressed this in several ways. In our quarterly IAB visits we have incorporated a review template that includes at section where the team identifies what industry can do to become engaged. This may be in the form of design reviews, technical or laboratory support, product information or potentially product or equipment to move the research effort forward. This has been well received by industry. The proposal scorecard for Y5&6 and Y7&8 project proposals included a rating for industry sponsorship. Many project teams have leveraged this relation into significant support
- **New communications programs not yet proven-** The IAB visits to member universities has significantly improved communications between researchers. The CCEFP continues to develop its communication infrastructure. Our communications with industry has different approaches and

focuses for the three main types of recipients: senior executives (e.g., CEOs, GMs, etc.), senior managers (e.g., IAB members), and mid-level managers and individual contributors (e.g., project champions). We filled the communications director role with a long time CCEFP supporter serving in a part time role until the sustainability plan was better defined. An overview of our communications activities appears in section 5.3 of this report.

- **Portfolio approach to risk needed** (**ensure taking some high risk and some foreseeable commercial projects)** – Balancing risk is an ongoing effort. By their nature the most challenging opportunities typically have the highest potential reward. We have also demonstrated that many of our projects have rather quickly produced results and technologies that industry in interested in pursuing.
- **Insufficient focus on critical environmental issues of leaks and NVH** – This year, 11 of our 12 invention disclosures were associated with seals and noise management / attenuation. For our Y7 & Y8 funding cycle, we received 2 seal related proposals. Both of these will be funded. Industry recommended that we sunset the acoustics project as they felt that it had advanced to a level that industry could likely take over the development.

Threats

- **Perception of fluid power as stodgy, ineffective, outdated** – The development of power electronics is very fast paced. However the high power density that fluid power offers is still a key differentiator in many markets where high force or torque is required.
- **High pace of development and cost reduction of alternative technologies -** We agree with this statement. One example is hybrid vehicles. Toyota and other have had electric hybrids in the passenger car market for more than a decade and are seeing good commercial success. In speaking with US Auto makers and the DOE, we believe that electric hybrid technologies will be the leaders in the automotive market in the near term. However, the higher power markets including trucks, off-road vehicle, excavators and wind energy are potentially areas where the advantages of fluid power will be realized.
- **CCEFP research results don't meet industry member expectations** - We observe a wide diversity of expectations among our industry members. They vary by size of company, type of business (component, system, OEM), and other aspects such as the specific individual representing the company in Center activities. The key to meeting or exceeding the expectations is communications. The IAB meetings that are being held 3-4 times a year at our member universities is helping all involved gain a better understanding of each other's wants, needs, and expectations. Effective multi-way communications is critical to assure this alignment.

5. INFRASTRUCTURE

5.1 CONFIGURATION AND LEADERSHIP EFFORT

The CCEFP institutional configuration is shown in Table 6. “Location of Lead, Core Partner, and All Domestic Collaborating Institutions” is shown in Figure 6a. “Country of Citizenship of ERC Foreign Personnel for the Center for Compact and Efficient Fluid Power” is shown in Figure 6c. Table 6 and Figures 6a and 6c are at the end of this section.

The CCEFP institutional configuration is optimal for its vision and goals. The CCEFP lead and core universities; the University of Minnesota (lead), Georgia Institute of Technology, Purdue University, University of Illinois at Urbana-Champaign and Vanderbilt University; involve the majority of fluid power university researchers in the United States. Each university has been carefully chosen because its expertise is essential to realize the CCEFP vision.

The collaborating institutions have also been carefully chosen. North Carolina A & T State University (NCAT) is the leading producer of African-American engineering graduates at both undergraduate and graduate levels. The human factors researchers in the Industrial Engineering Department at NCAT provide necessary expertise to realize the CCEFP vision, and complement the abilities of the other researchers. Milwaukee School of Engineering (MSOE) has an unusually strong emphasis on fluid power in its mechanical engineering curriculum. MSOE graduates are prominent in the engineering workforce of the fluid power industry. The school emphasizes undergraduate engineering education, but has a small graduate program, and effectively uses both undergraduate and graduate students in fluid power research.

Inspection of the strategic plan will show that eliminating any of these seven institutions would cause major gaps that would reduce the effectiveness of the CCEFP. Having a total of seven universities in the CCEFP increases the management challenge, but has been found to be manageable.

The domestic location of lead, core partner, outreach, and REU, Fluid Power Scholar (FPS), and RET participating institutions is shown in Figure 6A. There have been no changes in institutional configuration expect for REU student institution. 18 REU students, 38% women in addition to 27% underrepresented racial or ethnic minority status and 8 Fluid Power Scholar students, 0% of underrepresented gender, racial or ethnic minority status have been recruited from ERC and non-ERC institutions. Institutions outside of the CCEFP network which are represented in the 2011 REU and FPS program include: Case Western Reserve University, Clarkson University, Georgia Institute of Technology, Humboldt State University, Illinois Institute of Technology, Loyola University Chicago, Louisiana State University, Montana State University, Minneapolis Community and Technical College, New Mexico State University, North Carolina A&T State University, Princeton University, Purdue University, Texas A&M, University of Florida, University of Michigan, University of Missouri-Columbia, and the University of South Florida, University of Minnesota, Vanderbilt University, Yale University . Continuous efforts are made to recruit REU and FPS students through targeted institution-based and specific local student chapters, offices and programs that promote diversity in the sciences in addition to NSF Diversity Programs, LSAMP and TCUP partners of the Center.

The CCEFP’s Director has demonstrated effective leadership in guiding and managing the CCEFP by successful implementation of key management tools in strategic planning, project selection, budgeting, progress tracking and communication. The strategic plan has gone through several iterations and now effectively identifies the Center’s goals and their links to the research, education and outreach programs that are designed with which they are associated. Since the CCEFP’s launch in June 2006, projects have been both terminated and initiated and two test beds have been terminated to reflect the evolving strategic plan. Research on two associated test beds continues with a combination of University, federal and industry funding. These test beds extend the range of our research from 4 to 6 orders of magnitude of energy output. The appropriate management structure is in place to manage these processes. A total of 24 research projects were funded for Years 5-6. To assure adequate funding for each project, it is planned to have fewer projects in Years 7-8. The Director's decision to change from a one year to a two year funding cycle in Year 5 has been well accepted by all Center participants. An effective budgeting process has been implemented where resource allocations and project efforts are closely coupled. Also, the practice of reallocating unspent funds annually has been suspended. This has simplified the budget process and made is less arbitrary and contentious. This approach is also more appropriate as the Center has matured and all member universities have shown themselves to be capable of more independently managing their own finances. An effective progress tracking process has been implemented, and research, education and outreach projects are being re-directed as a result of progress tracking process. Lastly, an effective communications plan for both internal and external communication has been implemented.

The other members of the leadership team are also highly effective, and are becoming more effective as our processes become more refined. The Administrative Director greatly improved the budgeting process and oversaw the successful implementation of a Center-wide database which is a repository for information on the Center, its research, its people, and its impact. The development and launch were very challenging, but the AD provided strong leadership to make the database a reality. The former position of Communications Director has been split into two new positions reflecting the increased need for communication, event planning and administrative effort. It is expected that an additional staff position will be filled in the next year. A Sustainability Director was added during the reporting period. He has a strong fluid power industry background including 13 years at one of our member companies where he was also responsible for procuring grant funding for the business unit. A new Industrial Liaison Officer was also added during the reporting period. He has an extensive industry background and has played a leadership role in developing the Center's plan for sustainability beyond Year 10 and increasing the involvement of our industry partners. The Director meets biweekly with the Industrial Liaison Officer and Sustainability Director to maintain focus on issues including research strategy, industry membership and Center sustainability. A major new initiative from this group has been the hosting of three to four on-site IAB visits at CCEFP universities annually. This process has greatly improved communication between university researchers and industry. The Education Director communicates and strategizes with the Education and Outreach Director on education and outreach programs at all levels. They have increased engagement with the Student Leadership Council (SLC), and opened a channel of two way communications which provides student feedback to CCEFP management and helps facilitate the SLC's initiation and implementation of Center projects.

CCEFP is a complex, distributed multi-institutional organization. It is important to augment the leadership team with a group that has broader representation. The CCEFP is lead by the Executive Committee (EC). The Director is Chair of the EC and there is a representative from each member university, one SLC representative and four industry representatives. The EC meets at least three times a year, with additional meetings needed in the alternate years where the project renewal process is implemented. Responsibilities include defining and updating of the Center strategy, new project selection and progress tracking. Central to facilitating CCEFP internal communication and decision-making is the Management Committee and the Education and Outreach Network (EON). Each has at least one representative from each university. The Management Committee has responsibility for the day-to-day operation of the Center. The EON serves as both an advisory group for the Center's education and outreach projects as well as a facilitator for those programs that directly involve faculty and students (e.g., REU, RET, outreach, etc.).

The CCEFP multi-disciplinary research team has the depth and breadth of disciplines needed to achieved the CCEFP systems vision. The question of disciplinary composition must be considered carefully, since it is an important factor in determining CCEFP success. The QRC data system defines disciplines in terms of departments, but the two are not the same. A department is a university administrative entity. A discipline is a research entity where the members have a common background and understand and are aware of each other's work.

Table 2a (section 2.1) shows the CCEFP disciplinary composition as shown by the QRC data system. It can be seen that the majority of the faculty belong to mechanical engineering, with smaller numbers belonging to aeronautical engineering, agricultural and biological engineering, chemistry and industrial engineering.

The SLC updated its SWOT analysis in March 2012. The analysis and CCEFP leadership response are shown below.

<u>Y6 SLC SWOT</u>

Following the year 5 NSF site visit, the Student leadership Council (SLC) implemented many changes to its organization and operation based on feedback which came from the SWOT discussion. These changes included funding the SLC as an education and outreach project, reducing the number of representatives and officers to streamline the SLC structure, and refocusing the SLC as an integrator within the CCEFP. To achieve our new vision as an integrator several new programs were initiated, including an orientation program and travel grant fund.

For the year 6 SWOT analysis the SLC conducted a survey of current students to determine how they felt the strengths, weaknesses, opportunities, and threats have changed in light of changes within the SLC and throughout the Center. For each category students were asked to specify whether they strongly agreed or strongly disagreed with the items from the previous SWOT analysis using a 5 point scale (Strongly agree: 5, Agree: 4, Neutral: 3, Disagree: 2, Strongly disagree: 1). A few items were added to the list of characteristics to reflect changes in the Center. A breakdown of the response from each institution is shown in Fig. 1.

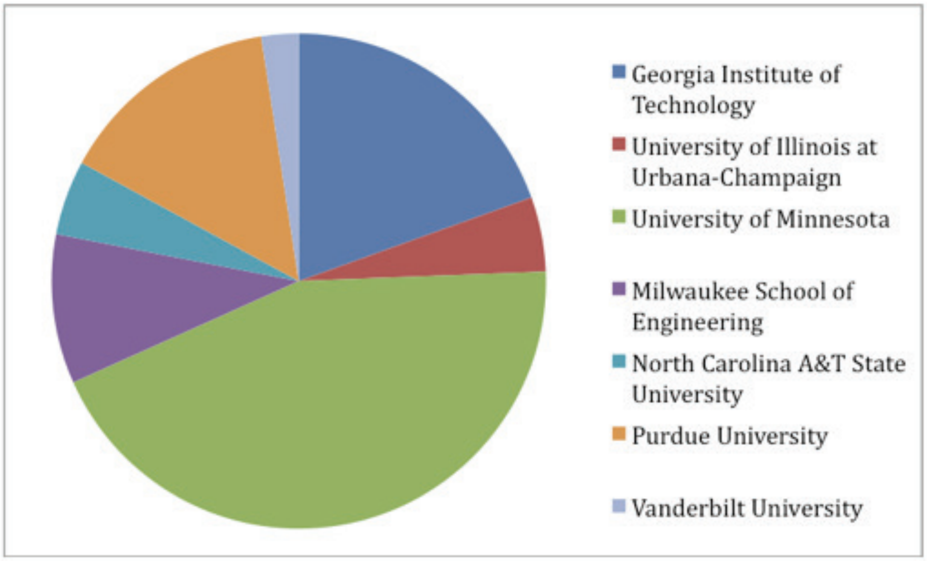


Figure 1: Demographic information of responses, 41 total

The results of the strengths analysis is shown in Fig. 2. From this data one can see that students feel the Center has maintained its strengths since the year 5 review and strongly agree that they are conducting multidisciplinary research that is impactful and meaningful. In addition, students agree that the REU program and the new travel grant program are also strengths of CCEFP. There is not as clear of a consensus for the new student orientation program which suggests that this program could be improved.

<u>CCEFP Response</u>: We are pleased the students recognize that the CCEFP multidisciplinary research is impactful and meaningful. We agree the *new* travel grant program and the REU program are worthwhile Center activities. We will work with the SLC to understand the shortcomings of the new student orientation program in order to improve it.

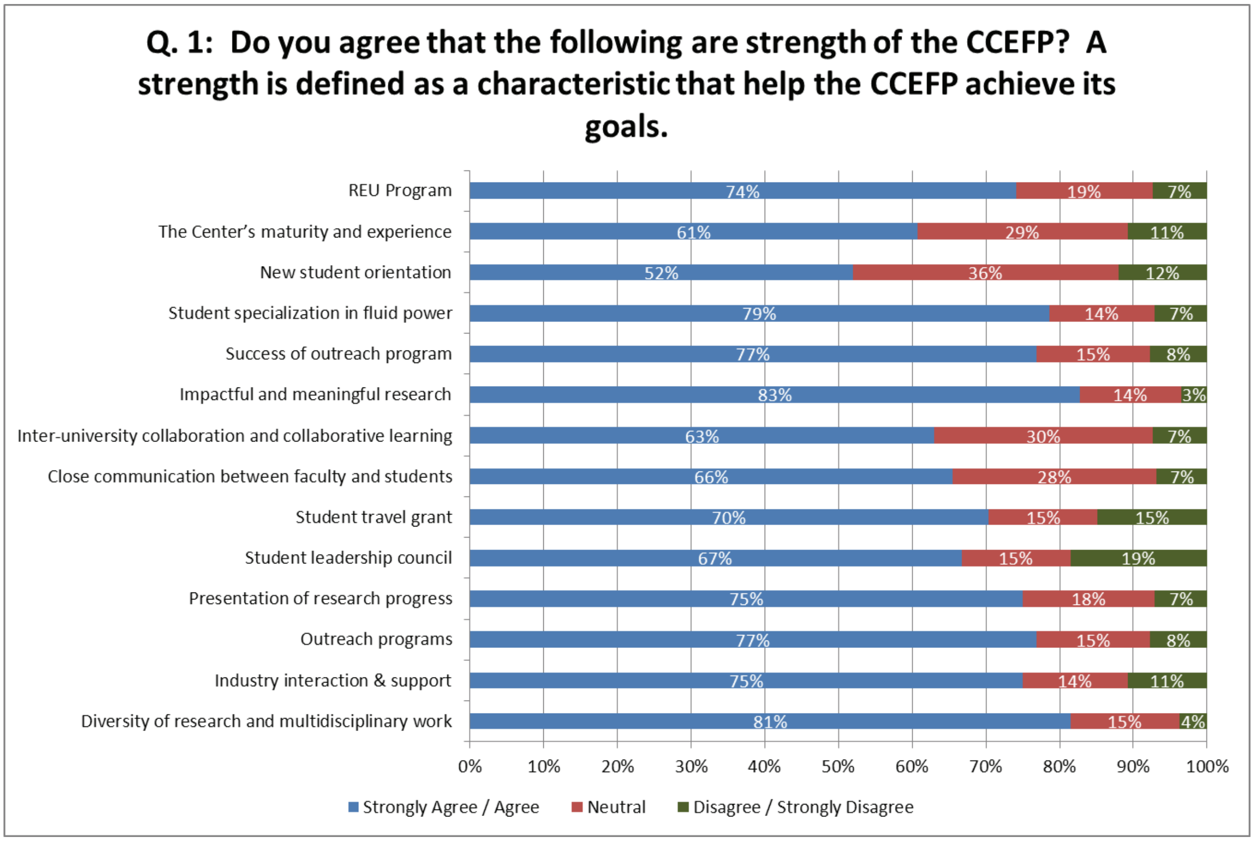


Figure 2: Student responses to Strength assessment of the CCEFP

From the weakness assessment shown in Fig. 3, one can see that students feel lack of communication and loss of interest or maintaining vision are no longer clear weaknesses of the Center. However, the isolation of physical resources within member institutions and a lack of student interest in participating on webcast for other projects were both identified as weaknesses of the Center. The CCEFP and the SLC have attempted to make the hardware resources within each University more available to other students through the travel grant program. Based on the student responses this program may need to be expanded in the future to better meet research needs. Also, it is clear that steps should be taken to encourage greater participation in webcast. This could be addressed by facilitating group viewing of webcast within each institution and providing greater incentives such as food.

CCEFP Response: It is critical that the Center has made strides to answer the former weakness assessment of communication. We appreciate the acknowledgement that we have addressed, in at least some part, the needs for better communication.
Based on our experience with the success of the first year of the travel grant program, we will consider expanding it in future years.

The Center is committed to reviewing the current webcast model for information dissemination. We agree the communal experience is more effective in technology transfer and collaboration across the Center. In exploring ways to improve the webcast program, we expect to vary the content of the presentations and speakers, ideally answering to the interests of both audiences - students, faculty and industry.

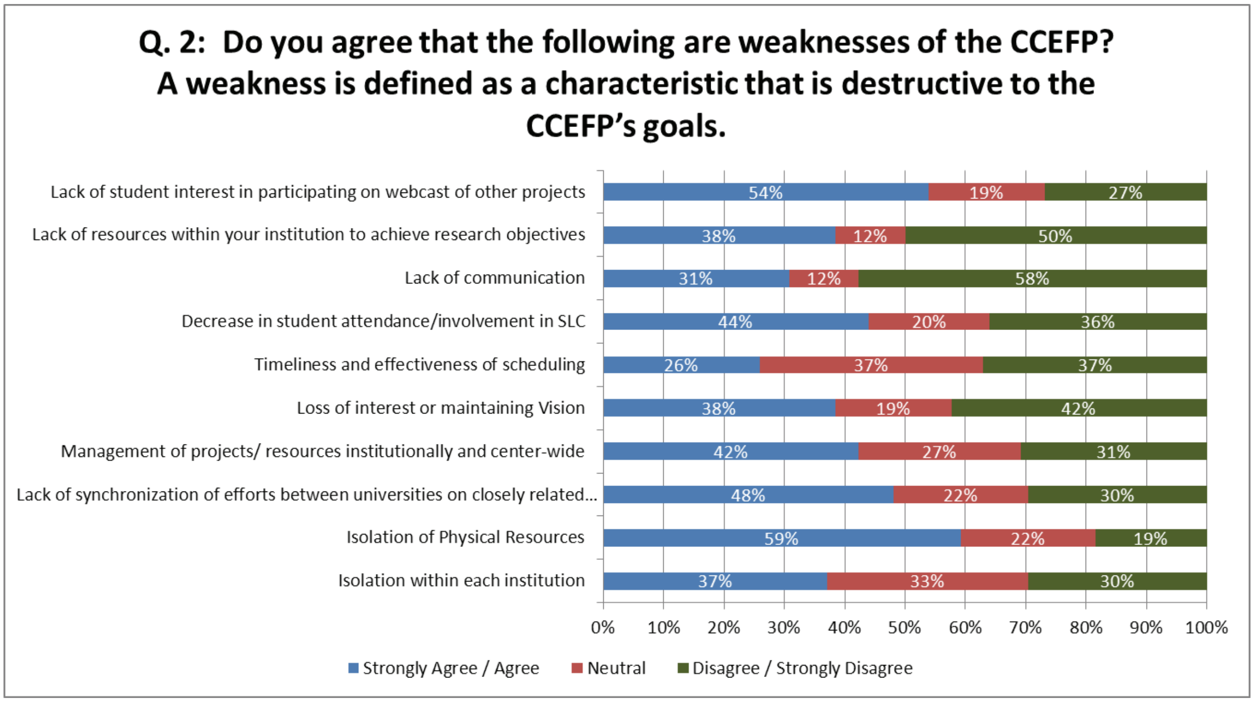


Figure 3: Student responses to Weakness assessment of the CCEFP

Students agreed with all of the characteristics identified as opportunities for the Center. For a list of characteristics and assessment results see Fig. 4. The characteristic which had the strongest agreement was the international fluid power community indicating that the Center should seek out opportunists to have students share their work with the global fluid power community.

CCEFP Response: It is true; the global fluid power community has a greater international presence than in the United States. The fluid power community is small in the US. We encourage international collaboration where possible. The CCEFP does promote participation in conferences for faculty and students alike. Examples of such meetings include the FPNI PhD Symposium, upcoming in Reggio Emilia, Italy, June 27-30, 2012. The FPNI PhD Symposium is specifically focused exclusively on student presentations. Secondly, the ASME Bath Symposium on Fluid Power and Motion Control, September 12-14, 2012. We agree that better communication about professional opportunities and encouragement to attend may influence participation. In future years, the CCEFP will consider supporting travel, perhaps as a special amendment to the SLC Travel Grant program. Also, in future years, there will be fewer CCEFP research projects which will allow greater funding availability for international travel opportunities. There are ways to collaborate beyond conferences as well. There is a high number of international students visiting institutions in the United States, but few American students visit international partners. There is surely an opportunity if a student was interested. We agree to help forge those connections to those who express a desire to travel.

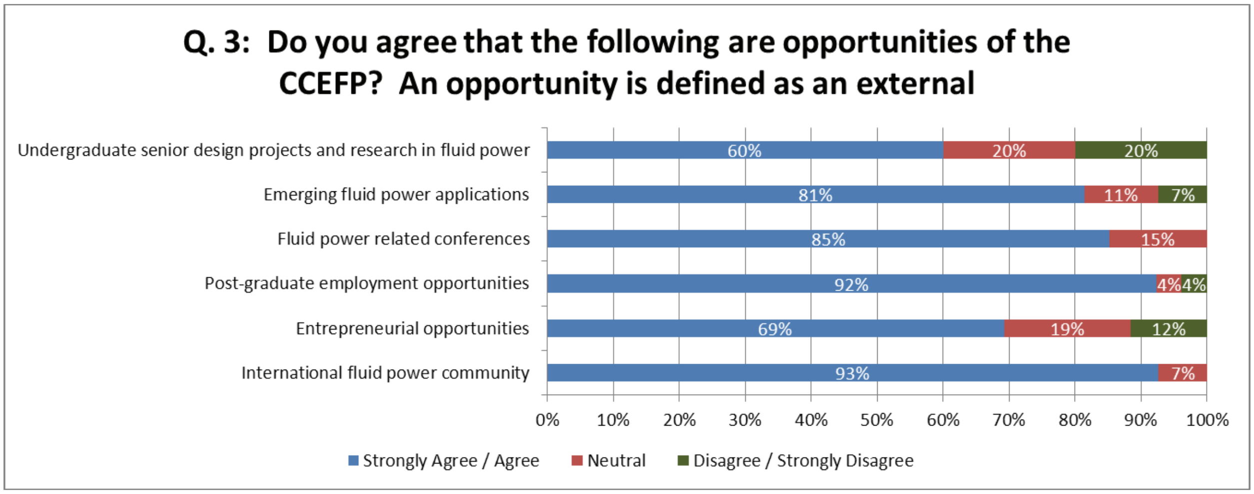


Figure 4: Student responses to Opportunity assessment of the CCEFP

Of the threats identified by the SLC, decrease in NSF financial support had the strongest overall agreement amongst students. This is not surprising as the sustainability of the Center is dependent upon bringing in additional resources and this is one of the major challenges faced by the CCEFP today.

CCEFP Response: We agree that sustainability is the greatest challenge of the CCEFP and we are working hard on a viable plan.

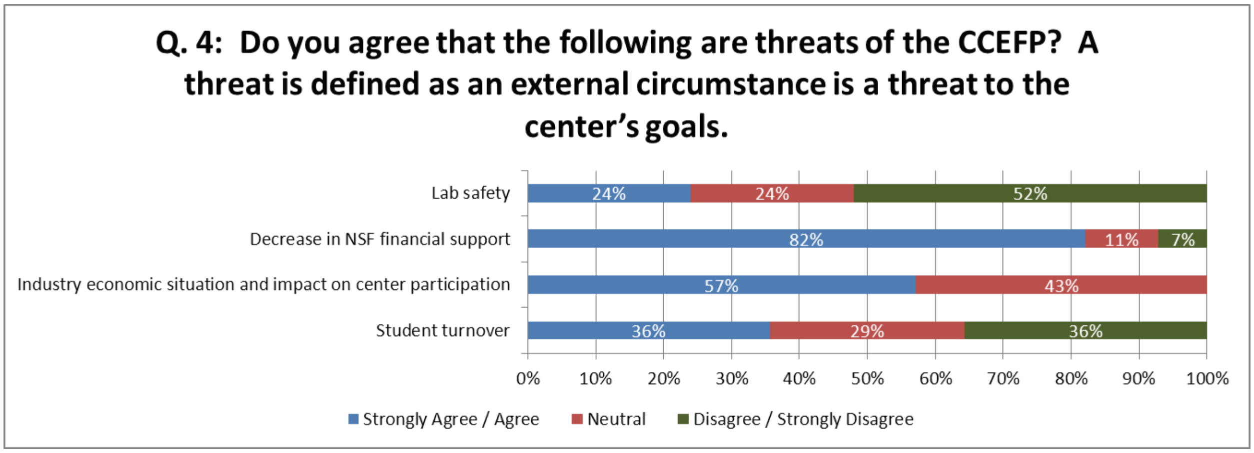


Figure 5: Student responses to Threat assessment of the CCEFP

Overall, the student assessment of the CCEFP is consistent with the expectations of the SLC and as the Center moves forward it is important that it continues to find ways to promote collaboration and integration within the Center and bring new companies and researchers into the Center.

CCEFP Response: We would like to thank the SLC for the thorough evaluation of the Center; we appreciate the recommendations. We commend the SLC for initiating the student-lead and student-focused projects under the Education and Outreach portfolio of the Center. The SLC has restructured themselves and it is evident in the proactive insight of the leadership and organization of the group. The Center also applauds the vision of its Officers, the cooperation of its Representatives as well as the entire CCEFP student body and deeply expresses our gratitude for helping us achieve our short and long-term goals.

Table 6: Institutions Executing the ERC's Research, Technology Transfer, and Education Programs

Institutions							Personnel in ERC Activities [1]								
Name and Type	Total	Female Serving	Minority Serving	HBCU	Hispanic Serving	Large Number of URM Students in Engineering	Faculty	Post Docs	Students				Teachers		Young Scholars
									UG Non-REU	REU	Graduate		Non-RET	RET	
											Masters	Doctoral			
I. Lead	**1**	**0**	**0**	**0**	**0**	**0**	**10**	**2**	**30**	**2**	**9**	**14**	**N/A**	**N/A**	**N/A**
University of Minnesota, Minneapolis, MN							10	2	30	2	9	14	N/A	N/A	N/A
II. Core Partners	**4**	**0**	**0**	**0**	**0**	**0**	**17**	**1**	**21**	**11**	**14**	**30**	**N/A**	**N/A**	**N/A**
Georgia Institute of Technology, Atlanta, GA							6	1	8	2	3	9	N/A	N/A	N/A
Purdue University, West Lafayette, IN							4	0	7	4	9	11	N/A	N/A	N/A
University of Illinois at Urbana-Champaign, Urbana, IL							3	0	4	3	1	6	N/A	N/A	N/A
Vanderbilt University, Nashville, TN							4	0	2	2	1	4	N/A	N/A	N/A
III. Collaborating Institutions	**16**	**0**	**1**	**0**	**0**	**1**	**8**	**0**	**50**	**5**	**6**	**8**	**N/A**	**N/A**	**N/A**
Bemidji State University, Bemidji, MN						✓	0	0	1	0	0	0	N/A	N/A	N/A
Case Western Reserve University, Cleveland, OH							0	0	1	0	0	0	N/A	N/A	N/A
Clarkson University, Potsdam, NY							0	0	1	0	0	0	N/A	N/A	N/A
Eolos Wind Energy Research Consortium, Minneapolis, MN							0	0	0	0	0	0	N/A	N/A	N/A
Hennepin Technical College, Brooklyn Park, MN							1	0	4	0	0	0	N/A	N/A	N/A
Michigan Technological University, Houghton, MI							0	0	1	0	0	0	N/A	N/A	N/A
Milwaukee School of Engineering, Milwaukee, WI							1	0	9	2	6	0	N/A	N/A	N/A
National Center for Earth-surface Dynamics, Minneapolis, MN							0	0	0	0	0	0	N/A	N/A	N/A
North Carolina Agriculture and Technical State University, Greensboro, NC			✓				4	0	3	3	0	8	N/A	N/A	N/A
Science Museum of Minnesota, St. Paul, MN							0	0	0	0	0	0	N/A	N/A	N/A
St. Cloud State University, St. Cloud, MN							0	0	4	0	0	0	N/A	N/A	N/A
STEM Education Center, Minneapolis, MN							2	0	0	0	0	0	N/A	N/A	N/A
University of Florida, Gainesville, FL							0	0	1	0	0	0	N/A	N/A	N/A
University of Minnesota - Morris, Morris, MN							0	0	17	0	0	0	N/A	N/A	N/A
University of Missouri-Columbia, Columbia, MO							0	0	2	0	0	0	N/A	N/A	N/A
University of North Dakota, Fargo, ND							0	0	6	0	0	0	N/A	N/A	N/A
IV. Non-ERC Institutions Providing REU Students	**9**	**1**	**1**	**0**	**3**	**4**	**N/A**	**N/A**	**N/A**	**10**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
Humboldt State University, Arcata, CA							N/A	N/A	N/A	1	N/A	N/A	N/A	N/A	N/A
Louisana State University, Baton Rouge, LA							N/A	N/A	N/A	1	N/A	N/A	N/A	N/A	N/A
Loyola University Chicago, Chicago, IL		✓					N/A	N/A	N/A	1	N/A	N/A	N/A	N/A	N/A
Minneapolis Community and Technical College, Minneapolis, MN						✓	N/A	N/A	N/A	1	N/A	N/A	N/A	N/A	N/A
New Mexico State University, Las Cruces, NM			✓		✓	✓	N/A	N/A	N/A	1	N/A	N/A	N/A	N/A	N/A
Princeton University, Princeton, NJ							N/A	N/A	N/A	2	N/A	N/A	N/A	N/A	N/A
Texas A and M University, College Station, TX					✓	✓	N/A	N/A	N/A	1	N/A	N/A	N/A	N/A	N/A
University of Texas at El Paso, El Paso, TX					✓	✓	N/A	N/A	N/A	1	N/A	N/A	N/A	N/A	N/A
Yale University, New Haven, CT							N/A	N/A	N/A	1	N/A	N/A	N/A	N/A	N/A

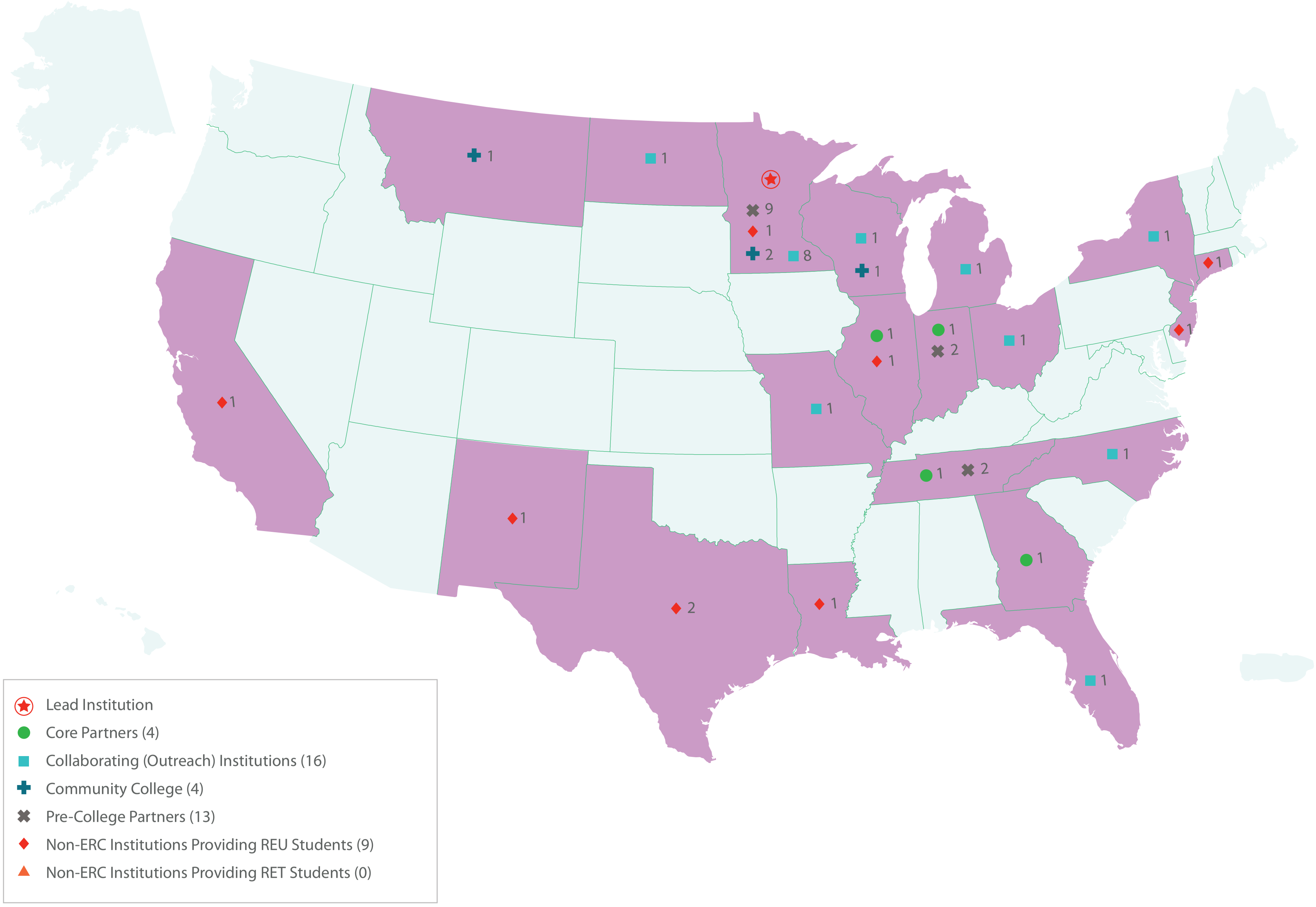
Table 6: Institutions Executing the ERC’s Research, Technology Transfer, and Education Programs

	Institutions						Personnel in ERC Activities [1]								
V. NSF Diversity Program Awardees	**5**	**0**	**0**	**0**	**0**	**3**	**0**	**0**	**40**	**0**	**0**	**0**	**N/A**	**N/A**	**N/A**
Alliances for Graduate Education and the Professoriate (AGEP)	**1**	**0**	**0**	**0**	**0**	**0**	**N/A**	**N/A**	**0**	**0**	**0**	**0**	**N/A**	**N/A**	**N/A**
AGEP: FACES							N/A	N/A	0	0	0	0	N/A	N/A	N/A
Centers of Research Excellence in Science and Technology (CREST)	**0**	**0**	**0**	**0**	**0**	**0**	**N/A**	**N/A**	**0**	**0**	**0**	**0**	**N/A**	**N/A**	**N/A**
No CREST institutions were entered.															
Louis Stokes Alliances for Minority Participation (LSAMP)	**2**	**0**	**0**	**0**	**0**	**1**	**N/A**	**N/A**	**25**	**0**	**0**	**0**	**N/A**	**N/A**	**N/A**
North Star STEM Alliance							N/A	N/A	23	0	0	0	N/A	N/A	N/A
The All Nations Louis Stokes Alliance for Minority Participation						✓	N/A	N/A	2	0	0	0	N/A	N/A	N/A
Tribal Colleges and Universities Program (TCUP)	**1**	**0**	**0**	**0**	**0**	**1**	**N/A**	**N/A**	**15**	**0**	**0**	**0**	**N/A**	**N/A**	**N/A**
New Baccalaureate Degrees and STEM Program Improvement at Salish Kootenai College						✓	N/A	N/A	15	0	0	0	N/A	N/A	N/A
NSF Diversity Program Collaborations (NSF Diversity Program Collaborations)	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**N/A**	**N/A**	**N/A**
Northstar STEM Program						✓	0	0	0	0	0	0	N/A	N/A	N/A
VI. Precollege Partners	**13**	**0**	**5**	**0**	**0**	**1**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**15**	**6**	**0**
Brentwood High School, Brentwood, TN							N/A	N/A	N/A	N/A	N/A	N/A	0	1	0
Circle of Life School, White Earth, MN			✓				N/A	N/A	N/A	N/A	N/A	N/A	2	0	0
Cloquet High School, Cloquet, MN							N/A	N/A	N/A	N/A	N/A	N/A	1	0	0
Gibbon, Fairfax, Winthrop School, Gibbon, MN							N/A	N/A	N/A	N/A	N/A	N/A	0	1	0
Independence High School, Thompson Station, TN							N/A	N/A	N/A	N/A	N/A	N/A	0	1	0
KidWind, Saint Paul, MN							N/A	N/A	N/A	N/A	N/A	N/A	2	0	0
Mahtomedi High School, Mahtomedi, MN							N/A	N/A	N/A	N/A	N/A	N/A	1	1	0
McCutcheon High School, Lafayette, IN							N/A	N/A	N/A	N/A	N/A	N/A	0	1	0
Ojibwe School, Cloquet, MN			✓				N/A	N/A	N/A	N/A	N/A	N/A	2	0	0
Ponemah Elementary School, Ponemah, MN			✓				N/A	N/A	N/A	N/A	N/A	N/A	1	0	0
Red Lake Middle School, Red Lake, MN			✓				N/A	N/A	N/A	N/A	N/A	N/A	1	0	0
South Ridge School (formerly Albrook School), Culver, MN			✓			✓	N/A	N/A	N/A	N/A	N/A	N/A	5	0	0
Tippecanoe School Corporation, Lafeyette, IN							N/A	N/A	N/A	N/A	N/A	N/A	0	1	0
VII. Community Colleges	**4**	**0**	**4**	**0**	**0**	**2**	**2**	**0**	**22**	**0**	**0**	**0**	**N/A**	**N/A**	**N/A**
Fond du Lac Tribal and Community College, Cloquet, MN			✓			✓	0	0	2	0	0	0	N/A	N/A	N/A
Lac Courte Oreilles Ojibwa Community College, Hayward, WI			✓				0	0	2	0	0	0	N/A	N/A	N/A
Leech Lake Tribal College, Leech Lake, MN			✓			✓	1	0	3	0	0	0	N/A	N/A	N/A
Salish Kootenai College, Pablo, MT			✓				1	0	15	0	0	0	N/A	N/A	N/A
Total	**52**	**1**	**11**	**0**	**3**	**11**	**37**	**3**	**163**	**28**	**29**	**52**	**15**	**6**	**0**

[1] - Only ERC personnel executing the ERC mission are shown in this table.

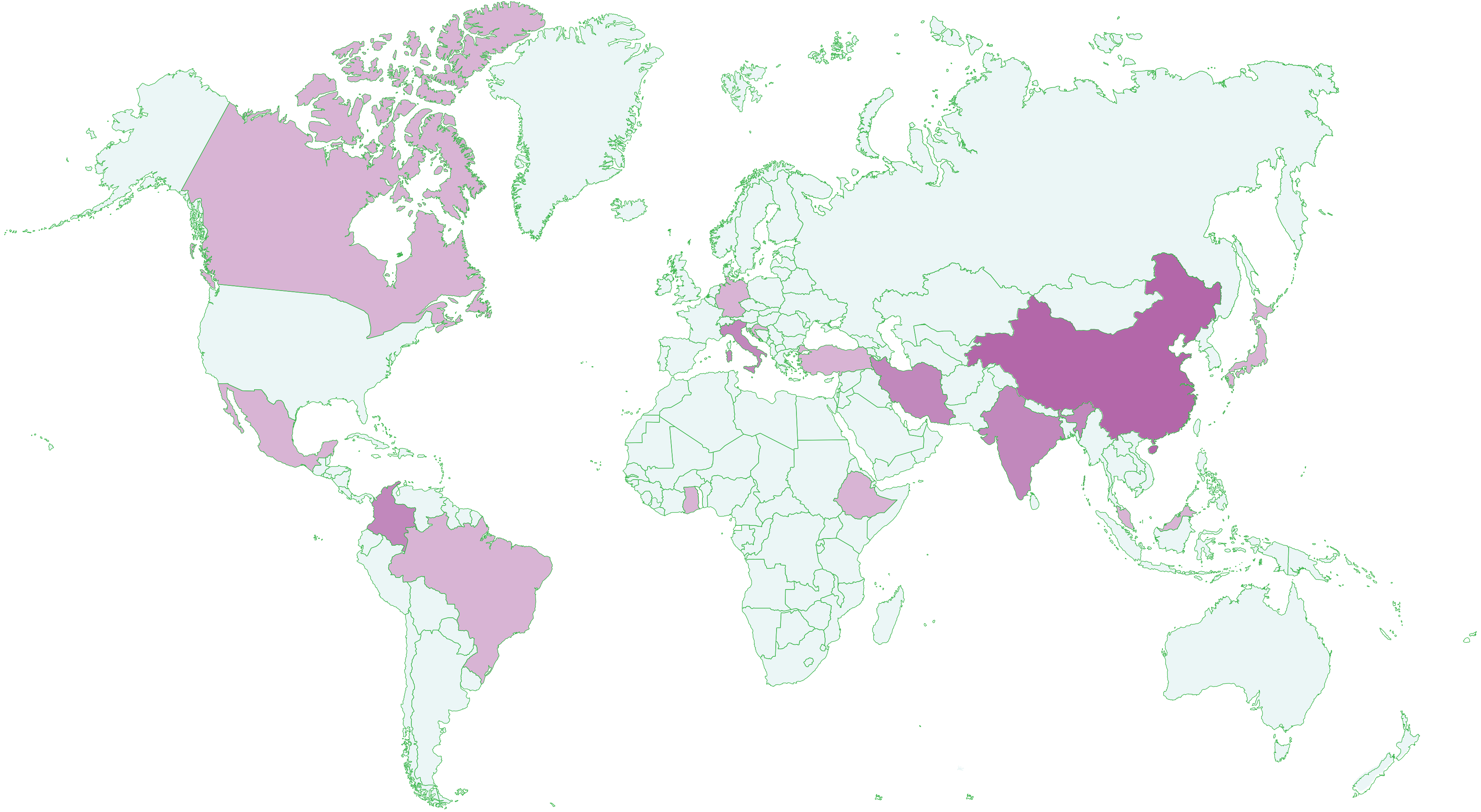
6a

Location of Lead, Core Partner, and All Domestic Collaborating Institutions



6c

Country of Citizenship for ERC Foreign Personnel



👤 = Number of ERC personnel from this country

- 🟪 1 person
- 🟪 2–10 people
- 🟪 11+ people

1 person 👤	
Brazil	Ghana
Canada	Japan
Croatia	Malaysia
Ethiopia	Mexico
Germany	Turkey

2–10 people	👤
Colombia	2
India	6
Iran	2
Italy	3

11+ people	👤
China	13

	👤
Country Not Reported	0*

* Number of ERC personnel who are foreign and did not provide a country name

5.2 DIVERSITY EFFORT AND IMPACT

The Center for Compact and Efficient Fluid Power has an active and diverse research and educational agenda, directed from its headquarters, amplified through its seven academic institutions, and extended through its partnerships in the education and outreach communities. Projects and programs on this agenda emphasize efforts to increase diversity throughout the Center, in the fluid power industry, and among students of all ages engaged in STEM-related initiatives.

The Center's Diversity Program: Goals and Mission

A CCEFP-stated goal calls for an increase in the diversity of students, faculty, fluid power industry practitioners, and those involved in STEM-relevant studies. A Center-led mission is to assure that individuals in each of these groups reflect the gender, racial and ethnic composition of the country. In its sixth year, the CCEFP has continued to see sustainability in the engagement of women and those of racially diverse backgrounds in Center activities. The Center does recognize its challenge in engaging U.S. citizens who are ethnically diverse as well as persons with disabilities. We continue to work to assure similar opportunities for those who are recent war veterans.

The Center's Approach

We strive to reach these outcomes through a variety of approaches. Key among them are:

- Work and support efforts at partner schools and other ERCs to recruit and fund underrepresented students in CCEFP-related undergraduate and graduate research. This includes building relationships with outreach and diversity offices across partner institutions as well as others nationwide to bridge learning and teaching opportunities. Such partners include the National Society for Black Engineers (NSBE); Society of Women Engineers (SWE); the Society of Hispanic Professional Engineers (SHPE); SACNAS (Society Devoted to Hispanics, Chicanos and Native Americans in the Sciences); American Indian Science and Engineering Society (AISES); and the Louis Stokes' Alliances for Minority Participation (LSAMP).
- Develop an innovative relationship between Engineering Research Centers and the National GEM Consortium, a well-established and highly regarded program aimed at increasing the participation of underrepresented groups.
- Develop a large and vigorous Research Experiences for Undergraduates (REU) Program to bring highly-qualified underrepresented students from across the country to CCEFP universities for summer research.
- Develop a dynamic Fluid Power Scholars Program to bring highly-qualified underrepresented students from across the country to CCEFP industrial members for summer internships.
- Develop an award program following the NSF Graduate Research Diversity Supplement model: CCEFP Undergraduate Research Diversity Supplement (URDS) award for CCEFP faculty who recruit and retain underrepresented students in engineering.
- Continue to leverage funding and support from the NSF Graduate Research Diversity Supplement proposal.
- In order to build a strong recruiting network for Center-wide programs, one that insures widespread awareness of opportunities within the CCEFP and the fluid power industry itself, establish relationships with engineering faculty across the country in ABET-accredited colleges and universities, with an emphasis on those in minority-serving institutions and those engaged in fluid power and related engineering curricula.
- Through the Center's cooperative efforts with Project Lead The Way and its Research Experiences for Teachers (RET) Program, develop new understandings of scientific research and fluid power technology among a growing number of teachers who can, in turn, impact students in schools across the country. Because of their CCEFP experiences, these teachers can take lead roles in developing and teaching curriculum modules that are STEM-oriented, using examples from fluid power where appropriate, and encouraging their colleagues to do the same.
- In collaboration with local communities and the Fond du Lac Tribal and Community College, increase the number of Native Americans in engineering professions through support of Native

American undergraduate and youth STEM enrichment programs. These include weekend and summer camps, a robotics curriculum, and local, regional and national science fairs.

- Facilitate a partnership between the American Indian Science and Engineering Society (AISES) and the Northstar STEM LSAMP Alliance in order to bring academic, research and industrial opportunities to Native American undergraduate students in STEM fields throughout Minnesota.
- Identify new partners to work with in implementing this agenda. As an example, see the account of the CCEFP's new partnership with BRIDGE (Project B5.) and Innovative Engineers (Project C.11).

Our Progress

The Center recognizes opportunities to expand upon the recruitment, retention and participation of underrepresented students—women, racial and ethnic minorities, persons with disabilities, and recent war veterans—by creating more research and educational opportunities within the Center as these students consider study and career choices in mechanical engineering and fluid power. With successes and lessons learned from Years 1 - 5, the CCEFP continued efforts in Year 6 to engage individuals within each of these underrepresented groups in its programs.

Though there are instances of success, other results are frankly disappointing, but we believe only in the short term. There is promise that the CCEFP programs and activities--new and newly enhanced--will bring long-term improvements given that the early stages of redesign and launch are behind us. Program highlights and activities, many of which address feedback from the Site Visit Team in Year 5, are described below.

- GEM: CCEFP is exploring a novel interface between the NSF ERCs, the Industry Members of ERCs, and the National GEM Consortium, a well-established and highly regarded program aimed at increasing the participation of underrepresented groups (African Americans, American Indians, and Hispanic Americans) at the undergraduate, master's and doctoral levels in engineering and science. Currently, partnerships exist between ERCs and Industry, between GEM and Industry, and between GEM and ERCs. The unique concept here is a partnership that leverages each organization to work in collaboration with each other--an ERC-GEM-Industry partnership. The CCEFP is taking the initial and exploratory role in determining just what this partnership might look like. Currently, GEM is preparing a strategic selling plan and participated as a guest speaker at the NSF ERC Annual Meeting in December 2011. A proposed ERC-GEM membership structure will be determined by the end of Year 6.
- NSF Graduate Research Diversity Supplement (GRDS): The Center has successfully received funding for two consecutive years to support two women in the field of engineering with an emphasis in fluid power research--one at the University of Minnesota and the other at the University of Illinois, Urbana-Champaign--under the NSF Graduate Research Diversity Supplement. The Center has recently received a third year of funding to continue to support the UIUC PhD student and to fund a new PhD candidate, an African American woman, at Vanderbilt University.
- CCEFP Undergraduates Research Diversity Supplement (URDS): In Year 6, the CCEFP has launched an academic year URDS program for students with diverse ethnic, racial, gender, economic and educational backgrounds. The CCEFP is enlisting faculty across the Center as well as local student groups such as SWE (Society for Women Engineers), SHPE (Society for Hispanic Professional Engineers), SACNAS (Society Devoted to Advancing Hispanics, Chicanos and Native Americans in the Sciences), AISES (American Indians Science and Engineering Society), NSBE (National Society of Black Engineers), NSF LSAMP programs as well as local CCEFP diversity offices to recruit undergraduate students into the Center's research laboratories. To date, the program has sponsored two new diverse students to the CCEFP, a Caucasian female at the University of Illinois, Urbana-Champaign, and an African American female at North

Carolina A&T State University both working on research projects related to Test bed 6 Fluid Power Orthosis.

- CCEFP's Research Experiences for Undergraduates (REU): This program has traditionally been very successful in recruiting diverse participants, in race, ethnicity and/or gender. Since revising the CCEFP REU program structure in 2008, the CCEFP REU Program has recruited, on average, over 35% women, and over 30% racially or ethnically underrepresented students into the program on a yearly basis. The CCEFP's recruiting strategy includes identifying institutions, programs and people with whom to develop relationships that, in turn, open pathways to CCEFP summer programs and beyond for underrepresented students. (Note: The CCEFP applied for an REU Site award in the recent 2011 solicitation, following very positive feedback from the 2010 proposal.)
- The CCEFP has recently initiated a formal partnership with Larry Villasmil, a faculty member at Rochester Institute of Technology (RIT), who has committed to helping the CCEFP recruit underrepresented students (Hispanic students in particular), as well as students with disabilities. RIT is home to the National Technical Institute for the Deaf (NTID) and is the world's largest technical college for deaf and hard of hearing students. As the program builds, so does the recruiting network.
- Distance learning: The CCEFP aims to launch a distance education course "Introduction to Engineering Design" at Fond du Lac Tribal and Community College (FDLTCC) in the Fall of 2013 for interested undergraduates and local post-secondary high school students. The vision is to design a pre-engineering program or certificate for FDLTCC students and to expand this package of STEM courses into other tribal colleges in and around the State of Minnesota.
- AISES:
    - CCEFP's giiwed'anang North Star AISES (American Indian in Science and Engineering Society) Alliance is sponsoring its second First Nations Rocket Launch Competition in cooperation with the Minnesota NASA Space Consortium for AISES Chapters at the University of Minnesota and Fond du Lac Tribal and Community College (FDLTCC).
    - In 2011, the CCEFP recruited five engineering students from UMN to AISES and the rocket project. CCEFP previously supported two engineering and two pre-engineering students in 2010.
    - CCEFP has recruited one AISES mechanical engineering junior, Mr. John Carlson, to conduct wind power research in the CCEFP during the academic year, funded in the NSF North Star STEM LSAMP Program.
    - Other AISES engineering students are actively leading fluid power outreach activities.
- ERC Exhibitor Booth: CCEFP again took the lead in organizing an ERC exhibitor booth at both AISES and SACNAS in the fall of 2011. The idea has gained momentum and other ERCs are now making plans to attend NSBE, SHPE, and others, as NSF ERC representatives.
- Innovative Engineers (IE): The CCEFP is now a partner of the University of Minnesota's Innovative Engineers (innovative-engineers.org) student organization which is focused on getting renewable energy into the hands of third world communities.
    - A significant number of members are part of NSBE (National Society of Black Engineers), AISES (American Indian in Science and Engineering Society) and SHPE (Society of Hispanic Professional Engineers) student organizations. Innovative Engineers will be leveraging CCEFP research into its outreach technologies in developing nations. The IE students will be implementing the CCEFP's open accumulator in the wind turbine, built by hand, which will be installed in the small village of La Hermita, Nicaragua. CCEFP's Education Director, Professor Paul Imbertson, is the IE Chapter Advisor.
    - An IE undergraduate student, taking the senior Fluid Power Laboratory taught by Professor Kim Stelson, is now working on a CCEFP research project related to the

hydrostatic transmission as part of a UMN Undergraduate Research Opportunity Program (UROP) experience.

Table 7a indicates the percentage of the Center's diversity statistics in comparison to the National Engineering Average data and averages data within other ERCs. Line by line, the CCEFP tells a promising story. Following are added details.

- The American Society for Engineering Education [ASEE] "Engineering By the Numbers" reports that 11.4% of women earn a bachelor degree in mechanical engineering, and of all undergraduate engineering degrees, 4.7% are African American students and 6.5% are Hispanic/Latino students. Similarly, of those students who pursue a Master's degree in mechanical engineering, 14.7% are women, 4.8% are African American and 5.4% are Hispanic in all engineering fields. As you will see in the Table 7a, the CCEFP's data indicates that we compare favorably with these national engineering percentages.
- According to Table 7a, it is clear that the Center for Compact and Efficient Fluid Power is impacting underrepresented populations when compared to the national engineering averages.
    - As in previous years, in 2011, the Center continues to demonstrate a strong representation of women by matching or exceeding national averages at the undergraduate, REU and faculty level. The percentage of women in CCEFP doctoral and masters programs remains average, although, as previously noted, mechanical engineering typically serves the smallest percentage of females. Sustaining the positive numbers of women across the Center is critical.
    - Representation of women, persons with disabilities and ethnic and racial minorities within the CCEFP faculty continues to exceed, or at minimum, equal national averages. We are hopeful for additional diverse faculty hires which has happened in small increments due to the poor economy.
    - The Center has experienced sustained improvement in the number of underrepresented racial minorities, well above the national averages in all categories of academic participants. Underrepresented racial minorities make up over 15% of CCEFP faculty, over 18% of doctoral candidates and over 60% of undergraduates (non-REU), while 31% of REU students represent racial minorities.
    - The CCEFP has made it a priority to enhance its recruitment of Hispanic/Latino/a participants while increasing Center mentorship opportunities. As a result, there have been some advancements, although the Center has experienced a decrease in the number of Hispanic/Latino/a students in the recent reporting year. The Center will continue to focus new efforts on undergraduate recruitment from institutions with significant numbers of Hispanic/Latino/a students.
    - Participation by persons with disabilities continues to hover at national averages. The Center will continue to not only utilize by also identify new resources, organizations and affiliations where CCEFP program information can be disseminated and also through which students with disabilities can be reached.
- The Center's diversity strategy continues to focus on building a network of recruiting partners across the country. The strategy starts with identifying key colleges and universities, including ABET-accredited programs and minority-serving institutions (including 2-year and 4-year) with engineering or related academic paths. Once the primary institution is identified, the next step is to locate programs or people within the organization whose focus is directly related to providing student services, including support, to under-served populations. A third step aims at identifying and making connections with individuals within a specific program or teaching specialty who have demonstrated interests in mechanical engineering, fluid power research and applications. The e-relationships built upon this strategy tend to generate positive outcomes for student recruitment and relationship retention. In the recent reporting year, the Center expanded its networking database by ⅓, over 750 unique contacts.
- The outreach efforts of the CCEFP report a significant representation of diverse populations in programs across the Center. The REU and URDS programs have served as effective and influential tools in recruiting underrepresented students for research within the CCEFP, as well as in developing a strong and diverse network of contacts within schools outside of the Center.

- The Fluid Power Scholars Program holds promise here, too. The CCEFP will continue to recruit underrepresented, diverse students to its database of applicants for this program. Note that industry is ultimately responsible for a given year's demographics since each mentoring company select its intern(s) from this pool.
- The Center maintains a formal relationship with the North Star STEM Alliance, an NSF LSAMP Program headquartered at the University of Minnesota that includes 16 partner institutions across the state. The North Star STEM Alliance fully supports the activities of the giiwed'anang North Star Alliance (Project C.5) and considers this program an official undergraduate activity for Native American students in the LSAMP. This partnership includes recruiting efforts; disseminating information about academic, research and internship opportunities; providing resources for conferences and relevant meetings and offering support to North Star STEM Alliance student fellows and scholars. As subsequent charts indicate, these efforts are yielding positive outcomes.

Partners for Diversity

There is appreciation throughout the Center of the importance of individual efforts as well as partnerships in fulfilling an overarching goal of the CCEFP: increasing the diversity of students and practitioners in STEM-related study and in fluid power research and the industry it serves. The Center recognizes that the research and educational opportunities led and funded by the Center provide key pathways for reaching this goal.

Pre-College: An essential part of the CCEFP strategic plan is to promote the study of science, technology, engineering, and math (STEM), and to encourage a diverse group of young students to enter these fields. A special focus in these efforts lies in Center-supported work to increase the number of Native Americans choosing STEM-related study tracks through its gidaa STEM and robotics programs. For now, the CCEFP's Native American programs are centered at the University of Minnesota because of the large number of tribal colleges in the upper Midwest as well as the large population of Native Americans in Minnesota and its surrounding states. In these initiatives, the Center envisions that project successes will be duplicated within larger networks. At the national level, the Center's partnership with Project Lead The Way (PLTW), and its work with the Science Museum of Minnesota (SMM), a recognized leader in museum-based education, support STEM initiatives that involve diverse student populations. Years 3 - 5 marked progress in developing fluid power content for selected PLTW courses and in creating the prototype of a pneumatics workshop that can be used by many students including FIRST Robotics teams. In year 6, our focus is on helping teachers to effectively understand and teach this content. Further, our partnership with PLTW and our RET program continues; several RETs are also PLTW teachers, five in 2009, three in 2010, four in 2011.

College: At the university level, the Center continues to build the communications and database networks needed in recruiting undergraduate and graduate students, faculty and researchers from a diverse population. To accomplish this, the Center has identified key schools and programs at institutions that cater specifically to these target populations, creating formal and informal relationships that will support recruitment efforts. The Center is also driving its diversity and recruiting efforts by developing formal alliances and collaborations among several other National Science Foundation-funded organizations and with professional and national organizations. The CCEFP's outreach database grew to over 750 direct and unique contacts.

At the grass-roots level: members of the Center's Education Outreach Network help in recruiting within their universities. The Center has also formed partnerships for outreach programs that are led by its seven partner institutions. In casting this wider net, both the Center's website and its presence on Internet job boards (for its Fluid Power Scholars and REU programs) inform and promote the work of the CCEFP, thereby extending its outreach opportunities.

Within the Center network: The Center works through the various student-centered organizations, including the diversity, LSAMP and diversity programs of its collaborating institutions. CCEFP also works with associated Deans and Department Chairs to increase diversity through faculty hiring.

Major Initiatives
Every research and every education project at every CCEFP institution is committed to actively recruiting underrepresented and minority students to participate as the following examples illustrate.

Research Experiences for Undergraduates - REU (Project C.1)
REU is an NSF program whose purpose is to provide undergraduate STEM students with a summer experience in a university research lab. An objective of the program is to increase the number of top students, reflecting the racial, ethnic and gender composition of our country, who attend graduate schools in STEM areas. Every summer the CCEFP hosts an average of 15 REU students. Within this total, the number of participants from outside the Center's network should be greater than the number of students admitted from its seven universities. The CCEFP's REU students begin the summer with a Fluid Power Bootcamp and instruction in fluid power technology, its applications and the research activities of the CCEFP. Continuing interaction among CCEFP REU students at the seven sites occurs weekly during the summer through a research blog where REU students submit descriptions and updates of their own research activities. The CCEFP actively recruits underrepresented students in STEM including racial and ethnic minorities, women, persons with disabilities and recent war veterans for its REU program.

Y6 Outcomes:

Research Experiences for Undergraduates	2011	TOTAL (Y2-Y6)
Number of Students	18	107
Male	11	70
Female	7	37
Percentage of diverse students 1) racial minority 2) gender minority 3) disability	 1) 27% 2) 38% 3) 1%	 1) 31% 2) 35% 3) .01%

Fluid Power Scholars Program (Project D.1)
As interns, students gain hands-on experience in fluid power technology. Companies hosting interns benefit, too, as students bring fresh insights learned in the classroom. Recognizing these benefits, the CCEFP has enhanced the traditional internship model by adding an intensive orientation to fluid power at the outset of the internship experience in order to expedite knowledge transfer while enabling student interns to make more immediate and effective contributions to their host companies. This program was launched in 2010. (Note that host companies select their scholar/interns from a pool of applicants recruited by the CCEFP.)

Y6 Outcomes:

Fluid Power Scholars	2011	TOTAL
Number of Students	8	16
Male	8	14
Female	0	2
Percentage of students from underrepresented groups 1) racial minority 2) gender minority 3) disability	 1) 0% 2) 0% 3) 0%	 1) 13% 2) 25% 3) 0%

NEW **Undergraduate and Graduate Research Diversity (URDS and GRDS) Supplement** (Project C.9 and C.10)
Recognizing the need for additional programs to strengthen its efforts to recruit and retain a diverse student population, the CCEFP launched two new programs in year 6. The short and long-term goals of these programs are: 1) to provide CCEFP faculty with the means to involve additional graduate students on CCEFP research projects; 2) to identify a graduate student who might not otherwise consider a research opportunity in CCEFP laboratories; 3) to encourage students to consider graduate study or an employment position in the fluid power industry by fostering a learning and career advancement

environment; 4) to further provide exposure to fluid power technology to a diverse audience; 5) to answer the country's need of greater retention of underrepresented students in engineering.

Y6 Outcomes:

Undergraduate and Graduate Research Diversity Supplement	2011	TOTAL
Number of Students	4	6
Male	0	0
Female	4	6
Percentage of students from underrepresented groups 1) racial minority 2) gender minority 3) disability	1) 25% 2) 100% 3) 0%	1) 16% 2) 100% 3) 0%

Research Experiences for Teachers (Project B.1)
RET is an NSF program whose purpose is to improve science, technology, engineering and mathematics (STEM) education in schools by funding high school teachers to spend the summer in a university research lab. During that time, participating teachers complete a research project and develop curriculum to be used in their classes. Every summer the CCEFP hosts at least six RET teachers at at least three CCEFP universities. A special CCEFP RET focus is recruiting teachers from area high schools participating in the PLTW program.

Y6 Outcomes:

Research Experiences for Teachers	2011	TOTAL
Number of Teachers	6	36*
Male	6	30
Female	0	6
% from underrepresented groups	0%	19%
% PLTW Teachers	67%	47%

**Several repeat participants*

gidaa STEM Programs (Projects B.4, B.4a, B.4b)
CCEFP, Fond du Lac Tribal and Community College (FDLTCC), together with the National Center for Earth-surface Dynamics (NCED) organize programs in the Cloquet, Minnesota region that is home to the Fond du Lac Indian Reservation. Camps for K-12 Native students originally known as *gidakiimanaaniwigamig* (Our Earth Lodge, in Anishinaabe) have been held on a regular seasonal basis since *gidaa's* inception in 2003. Since then the "*gidaa*" program has taken on a life of its own to include programs that bridge several federally funded organizations. *gidakiimanaaniwigamig* is committed to engaging Native American students as they work towards their high school graduation while helping them to prepare for their post-secondary education in the areas of science, engineering, technology and mathematics (STEM). Since its first year, the Center has co-sponsored the gidaa STEM Programs which annually brings over 150 youth from local middle and high schools to Native American math and science camps and also engages them in after-school and weekend programs and science fairs. These programs provide students with a mix of lab science and field science experiences. Program highlights include an introduction to scientific methods coupled with a focus on Native American culture. During each camp, the CCEFP presents a workshop on hydraulic and pneumatic principles based on fundamental math, science and physics. Students have hands-on opportunities to test these principles by using a variety of curricula designed by either the CCEFP or gidaa teachers. The same consortium offers a *gidaa odaangiina anaangoog Robotics Program*, which introduces an even greater number of students to basic principles of engineering and related disciplines.

Outcomes:

gidaa STEM Camps		
1. Number of Native American K-12 Students participating in gidaa STEM Camps (*since its inception in 2003 by NCED, joint partnership with CCEFP initiated in 2006*)	Number of students	397
2. Repeat contacts with students	1 Camp	32
	2 Camps	45
	3 Camps	42
	4 Camps	25
	5+ Camps	76

Outcomes:
gidaa students Competing in Local and National Science Fairs

Year	Total gidaa Native American Regional Science Fair entrants	Attended NAISEF	Medals and awards won at NAISEF	NAISEF Grand Award winners sent to compete at Intel ISEF
2005	35	8	7	3
2006	42	16	20	2
2007	46	16	20	1
2008	68	15	30	2
2009	55	13	24	4
2010	58	8	15	2
2011	82	6	15	4

gidaa odaangiina anaangoog (Shooting for the Stars) Robotics Program (Project B.4c) Under the *gidaa* STEM Program umbrella, staff and teachers have drawn on lessons learned through FIRST robotics and introduced K-12 robotics day and after-school curricula using Lego Wedo-Webots, NXT Kits, Vex Kits and Textrix kits and software. The *odaangiina anaangoog* Shooting for the Stars Robotics Program enables students in and around Cloquet, Minnesota to use concrete learning experiences with robotics to better understand physics concepts; develop mathematical thinking, problem solving, and programming skills; and participate in team-building through hands-on construction engineering. This program currently engages challenged students at the elementary, middle and high school levels. A college-level robotics course at Fond du Lac Tribal and Community College is in its third year. Ideally, graduates of *gidaa* and the *gidaa odaangiina anaangoog* Robotics Program will continue their education either at a community college or a four-year university, joining the *giiwed'anang* North Star Alliance (Project C.5) there as active undergraduate members.

Y6 Outcomes:

gidaa odaangiina anaangoog Robotics Program*	**2011**	**TOTAL**
Number of Students	60	214
Male	35	123
Female	25	91
% from underrepresented groups	65%	70%

**Initiated program in 2009, Y3*

giiwed'anang North Star AISES Alliance (Project C.5)
In support of Native American students in the state of Minnesota, collaborative efforts between the CCEFP, NCED, the Northstar STEM (LSAMP) Alliance, have led to the formation of the *giiwed'anang Northstar Alliance* of undergraduate AISES chapters in the state of Minnesota. The collaboration seeks to deliver academic support for all Native American students in STEM disciplines in Minnesota. The goals of *giiwed'anang* (gee-way-di-nan) are to form relationships between Minnesota AISES undergraduate and

high school chapters, provide educational opportunities, academic guidance, open research doors, and bridge the gap between high school, pre- and post-secondary education and industry STEM fields. This alliance fosters fundraising capabilities and professional support and, in so doing, increases the potential for growth in the number of AISES chapters in Minnesota as well as a larger representation of Native Americans in STEM fields and disciplines.

Various outreach efforts throughout the course of the academic year have created the foundation AISES students need to stay engaged, have a student-body family, have educational support and serve as mentors to others. The giiwed'anang Alliance leverages AISES activities and supports student participation. As participation and interest grows, as does student recruitment and retention.

Outcomes:

giiwed'anang North Star AISES Alliance Activity*	# of students
Retreat 1, Cloquet, MN: January 2008	8
Region V AISES Meeting, SD: April 2008	13
Retreat 2, Cloquet, MN: May 2008	19
North Star STEM LSAMP Kickoff Meeting: September 2008	10
Retreat 3, Minneapolis, MN: October 2008	26
AISES National Conference: November 2008	14
Retreat 4, Cloquet, MN: February 2009	14
AISES Region V Annual Meeting: March 2009	13
AISES National Conference: October 2009	8
giiwed'anang Presentation at AISES National	20
Retreat 5, Portland, OR: October 2009	15
Outreach Activity: gidaa STEM Camp, Cloquet, MN	6
AISES Professional Chapter: Meeting 1, December 2009	4
AISES Professional Chapter: Meeting 2, January 2010	4
AISES Region V Annual Meeting: April 2010	8
AISES National Conference: November 2010	10
giiwed'anang Dinner at AISES National: November 2010 (co-sponsored with UMN Northstar LSAMP)	40+
giiwed'anang Special Presentation: Native Skywalkers at St. Cloud State University (co-sponsored with Northstar LSAMP): November 2010	20+
Received funding from Minnesota NASA Space Grant Consortium for two Rocket Teams	4
AISES Region V Annual Meeting, Rapid City, SD: April 2011	22
AISES National Conference, Minneapolis, MN: November 2011	10
giiwed'anang Northstar Alliance Dinner, Minneapolis, MN: November 2011	65+
AISES Rocket Team 2011, University of Minnesota AISES Chapter	4
AISES Leadership Conference, February 2012, co-sponsored three students. Co-sponsor was UMN Northstar STEM LSAMP Program	3

**Initiated program in 2008, Y2 Participating institutions include: University of Minnesota (Twin Cities, Morris, and Duluth); Fond du Lac Tribal and Community College, Leech Lake Tribal College, Bemidji State University and St. Cloud University and networks in North Dakota and Wisconsin.*

Table 7a: Diversity Statistics for ERC Faculty and Students

	US Citizens or Permanent Residents						Foreign (Temporary Visa Holders)						Citizenship Not Reported					
	Leadership Team[3]	Faculty [4]	Doctoral Students	Masters Students	Undergrad Non-REU	REU Students	Leadership Team[3]	Faculty [4]	Doctoral Students	Masters Students	Undergrad Non-REU	REU Students	Leadership Team[3]	Faculty [4]	Doctoral Students	Masters Students	Undergrad Non-REU	REU Students
Center Total	**10**	**32**	**27**	**22**	**100**	**16**	**0**	**3**	**23**	**3**	**5**	**1**	**0**	**1**	**2**	**4**	**18**	**2**
Women																		
Category Total	3	7	5	4	32	7	0	0	2	0	0	0	0	0	0	0	3	0
Center Percent	30.0%	21.9%	18.5%	18.2%	32.0%	43.8%	0	0.0%	8.7%	0.0%	0.0%	0.0%	0	0.0%	0.0%	0.0%	16.7%	0.0%
National Percent [1]	N/A	13.2%	22.8%	21.8%	18.6%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Underrepresented Racial Minorities																		
Category Total	1	5	5	1	60	5	0	0	2	0	1	0	0	0	0	0	6	0
Center Percent	10.0%	15.6%	18.5%	4.5%	60.0%	31.3%	0	0.0%	8.7%	0.0%	20.0%	0.0%	0	0.0%	0.0%	0.0%	33.3%	0.0%
National Percent [1]	N/A	2.5%	2.1%	3.4%	5.8%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Hispanic/Latinos																		
Category Total	0	1	0	0	3	1	0	0	3	1	0	1	0	0	0	0	0	0
Center Percent	0.0%	3.1%	0.0%	0.0%	3.0%	6.3%	0	0.0%	13.0%	33.3%	0.0%	100.0%	0	0.0%	0.0%	0.0%	0.0%	0.0%
National Percent [1]	N/A	3.6%	2.5%	4.7%	9.6%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Persons With Disabilities																		
Category Total	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Center Percent	0.0%	0.0%	3.7%	4.5%	1.0%	0.0%	0	0.0%	0.0%	0.0%	0.0%	0.0%	0	0.0%	0.0%	0.0%	0.0%	0.0%
National Percent [1][2]	N/A	5%	0%	6.4%	11%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

[1] The National Percentages are based only on U.S. citizens / permanent residents.

[2] All National averages are from 2010 data, except persons with disabilities which is from 2006 data for Faculty and 2008 data for Masters, Doctoral and Undergraduate students.

[3] Leadership Team includes Directors, Thrust Leaders, Education Program Leaders, Industrial Liason Officer, Administrative Director, and Research Thrust Management and Strategic Planning.

[4] Faculty includes Directors, Thrust Leaders, Education Program Leaders, Research - Senior Faculty, Research - Junior Faculty, Research - Visiting Faculty, Curriculum Development and Outreach - Senior Faculty, Curriculum Development and Outreach - Junior Faculty and, Curriculum Development and Outreach - Visiting Faculty.

Table 7a Summary: Count of ERC Personnel

Faculty	Post Docs	Students				Teachers		Young Scholars	Other [5]	Total
		UG Non-REU	REU	Graduate		Non-RET	RET			
				Doctoral	Masters					
36	3	123	19	52	29	15	6	0	35	296

[5] Other includes Industrial Liaison Officer, Administrative Director, Research Thrust Management and Strategic Planning, Staff, Research - Industry Researchers, Research - Other Visiting College Students, Research - Research Staff, Curriculum Development and Outreach - Industry Researchers, Curriculum Development and Outreach - Other Visiting College Students and Curriculum Development and Outreach - Staff.

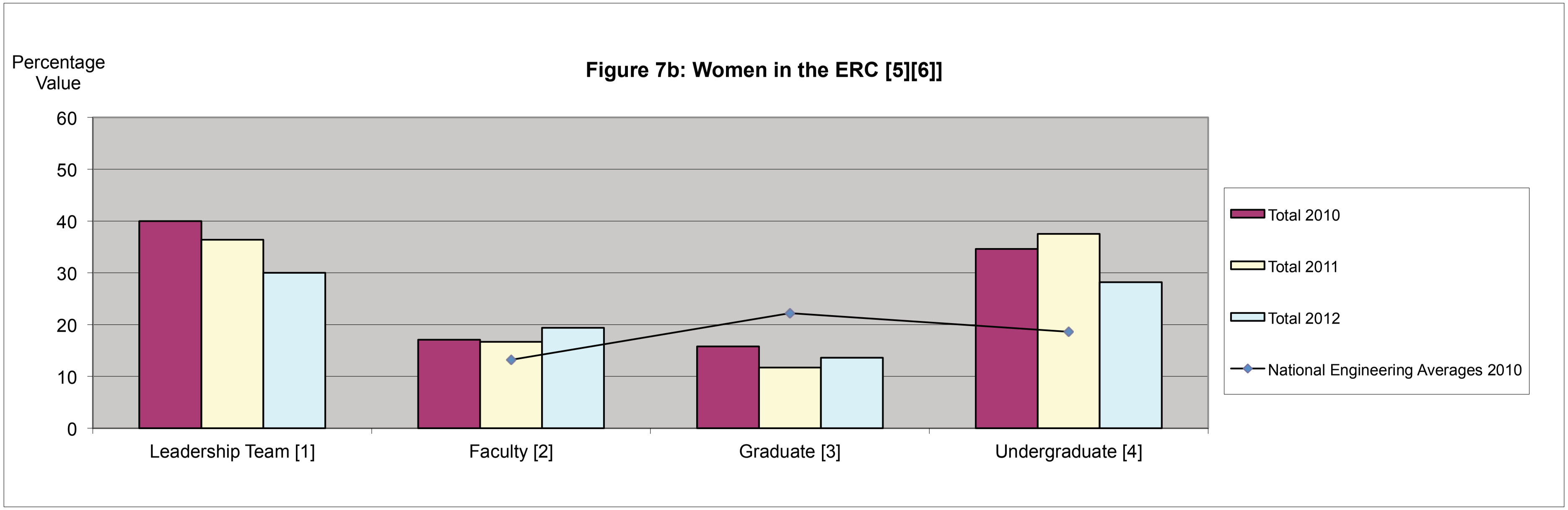


Figure 7b: Women in the ERC [5][6]

Averages	Leadership Team	Faculty	Graduate	Undergraduate
National Engineering Averages 2010	N/A	13.2%	22.2%	18.6%
All ERC's 2011	31.9%	21.7%	23.4%	32.2%
Percentage for Engineering Research Center for Compact and Efficient Fluid Power at the University of Minnesota – Twin Cities 2012	30%	19.4%	13.6%	28.2%

[1] The Leadership Team includes Directors, Thrust Leaders, Industrial Liaison Officer, Education Program Leaders, Administrative Directors, and Research Thrust Management and Strategic Planning.

[2] Faculty includes Directors, Thrust Leaders, Education Program Leaders, Research - Senior Faculty, Research - Junior Faculty, Research - Visiting Faculty, Curriculum Development and Outreach - Senior Faculty, Curriculum Development and Outreach - Junior Faculty, and Curriculum Development and Outreach - Visiting Faculty.

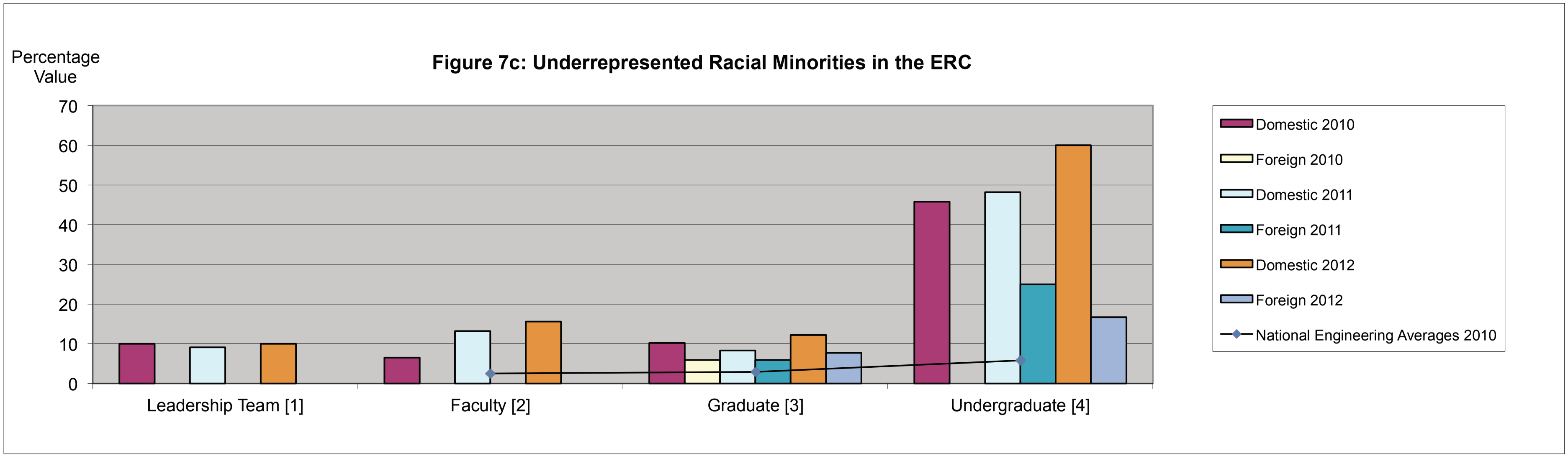
[3] Graduate students include Doctoral and Master's students.

[4] Undergraduate students include non-REU and REU students.

[5] Total counts include personnel regardless of citizenship status.

[6] The number of personnel for whom gender was not reported are not excluded from the percentage calculations.

Figure 7c: Underrepresented Racial Minorities in the ERC



Averages	Leadership Team	Faculty	Graduate	Undergraduate
National Engineering Averages 2010	N/A	2.5%	2.9%	5.8%
All ERC's 2011	11.7%	10%	11%	25.1%
Domestic Percentage for Engineering Research Center for Compact and Efficient Fluid Power at the University of Minnesota – Twin Cities 2012	10%	15.6%	12.2%	60%
Foreign Percentage for Engineering Research Center for Compact and Efficient Fluid Power at the University of Minnesota – Twin Cities 2012	0%	0%	7.7%	16.7%

[1] The Leadership Team includes Directors, Thrust Leaders, Industrial Liaison Officer, Education Program Leaders, Administrative Directors, and Research Thrust Management and Strategic Planning.

[2] Faculty includes Directors, Thrust Leaders, Education Program Leaders, Research - Senior Faculty, Research - Junior Faculty, Research - Visiting Faculty, Curriculum Development and Outreach - Senior Faculty, Curriculum Development and Outreach - Junior Faculty, and Curriculum Development and Outreach - Visiting Faculty.

[3] Graduate students include Doctoral and Master's students.

[4] Undergraduate students include non-REU and REU students.

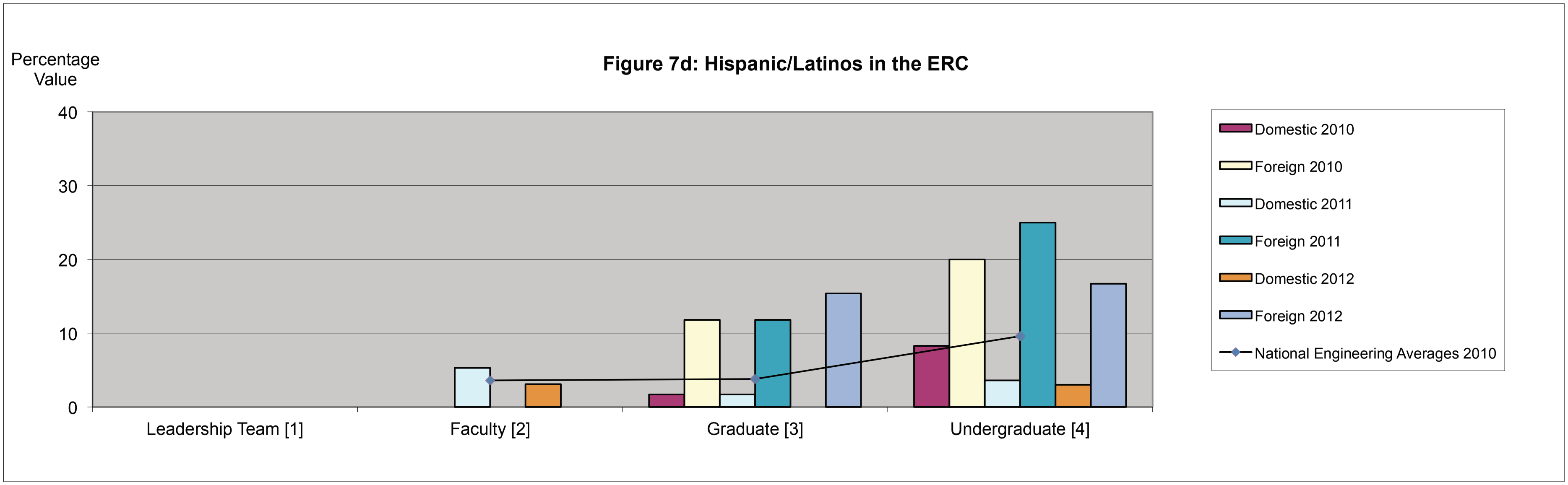


Figure 7d: Hispanic/Latinos in the ERC

Averages	Leadership Team	Faculty	Graduate	Undergraduate
National Engineering Averages 2010	N/A	3.6%	3.8%	9.6%
All ERC's 2011	7.2%	8.3%	10.3%	13%
Domestic Percentage for Engineering Research Center for Compact and Efficient Fluid Power at the University of Minnesota – Twin Cities 2012	0%	3.1%	0%	3%
Foreign Percentage for Engineering Research Center for Compact and Efficient Fluid Power at the University of Minnesota – Twin Cities 2012	0%	0%	15.4%	16.7%

[1] The Leadership Team includes Directors, Thrust Leaders, Industrial Liaison Officer, Education Program Leaders, Administrative Directors, and Research Thrust Management and Strategic Planning.

[2] Faculty includes Directors, Thrust Leaders, Education Program Leaders, Research - Senior Faculty, Research - Junior Faculty, Research - Visiting Faculty, Curriculum Development and Outreach - Senior Faculty, Curriculum Development and Outreach - Junior Faculty, and Curriculum Development and Outreach - Visiting Faculty.

[3] Graduate students include Doctoral and Master's students.

[4] Undergraduate students include non-REU and REU students.

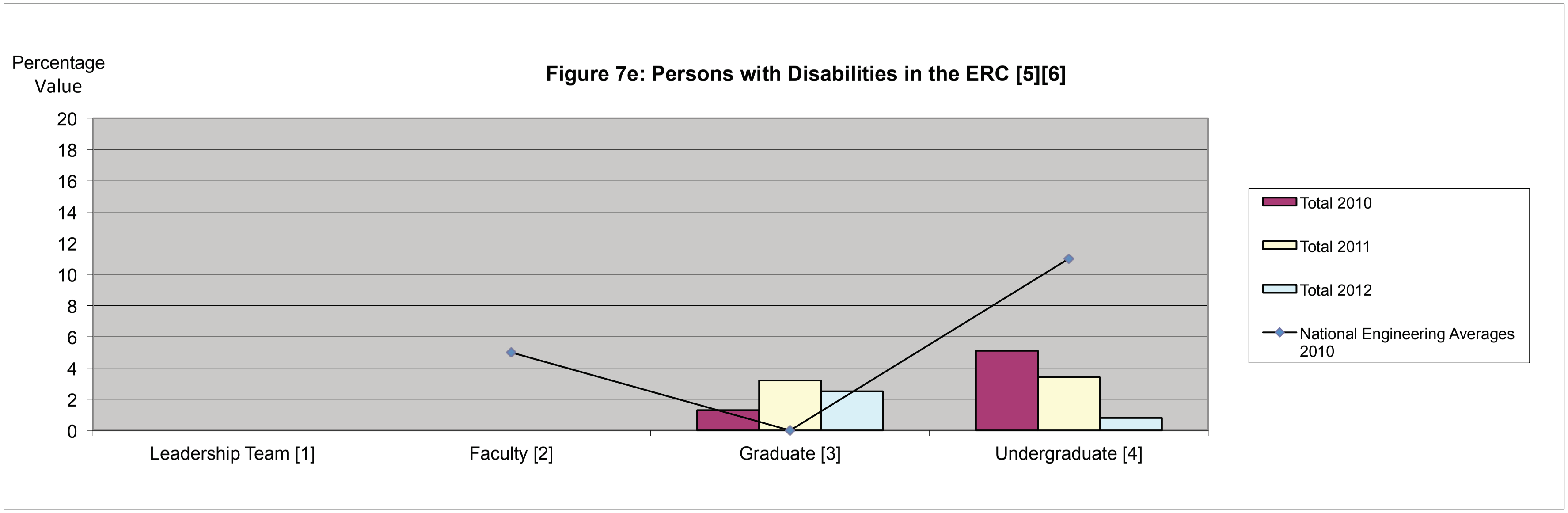


Figure 7e: Persons with Disabilities in the ERC [5][6]

Averages	Leadership Team	Faculty	Graduate	Undergraduate
National Engineering Averages 2010	N/A	5%	N/A	11%
All ERC's 2011	5.2%	1.9%	1%	2.5%
Percentage for Engineering Research Center for Compact and Efficient Fluid Power at the University of Minnesota – Twin Cities 2012	0%	0%	2.5%	0.8%

[1] The Leadership Team includes Directors, Thrust Leaders, Industrial Liaison Officer, Education Program Leaders, Administrative Directors, and Research Thrust Management and Strategic Planning.

[2] Faculty includes Directors, Thrust Leaders, Education Program Leaders, Research - Senior Faculty, Research - Junior Faculty, Research - Visiting Faculty, Curriculum Development and Outreach - Senior Faculty, Curriculum Development and Outreach - Junior Faculty, and Curriculum Development and Outreach - Visiting Faculty.

[3] Graduate students include Doctoral and Master's students.

[4] Undergraduate students include non-REU and REU students.

[5] Total counts include personnel regardless of citizenship status.

[6] The number of personnel for whom disability was not reported are not excluded from the percentage calculations.

Table 7f: Center Diversity, by Institution

Institution	Women		Underrepresented Racial Minorities [1] [2]		Hispanics [1] [3]	
	Number	Percent	Number	Percent	Number	Percent
Lead Institution						
University of Minnesota	18	22%	12	24%	1	2%
Core Partners						
Georgia Institute of Technology	5	17%	0	0%	0	0%
Purdue University	4	12%	0	0%	0	0%
University of Illinois at Urbana-Champaign	4	29%	1	9%	0	0%
Vanderbilt University	2	18%	1	13%	0	0%
Collaborating Institutions						
Bemidji State University	1	100%	1	100%	0	0%
Case Western Reserve University	0	0%	0	0%	0	0%
Clarkson University	0	0%	0	0%	0	0%
Eolos Wind Energy Research Consortium	0	0%	0	0%	0	0%
Hennepin Technical College	0	0%	0	0%	0	0%
Michigan Technological University	0	0%	1	100%	0	0%
Milwaukee School of Engineering	6	27%	1	5%	1	5%
National Center for Earth-surface Dynamics	1	100%	0	0%	0	0%
North Carolina Agriculture and Technical State University	4	27%	9	82%	0	0%
Science Museum of Minnesota	1	20%	0	0%	0	0%
St. Cloud State University	4	80%	5	100%	0	0%
STEM Education Center	2	100%	0	0%	0	0%
University of Florida	0	0%	0	0%	0	0%
University of Minnesota - Morris	9	53%	14	100%	0	0%
University of Missouri-Columbia	0	0%	0	0%	0	0%
University of North Dakota	3	50%	6	100%	2	33%
Non-ERC Institutions Providing REU Students						
Humboldt State University	0	0%	0	0%	0	0%
Louisana State University	1	100%	0	0%	0	0%
Loyola University Chicago	1	100%	0	0%	0	0%
Minneapolis Community and Technical College	0	0%	1	100%	0	0%
New Mexico State University	0	0%	0	0%	1	100%
Princeton University	1	50%	0	0%	0	0%
Texas A and M University	1	100%	0	0%	0	0%
University of Texas at El Paso	0	0%	0	0%	0	0%
Yale University	1	100%	0	0%	0	0%
Precollege Partners						
Brentwood High School	0	0%	0	0%	0	0%
Circle of Life School	0	0%	1	50%	0	0%
Cloquet High School	0	0%	0	0%	0	0%
Gibbon, Fairfax, Winthrop School	0	0%	0	0%	0	0%
Independence High School	0	0%	0	0%	0	0%
KidWind	1	50%	1	50%	0	0%
Mahtomedi High School	1	50%	0	0%	0	0%
McCutcheon High School	0	0%	0	0%	0	0%
Ojibwe School	1	50%	2	100%	1	50%
Ponemah Elementary School	1	100%	1	100%	0	0%
Red Lake Middle School	0	0%	0	0%	0	0%

Institution	Women		Underrepresented Racial Minorities [1] [2]		Hispanics [1] [3]	
	Number	Percent	Number	Percent	Number	Percent
South Ridge School (formerly Albrook School)	3	60%	0	0%	0	0%
Tippecanoe School Corporation	0	0%	0	0%	0	0%
Community Colleges						
Fond du Lac Tribal and Community College	0	0%	1	50%	0	0%
Lac Courte Oreilles Ojibwa Community College	0	0%	2	100%	0	0%
Leech Lake Tribal College	0	0%	4	100%	0	0%
Salish Kootenai College	1	6%	16	100%	0	0%
Louis Stokes Alliances for Minority Participation (LSAMP)						
North Star STEM Alliance	11	48%	17	100%	0	0%
The All Nations Louis Stokes Alliance for Minority Participation	0	0%	2	100%	0	0%
Tribal Colleges and Universities Program (TCUP)						
New Baccalaureate Degrees and STEM Program Improvement at Salish Kootenai College	1	7%	15	100%	0	0%
NSF Diversity Program Collaborations (NSF Diversity Program Collaborations)						
Northstar STEM Program	2	100%	0	0%	0	0%

[1] - This data only includes U.S. Citizens and Legal Permanent Residents.

[2] - Underrepresented Racial Minorities is a sum of all personnel entered in the following categories: American Indian or Alaska Native, Black or African American, Native Hawaiian or Other Pacific Islander, or More than one race reported, minority.

[3] - Hispanics is a sum of all U.S. Citizens that are indicated to be of hispanic ethnicity.

5.3 MANAGEMENT EFFORT

The CCEFP operational organization chart appears below.

CCEFP Organization Chart

Dr. Kim Stelson has been the center director since the CCEFP was established in 2006. He reports to the Dean of the College of Science and Engineering at the University of Minnesota. Dr. Stelson is very well respected in the fluid power field and leads the center with a clear vision of developing close relationships between academia and the fluid power industry. His balanced approach to focusing on fundamental research with industrial applications has created an active industry membership.

Dr. Perry Li is the Deputy Director of the CCEFP and has also been with the center since 2006. His role is to provide technology guidance for the center. He owns the strategic plan for technology and oversees the test bed integration. He also provides leadership for the bi-annual research project reviews.

The other positions at the CCEFP provide the following support:

- ILO – Conduit to Industry and responsible for business planning and development.
- Sustainability Director – Conduit to the researchers and responsible for research project management and the development of new project funding.
- Administrative Director – Responsible for operations and financial management of the center.
- Education Director – Leads the Education and Outreach activities.
- E&O Director – Responsible for the Education and Outreach planning and execution.
- Admin and E&O Assistant – Provides support for operations and E&O projects.
- Communications Specialist: Manages all communication and tools including the CCEFP Website.

The External Relations and Communications Coordinator role was not filled this year. Throughout the year, Linda Western, a longtime supporter of the CCEFP, held a contract position to fill this role. This allowed a Sustainability Plan to be further developed and the requirements of this position better understood.

There are also several advisory boards and committees associated with the CCEFP. These are summarized below.

Executive Committee (EC)
This committee is charged with defining CCEFP policy and strategies, then monitoring their effectiveness. Committee members also guide the research project selection and tracking processes. The Executive Committee is chaired by the Center Director. Committee members include a representative from each of the Center's seven universities, a representative of the Student Leadership Council, and four industry representatives—all drawn from the leadership of the Industrial Liaison Board. The Executive Committee meets at least three times each year, with additional meetings scheduled when needed.

Executive Committee Members:

Andrew Alleyne - University of Illinois - Urbana-Champaign
Eric Barth - Vanderbilt University
Wayne J. Book - Georgia Institute of Technology
Tim Deppen - SLC Representative
Vito R. Gervasi - Milwaukee School of Engineering
David Holt - ExxonMobil Research Engineering
Edwin Howe - Enfield Technologies
Monika Ivantysynova - Purdue University
Joe Kovach - Parker Hannifin Corporation
Perry Y. Li - University of Minnesota
Eui Park - North Carolina A&T State University
Joe Pfaff - Husco International
Kim A. Stelson - University of Minnesota

Management Committee (MC)
This Committee is responsible for implementing CCEFP strategy and guiding the Center's day-to-day operations. Chaired by the CCEFP Director, its members include a faculty representative from each of the Center's seven universities. Committee meetings, most often held via conference call, are typically scheduled twice each month.

Management Committee Members:

Andrew Alleyne - University of Illinois - Urbana-Champaign
Eric Barth - Vanderbilt University
Wayne J. Book - Georgia Institute of Technology
Vito R. Gervasi - Milwaukee School of Engineering
Monika Ivantysynova - Purdue University
Joe Kovach - Parker Hannifin Corporation
Perry Y. Li - University of Minnesota
Eui Park - North Carolina A&T State University
Kim A. Stelson - University of Minnesota

Industrial Advisory Board (IAB)
The CCEFP Industrial Advisory Board (IAB) provides advice and guidance on CCEFP research directions and policies. IAB members, representing companies supporting the Center at either the principal or sustaining level, meet regularly for discussions on key issues. Four representatives from the IAB serve on the CCEFP Executive Committee (EC) which sets the overall governing policies and strategic direction for CCEFP.

Current IAB Members:

Mark Devlin - Afton Chemical
Ed Greif - Bosch Rexroth Corp.
Gary Kassen - Case New Holland
Jerry Wear - Caterpillar Inc.
Marcus Royal - Deltrol Fluid Products
Srinivas Patri - Eaton Corp.
Ed Howe - Enfield Technologies
Steven Herzog - Evonik RohMax USA, Inc.
David Holt - ExxonMobil Research and Engineering
Phil Priolo - G.W. Lisk Co., Inc.
Patrick Lee - Gates Corporation
Joe Pfaff - HUSCO International
Scott Lane - Linde Hydraulics Corp.
Robert Profilet - Lubrizol
Craig Campbell - MTS Systems Corp.
Eric Lanke - National Fluid Power Association
Dave Moorman - Netshape Technologies
Joe Kovach - Parker Hannifin Corp.
Gilles Lamaire - Poclain Hydraulics
Eric Cummings - Ross Controls
Jeff Herrin - Sauer-Danfoss
Larry Castleman - Trelleborg Sealing Solutions
VG Srinivas - Veljan Hydrair Private Ltd.
Shahbaz Hydari - Woodward

Scientific Advisory Board (SAB)

Members of the SAB are internationally known experts in fluid power. They represent leading engineering universities, laboratories and academies with interests in fluid power and/or have had extensive experience in hydraulics and pneumatics through their distinguished careers in industry. The SAB's periodic reviews of Center research and organization are valued throughout the CCEFP and help guide the Executive Committee in developing Center strategy.

Scientific Advisory Board Members:

Dr. Hans Aichlmayr - Lawrence Livermore National Laboratory
Dr. John Bierlein - Eaton Corporation (Retired)
Prof. Richard Burton - University of Saskatchewan
Dr. Robert J. Cloutier - Stevens Institute of Technology
Prof. Kevin Edge - University of Bath
Prof. Frank Fronczak - University of Wisconsin
Prof. Stephen Jacobsen - University of Utah
Prof. Toshiharu Kagawa - Tokyo Institute of Technology
Dr. Lonnie J. Love - Oak Ridge National Laboratory
Prof. Dr. Ing. Hubertus Murrenhoff - RWTH-Aachen University
Prof. Jan-Ove Palmberg - Linkoping University
Prof. Masayoshi Tomizuka - University of California-Berkeley
Sohan Uppal – Former Vice President, Technology and Chief Technology Officer for Eaton Fluid Power
Professor Lu Yong Xiang - Chinese Academy of Sciences (Retired)

Education and Outreach Network (EON)

The Education Outreach Network (EON) has one representative from each of the seven universities in the CCEFP network, one representative of the Science Museum of Minnesota and three members of the CCEFP team charged with education and outreach activities. The EON facilitates communication among the CCEFP sites and is a core working group for a number of education and outreach activities.

EON Members:

Eric Barth - Vanderbilt University
Alyssa A. Burger - CCEFP
William K. Durfee - University of Minnesota
Medhat Khalil - Milwaukee School of Engineering
Elizabeth Hsiao-Wecksler - University of Illinois - Urbana-Champaign
Paul Imbertson - CCEFP
John Lumkes - Purdue University
J. Newlin - Science Museum of Minnesota
Chris Paredis - Georgia Institute of Technology
Zongliang Jiang - North Carolina A&T State University
Linda Western – CCEFP

Student Leadership Council (SLC)

The mission of the SLC is to act as a liaison between the ERC and the ERC Students; to promote collaboration between the Students at the ERC Institutions; to enhance communication between the advisors and Students of the ERC; and to encourage the study of engineering, math, and natural sciences for the future benefit of fluid power. The SLC is also responsible for preparing an annual Strengths, Weaknesses, Opportunities, Threats (SWOT) analysis and presenting it to National Science Foundation representatives.

Current SLC Officers:

Tim Deppen - President - University of Illinois at Urbana-Champaign
Jonathan Meyer - Vice President - University of Minnesota
Andrew Schenk - Secretary - Purdue University
Ken Marek - Treasurer - Georgia Institute of Technology

Each institution also has a representative on the committee:
Joseph Akyeampong- North Carolina A & T State University
Diana Cardona -Vanderbilt University
Mark Elton - Georgia Institute of Technology
Henry Kohring - University of Minnesota - email
Ashwin Ramesh - University of Illinois at Urbana-Champaign
Kyle Merrill - Purdue University
Meghan Miller - Milwaukee School of Engineering

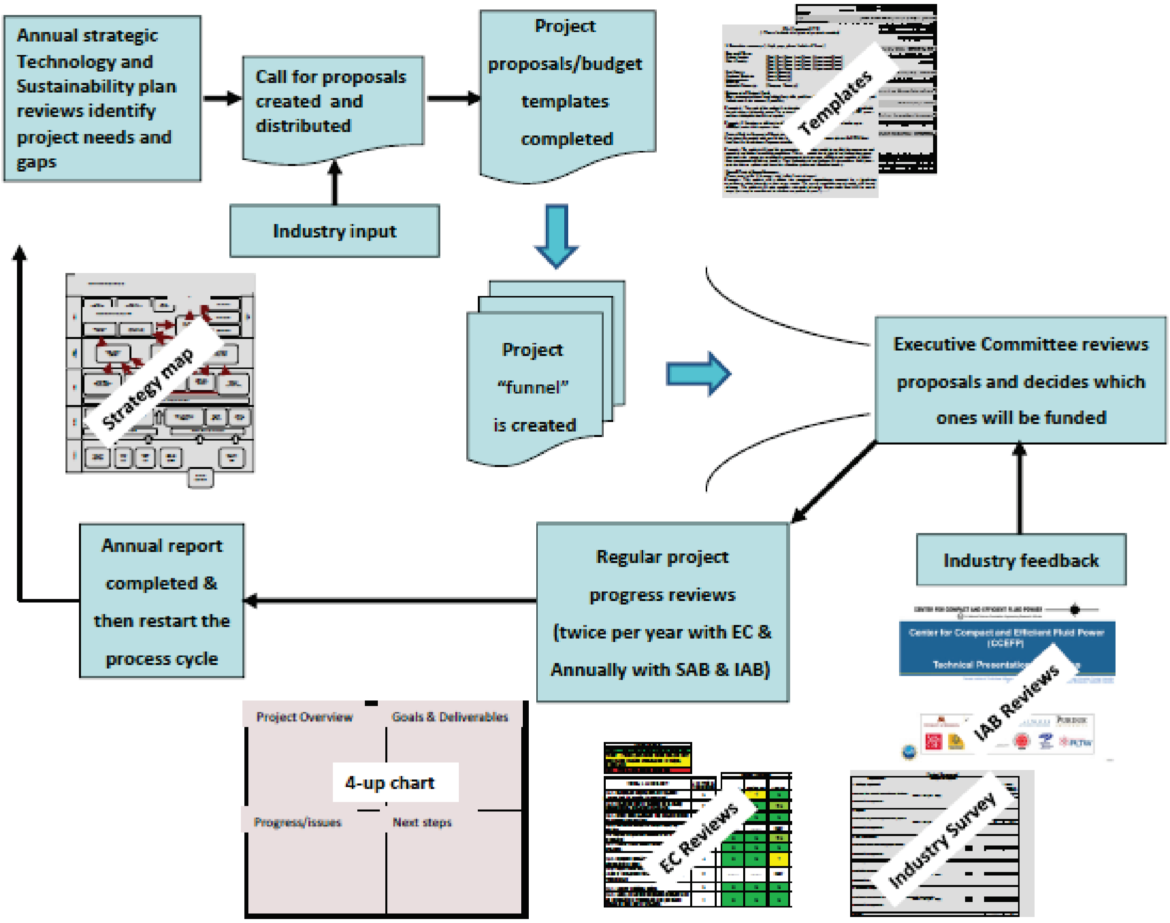
MANAGEMENT OF THE CCEFP

The CCEFP key management activities include strategic planning, budgeting, organizational leadership and control. These key functions are summarized below.

Strategic Planning: Each year the Strategic Technology and Sustainability plans are updated. Outputs from this process may reflect the need for specific projects, a new focus on membership, a required change in the organization or other factors affecting the center's ability to succeed. It may also identify areas where stronger leadership or a significant change of focus is required.

Research Project Selection

The process for selecting and managing research projects is shown in the diagram below. The process begins with a review of the CCEFP strategic Technology and Sustainability plans. The Executive Committee with input from Industry creates a call for proposals. The Executive Committee reviews the proposals and with input from the IAB, selects the funded projects.



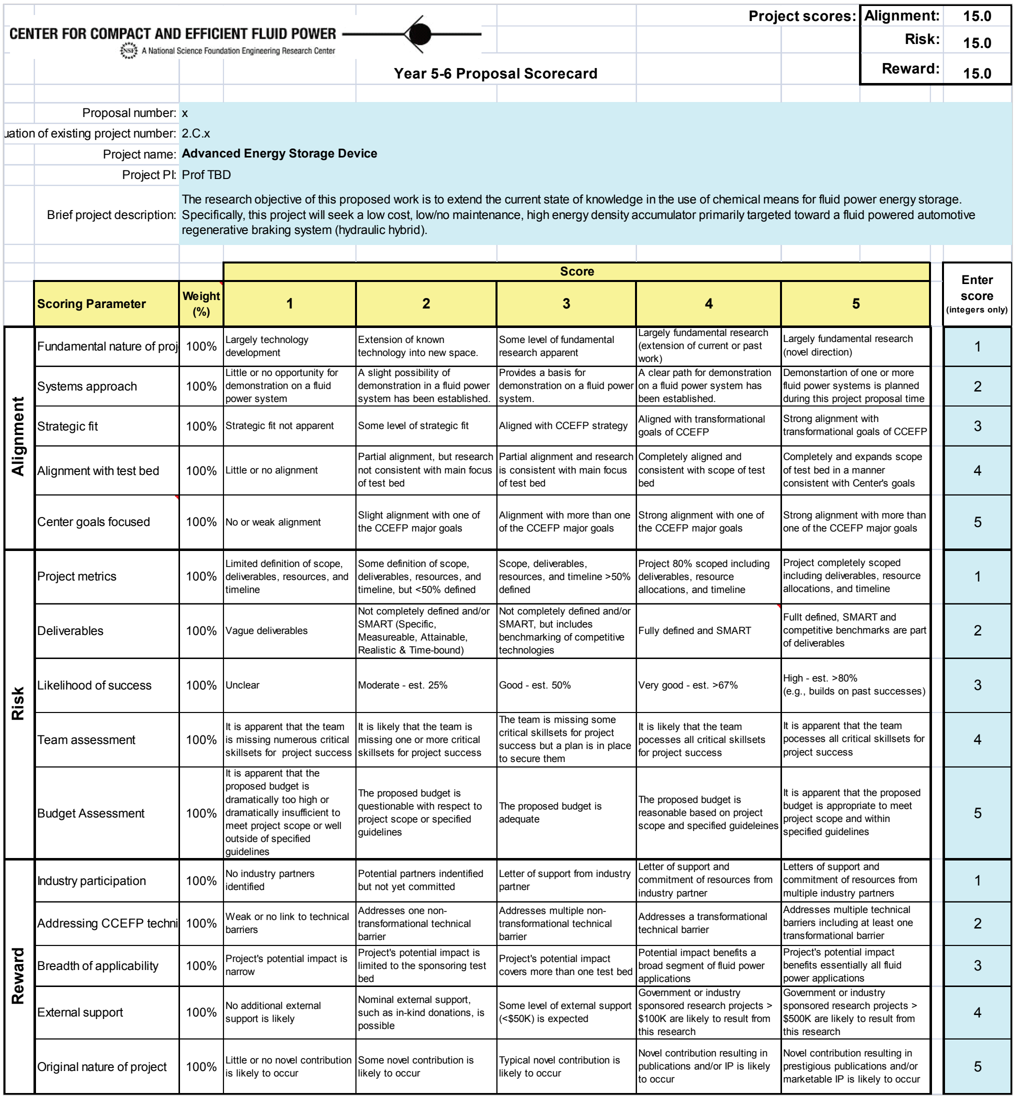
Project Selection and Management

The project selection process was modified to plan for a 2 year funding cycle. This was done to allow more time to pursue higher impact research. It also provides more stability to plan graduate student funding.

The main elements of the process include a center-wide strategic call for proposals, a standardized proposal format, and an extensive evaluation procedure. The strategic call for proposals is a carefully worded summary of our strategy that identifies research needs necessary to fulfill the strategy. It is widely circulated to both existing and potential new research project leaders along with an updated standardized proposal template. The template is focused on the project's research approach, the research team and collaboration, strategic fit, fundamental research content, schedule, deliverables and metrics.

For the Y5-Y6 funding cycle, five existing projects were terminated and four new ones were brought into the Center. The non-funded proposals make up a "project funnel" for future consideration when other funding sources are made available.

The CCEFP IAB enthusiastically embraced the new project selection process. They assigned review teams made up of over 30 experts from their organizations to review each and every proposal. Each proposal had at least two industry reviewers. To ensure uniformity, they developed and adopted the standardized review template with fifteen distinct criteria. These criteria were separated into three subgroups: project risk, reward or alignment (strategic fit). An example of the review scorecard template appears below. The review results were discussed extensively during IAB teleconferences until a final outcome was reached and forwarded to the IAB representatives on the CCEFP Executive Committee (EC).



CENTER FOR COMPACT AND EFFICIENT FLUID POWER
A National Science Foundation Engineering Research Center

Year 5-6 Proposal Scorecard

Project scores:
Alignment: 15.0
Risk: 15.0
Reward: 15.0

Proposal number: x
uation of existing project number: 2.C.x
Project name: **Advanced Energy Storage Device**
Project PI: Prof TBD
Brief project description: The research objective of this proposed work is to extend the current state of knowledge in the use of chemical means for fluid power energy storage. Specifically, this project will seek a low cost, low/no maintenance, high energy density accumulator primarily targeted toward a fluid powered automotive regenerative braking system (hydraulic hybrid).

			Score					**Enter score (integers only)**
	Scoring Parameter	**Weight (%)**	**1**	**2**	**3**	**4**	**5**	
Alignment	Fundamental nature of proj	100%	Largely technology development	Extension of known technology into new space.	Some level of fundamental research apparent	Largely fundamental research (extension of current or past work)	Largely fundamental research (novel direction)	1
	Systems approach	100%	Little or no opportunity for demonstration on a fluid power system	A slight possibility of demonstration in a fluid power system has been established.	Provides a basis for demonstration on a fluid power system.	A clear path for demonstration on a fluid power system has been established.	Demonstartion of one or more fluid power systems is planned during this project proposal time	2
	Strategic fit	100%	Strategic fit not apparent	Some level of strategic fit	Aligned with CCEFP strategy	Aligned with transformational goals of CCEFP	Strong alignment with transformational goals of CCEFP	3
	Alignment with test bed	100%	Little or no alignment	Partial alignment, but research not consistent with main focus of test bed	Partial alignment and research is consistent with main focus of test bed	Completely aligned and consistent with scope of test bed	Completely and expands scope of test bed in a manner consistent with Center's goals	4
	Center goals focused	100%	No or weak alignment	Slight alignment with one of the CCEFP major goals	Alignment with more than one of the CCEFP major goals	Strong alignment with one of the CCEFP major goals	Strong alignment with more than one of the CCEFP major goals	5
Risk	Project metrics	100%	Limited definition of scope, deliverables, resources, and timeline	Some definition of scope, deliverables, resources, and timeline, but <50% defined	Scope, deliverables, resources, and timeline >50% defined	Project 80% scoped including deliverables, resource allocations, and timeline	Project completely scoped including deliverables, resource allocations, and timeline	1
	Deliverables	100%	Vague deliverables	Not completely defined and/or SMART (Specific, Measureable, Attainable, Realistic & Time-bound)	Not completely defined and/or SMART, but includes benchmarking of competitive technologies	Fully defined and SMART	Fullt defined, SMART and competitive benchmarks are part of deliverables	2
	Likelihood of success	100%	Unclear	Moderate - est. 25%	Good - est. 50%	Very good - est. >67%	High - est. >80% (e.g., builds on past successes)	3
	Team assessment	100%	It is apparent that the team is missing numerous critical skillsets for project success	It is likely that the team is missing one or more critical skillsets for project success	The team is missing some critical skillsets for project success but a plan is in place to secure them	It is likely that the team pocesses all critical skillsets for project success	It is apparent that the team pocesses all critical skillsets for project success	4
	Budget Assessment	100%	It is apparent that the proposed budget is dramatically too high or dramatically insufficient to meet project scope or well outside of specified guidelines	The proposed budget is questionable with respect to project scope or specified guidelines	The proposed budget is adequate	The proposed budget is reasonable based on project scope and specified guideleines	It is apparent that the proposed budget is appropriate to meet project scope and within specified guidelines	5
Reward	Industry participation	100%	No industry partners identified	Potential partners indentified but not yet committed	Letter of support from industry partner	Letter of support and commitment of resources from industry partner	Letters of support and commitment of resources from multiple industry partners	1
	Addressing CCEFP techni	100%	Weak or no link to technical barriers	Addresses one non-transformational technical barrier	Addresses multiple non-transformational technical barrier	Addresses a transformational technical barrier	Addresses multiple technical barriers including at least one transformational barrier	2
	Breadth of applicability	100%	Project's potential impact is narrow	Project's potential impact is limited to the sponsoring test bed	Project's potential impact covers more than one test bed	Potential impact benefits a broad segment of fluid power applications	Project's potential impact benefits essentially all fluid power applications	3
	External support	100%	No additional external support is likely	Nominal external support, such as in-kind donations, is possible	Some level of external support (<$50K) is expected	Government or industry sponsored research projects > $100K are likely to result from this research	Government or industry sponsored research projects > $500K are likely to result from this research	4
	Original nature of project	100%	Little or no novel contribution is likely to occur	Some novel contribution is likely to occur	Typical novel contribution is likely to occur	Novel contribution resulting in publications and/or IP is likely to occur	Novel contribution resulting in prestigious publications and/or marketable IP is likely to occur	5

Standardized Proposal Review Template

The two-year funding cycle concludes at the end of May 2012. This cycle was well received by the researchers and by industry. Therefore a call for proposals was created in the fall of 2011using the same approach. This call was again created based on a review of our strategic technology and sustainability plans, input from the management committee and input from Industry. For years seven and eight funding, a total of thirty two research proposals were received. Budget forecasts will allow twenty one projects to be funded. As of this writing the evaluation process has been completed and announcements regarding projects to be funded for Y7 & Y8 will be distributed shortly. This will allow sufficient time to recruit graduate students to begin projects in fall 2012. The list of Y7- Y8 approved projects appears below:

1. Technology Transfer Process for Energy Management Systems
2. New Directions in the Rheology of Elastohydrodynamics
3. Advanced Strain Energy Accumulator
4. Controlled Stirling Thermocompressors (New)
5. Teleoperation Efficiency Improvements by Operator Interface
6. MEMS Proportional Valve
7. Pressure Ripple Energy Harvester (New) **or** Functionally Graded Saturating Strain Energy Accumulator (New)
8. Miniature HCCI Free-Piston Engine Compressor
9. Pump Switching and Prognostics for Displacement Controlled Multi-Actuator Hydraulic Hybrid Machines (New)
10. Next Steps towards Virtual Prototyping of Pumps and Motors
11. Human Performance Modeling and User Centered Design
12. Microtextured Surfaces for Low Friction / Leakage
13. System Configuration & Control Using Hydraulic Transformers (New)
14. Actively Controlled Digital Pump/Motor
15. High Performance Valves Enabled by Kinetic Energy (New)
16. Energy Efficient Fluids
17. Leakage/Seal Friction Reduction in Fluid Power Systems
18. Free-Piston Engine Hydraulic Pump
19. Active Vibration Damping of Mobile Hydraulic Machines (New)
20. Variable Displacement External Gear Machine (New)
21. Fluid-Powered Surgery & Rehabilitation via Compact, Integrated Systems

Project Reviews: There are several project reviews throughout the year. The Executive Committee reviews each project twice a year. The SAB reviews the projects annually and provides a written report to CCEFP management. The PI's present project reviews during the IAB meetings held at member universities. Feedback is provided by the IAB members. The IAB also responds to an annual survey on each project to provide the PI's and management feedback about the value of the project from an industry perspective. Corrective action is taken in response to each of these reviews. The NSF site review team also provides feedback to the CCEFP with recommendations.

Associated Projects

There are several ways that the CCEFP pursues associated projects. The first driver is created with the review of our strategic technology and sustainability plans. This may identify a need for research in a new area or the need to focus on a new area of technology. Once the call for proposals response is received, a gap analysis is done to identify areas that need additional focus.

This gap analysis is the basis for pursuing new associated projects. For example, in Year 5, this resulted in an associated project called Open Accumulator Compressed Air Storage Concept for Wind Power. New opportunities for funding are developed by monitoring government grants opportunities and working directly with members and potential industry member to solicit support.

Another output from this gap analysis is the identification of needs for new focus. After the Y7-Y8 call for proposals, the following areas were identified as potential opportunities:

- aerospace
- bio-medical
- filtration
- pneumatics
- power train

Activities are underway to identify research opportunities in these areas. This includes researching technical publications, contacting companies (both members and non-members) and experts in the field to better understand the technology needs and financial drivers in these markets. This process is also helping to identify opportunities for collaboration across and outside of the current center structure.

The CCEFP's visibility to the public also creates opportunities for associated projects. Recently a non-member company contacted us to understand more about a research summary they had found on our website. That company is now a member of the CCEFP and working with the PI to develop a focused research project.

Budgeting and Financial Management

The budgeting process is an annual event that includes planning for research and center operations. Budget proposals are submitted to the CCEFP director and are reviewed and approved by the management committee. Regular reports are created by the Administrative Director (AD) and distributed to those with budget responsibility. Deviations with the approved budget are reviewed with the AD and corrective action is taken as required. This topic is discussed in more detail in the financial section of this report.

RET & REU Integration

Please refer to project summaries for Projects B.1 and C.1. The CCEFP has very active REU and RET Programs.

Eighteen REU students participated in summer 2011, the fifth year of the program: two at the University of Minnesota, two at the University of Illinois, six at Purdue, two at MSOE, two at North Carolina A&T, two at Georgia Tech and two at Vanderbilt University. None of these REU students had previous CCEFP REU experience. Nine of the 18 were recruited from outside the CCEFP's core institutions.

Six teachers participated as RETs in summer 2011, the fifth year of the CCEFP RET program: two at the University of Minnesota, two at Vanderbilt and two at Purdue University. The CCEFP requires that all RET participants submit their classroom curriculum to the TeachEngineering.com website which is a repository of evaluated and reviewed curriculum modules. The CCEFP is the only ERC to have RET curriculum modules successfully accepted to the site. The three curriculum modules that have been accepted are named below; six more are under review.

- Hybrid Vehicle Design Challenge - Joel Daniels, Vanderbilt, CCEFP RET 2009
- Fun with Air-Powered Pneumatics - Jacob Givand, Jeffrey and Melissa Schreifels, University of Minnesota, CCEFP RET 2009
- Fluid Power Basics - Brian Bettag, Purdue, CCEFP RET 2009

POST DOCTORAL MENTORING

CCEFP's faculty mentors are obligated to set their post-docs on a path to develop an independent research thrust, to encourage post-docs to become lead writers or principal investigators on at least one research proposal, and to work with post-docs on the strategy and tactics of securing a permanent position. CCEFP post-docs routinely perform funded research, help teach graduate classes, mentor graduate students, and write papers and proposals that also prepare them for future employment.

Three examples of post-doc mentoring activities in CCEFP are:

Dr. Ilker Bayer, University of Illinois at Urbana-Champaign
Ilker has developed into a principal investigator and directly supervised both graduate and undergraduate students. Ilker took the lead in working with Gates Corporation on nano-texture coatings to substantially improve non-wetting characteristics and Haldex on nano-particle additives that improved their external gear pump efficiency by more than 25%. He helped invent a new type of nano-composite coating technique and led the efforts on three high-impact journal paper submissions through acceptance.

Dr. Feng Wang, University of Minnesota
Feng did his graduate studies at Zhejiang University and is preparing for an academic career. His time at UMN is focusing on broadening his experience with theoretical and applied studies at both the component and system level. Feng collaborated on hydraulics research with Sauer Danfoss (a CCEFP member company). He completed a theoretical study of the influence of viscosity and gap size on the efficiency of hydraulic pumps and motors. He also completed a system level comparison of hydraulic hybrid and electric hybrid vehicles. Feng has spent much of the past year doing research on the use of a hydrostatic transmission for wind power, a CCEFP associated project. He is a key member of the UMN team working with Eaton Corporation and Clipper Windpower on a Department of Energy-funded project focused on developing a hydrostatic drivetrain for off-shore wind turbines (6 MW+). He meets with Prof. Stelson on a regular basis and has functioned well in opportunities to provide leadership to graduate students. Feng has authored or co-authored 5 papers and had one published in the *IEEE/ASME Transactions on Mechatronics* during his time at UMN.

Dr. Ali Sadighi, University of Minnesota
Ali received his Ph.D. in Mechanical Engineering from Texas A&M University in 2010. He worked on the free piston engine hydraulic pump project during 2011. Ali’s background is on design, modeling and control of electromagnetic actuators. The CCEFP experience helped to broaden his skill sets into the fluid power area. Ali worked closely with the faculty advisor and the graduate students. We have weekly meetings to discuss the project status as well as future plan. Ali helped to supervise the graduate students and communicate with industry suppliers. Ali has authored and co-authored two conference papers on this subject and is a co-inventor of an IP disclosure.

The post-docs at CCEFP play a very important role bridging the development of strategy for and implementation of research, dissemination of results, and teaching and mentoring of students.

COMMUNICATIONS

The CCEFP uses several formats to communicate with stakeholders including NSF, industry, the scientific and engineering communities, students of all ages, and the general public. External communication uses multiple media outlets including meetings, web casts, print media, e-mail, the World Wide Web, video and television.

Having previously identified industry as comprised of two distinct audiences, we have continued to provide the *industry executives* with concise information affording an overall view of the research and education/outreach efforts taking place within the Center. Key among these efforts to reach industry executives are quarterly letters from the Director, monthly e-mail Newsblasts, and access to member’s only information via the private section of the CCEFP website. The second industry stakeholder identified are the *Industry technologists* who are provided with detailed information on a more frequent basis and of a more technical nature given their scientific interests and their role in collaborating with the research teams through the Project Champions program. Bi-weekly research project webcasts, monthly IAB teleconferences, and a quarterly newsletter are among the efforts targeted at this stakeholder group.

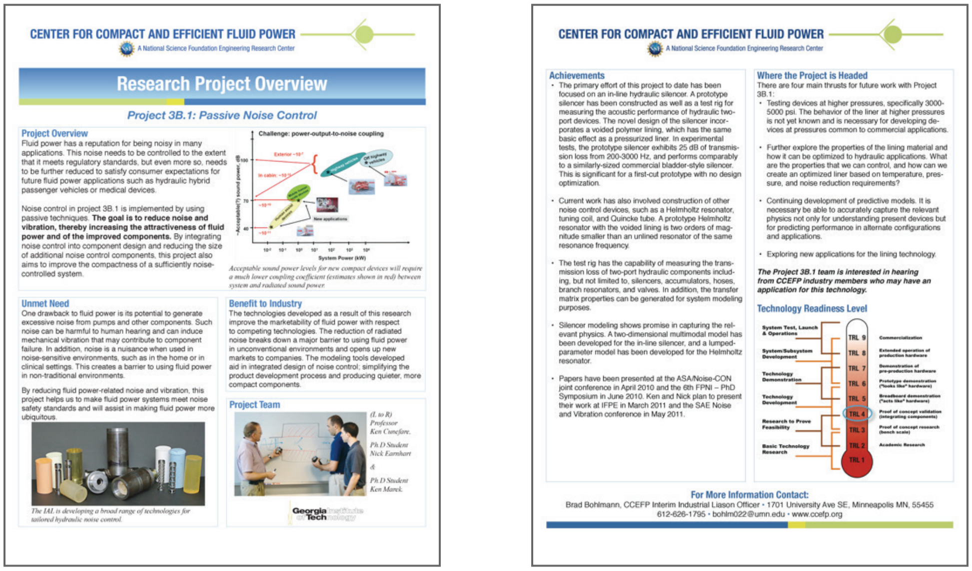
CCEFP efforts to further engage students and faculty have included a formal, online survey tool to provide feedback to Center leadership with regard to meetings, events, project reviews and other operations that require the participation of all members.

Communications outreach to the general public continues to be accomplished through a comprehensive, cutting-edge website presence and through online social media and the availability of our fluid power documentary “Discovering Fluid Power” in DVD format.

A brief description of key communications tools used to reach our many stakeholders follows:

Research Project Overviews – Each research project has been summarized in its own informational and promotional sheet. These Research Project Overview sheets outline the unmet need, benefit to industry, research personnel, project achievements and technology readiness level (TRL) of each CCEFP project. Not only are these sheets informative for member industry executives and technologists, but they are also beneficial to the recruitment of new industry partners. They were first made available during the 2011 IFPE show and are currently online at the CCEFP website (www.ccefp.org).

The research project overviews will be updated in 2012 to reflect the new project portfolio. Feedback from the SAB indicated that the TRL rating for the projects were likely set over-optimistically. This will also be addressed as the overviews are updated.



CENTER FOR COMPACT AND EFFICIENT FLUID POWER

A National Science Foundation Engineering Research Center

Research Project Overview

Project 3B.1: Passive Noise Control

Project Overview

Fluid power has a reputation for being noisy in many applications. This noise needs to be controlled to the extent that it meets regulatory standards, but even more so, needs to be further reduced to satisfy consumer expectations for future fluid power applications such as hydraulic hybrid passenger vehicles or medical devices.

Noise control in project 3B.1 is implemented by using passive techniques. **The goal is to reduce noise and vibration, thereby increasing the attractiveness of fluid power and of the improved components.** By integrating noise control into component design and reducing the size of additional noise control components, this project also aims to improve the compactness of a sufficiently noise-controlled system.

Acceptable sound power levels for new compact devices will require a much lower coupling coefficient (estimates shown in red) between system and radiated sound power.

Unmet Need

One drawback to fluid power is its potential to generate excessive noise from pumps and other components. Such noise can be harmful to human hearing and can induce mechanical vibration that may contribute to component failure. In addition, noise is a nuisance when used in noise-sensitive environments, such as in the home or in clinical settings. This creates a barrier to using fluid power in non-traditional environments.

By reducing fluid power-related noise and vibration, this project helps us to make fluid power systems meet noise safety standards and will assist in making fluid power more ubiquitous.

The IAL is developing a broad range of technologies for tailored hydraulic noise control.

Benefit to Industry

The technologies developed as a result of this research improve the marketability of fluid power with respect to competing technologies. The reduction of radiated noise breaks down a major barrier to using fluid power in unconventional environments and opens up new markets to companies. The modeling tools developed aid in integrated design of noise control; simplifying the product development process and producing quieter, more compact components.

Project Team

(L to R)
Professor
Ken Cunefare,

Ph.D Student
Nick Earnhart

&

Ph.D Student
Ken Marek.

Georgia Institute of Technology

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Achievements

- The primary effort of this project to date has been focused on an in-line hydraulic silencer. A prototype silencer has been constructed as well as a test rig for measuring the acoustic performance of hydraulic two-port devices. The novel design of the silencer incorporates a voided polymer lining, which has the same basic effect as a pressurized liner. In experimental tests, the prototype silencer exhibits 25 dB of transmission loss from 200-3000 Hz, and performs comparably to a similarly-sized commercial bladder-style silencer. This is significant for a first-cut prototype with no design optimization.
- Current work has also involved construction of other noise control devices, such as a Helmholtz resonator, tuning coil, and Quincke tube. A prototype Helmholtz resonator with the voided lining is two orders of magnitude smaller than an unlined resonator of the same resonance frequency.
- The test rig has the capability of measuring the transmission loss of two-port hydraulic components including, but not limited to, silencers, accumulators, hoses, branch resonators, and valves. In addition, the transfer matrix properties can be generated for system modeling purposes.
- Silencer modeling shows promise in capturing the relevant physics. A two-dimensional multimodal model has been developed for the in-line silencer, and a lumped-parameter model has been developed for the Helmholtz resonator.
- Papers have been presented at the ASA/Noise-CON joint conference in April 2010 and the 6th FPNI – PhD Symposium in June 2010. Ken and Nick plan to present their work at IFPE in March 2011 and the SAE Noise and Vibration conference in May 2011.

Where the Project is Headed

There are four main thrusts for future work with Project 3B.1:

- Testing devices at higher pressures, specifically 3000-5000 psi. The behavior of the liner at higher pressures is not yet known and is necessary for developing devices at pressures common to commercial applications.
- Further explore the properties of the lining material and how it can be optimized to hydraulic applications. What are the properties that we can control, and how can we create an optimized liner based on temperature, pressure, and noise reduction requirements?
- Continuing development of predictive models. It is necessary be able to accurately capture the relevant physics not only for understanding present devices but for predicting performance in alternate configurations and applications.
- Exploring new applications for the lining technology.

The Project 3B.1 team is interested in hearing from CCEFP industry members who may have an application for this technology.

Technology Readiness Level

For More Information Contact:

Brad Bohlmann, CCEFP Interim Industrial Liason Officer • 1701 University Ave SE, Minneapolis MN, 55455
612-626-1795 • bohlm022@umn.edu • www.ccefp.org

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Research Project Overviews

Meetings - The CCEFP has two annual meetings: the NSF Site Visit and the CCEFP Annual Meeting. The primary purpose of the Site Visit is for NSF Center review. The primary purpose of the Annual Meeting is to communicate directly with industry. The Site Visits have always been held at the University of Minnesota, and the Annual Meeting rotates among partner universities. Previous CCEFP Annual Meetings have taken place at the following locations:

2007 -- Georgia Institute of Technology
2008 -- Milwaukee School of Engineering
2009 -- North Carolina A&T State University
2010 -- Purdue University (in conjunction with the 6th Annual
Fluid Power Net International Ph.D Symposium
2011 -- CCEFP’s Site Visit and Annual Meeting held in conjunction with the International
Exposition for Power Transmission (IFPE)

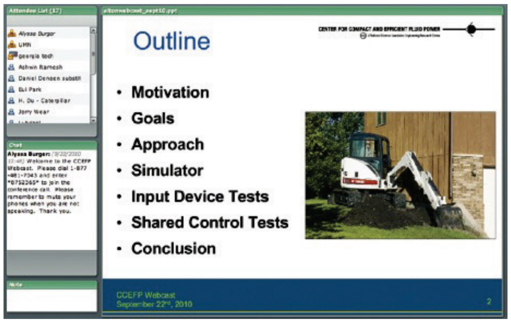
In September 2012 the CCEFP Annual Meeting will be held at the University of Illinois Urbana-Champaign. The event will be preceded by a joint event with the National Fluid Power Association (NFPA) called the Student Networking Summit to provide exposure of the students to the Fluid power Industry

Website - The CCEFP website, www.ccefp.org, continues to be a source for information to the public as well as for our members. The website is a means to communicate information to the widest audience and content is updated regularly. A password-protected member's only section allows industry members, faculty and student access to private information not available to the general public and non-member industry companies.

Industry CEO Letters from the Director - Once per quarter, CCEFP mails letters to all industry member CEOs highlighting achievements and important discoveries that have transpired in the previous three months. In this way, industry executives are made aware of the progress within the Center from a high-level view. Whenever possible, the Center also seeks to highlight the collaborative efforts of individual IAB representatives and Project Champions, so CEOs are aware of the efforts taking place on behalf of their companies.

E-mail Newsblasts - CCEFP Newsblasts provide visually interesting and concise updates on a variety of activities taking place in and around the Center each month. The abbreviated format of the stories enables the reader to see a brief synopsis of each with the option to read more. In this way, readers can stay abreast of the latest news items without having to read through the full articles.

Research Webcasts - Webcasts are a valuable form of communication and provide current information on CCEFP research projects and other topics of interest to members. The Student Leadership Council organizes a bi-weekly, one-hour webcast, each featuring three student research projects. The webcast is regularly viewed by a number of member companies, with robust interaction between the industry members and the student presenters during the Q & A portion. Archived recordings of all webcasts are available in the member's section of our website should listeners wish to watch them again or view them at a later time.



Alyssa Burger: 9/22/2010 12:46] Welcome to the CCEFP Webcast. Please dial 1-877-481-7343 and enter *6752365* to join the conference call. Please remember to mute your phones when you are not speaking. Thank you.

Outline

- Motivation
- Goals
- Approach
- Simulator
- Input Device Tests
- Shared Control Tests
- Conclusion

CCEFP Webcast
September 22nd, 2010

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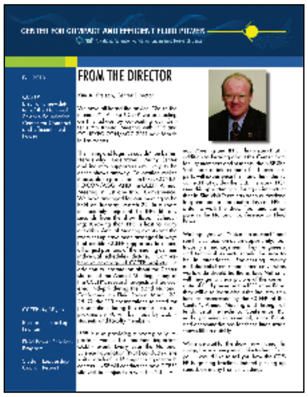
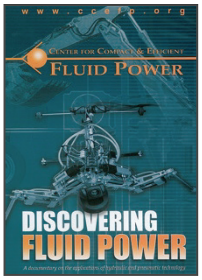


CCe-FP Electronic Newsletter
The CCEFP newsletter is published quarterly to allow for more in-depth content, specifically in the research areas. It is circulated electronically via our comprehensive e-mail list-serve and reaches subscribers in all stakeholder areas including academia, the trade press, industry, K-12 education, and many others both in the U.S. and internationally.

Online Survey Tool - Online surveying has been implemented to assess preferences of faculty, students and industry members prior to planning meetings and/or events at which the full membership will participate, and to gauge attendee satisfaction following such events. In addition, the tool has been used to obtain feedback on various other CCEFP administrative systems already in use, so the leadership can determine methods and frequency of use, preferences, and recommendations from the users before making changes to those systems.

Social Networking - Outreach to students, educators, friends of fluid power and the general public is currently underway using a variety of online social media to provide information about the Center and its many efforts. Some of this category of tools currently in use include Facebook, YouTube and TeacherTube. CCEFP will continue to reach out to various audiences using these and other free, ubiquitous online tools whenever appropriate.

Documentary DVD - The promise of fluid power is being communicated to K-12 educators and the wider public with two half-hour public television programs which have aired regularly on public television stations throughout the country. Additionally, the programs are available "on demand" through the Research Channel website and its cable television channels. Also of note, these programs are available for viewing on our website and are still being distributed in DVD format at no cost to those requesting one. In the year since these films were produced, there have been well over 100 requests from educators and other interested parties in the U.S. and internationally.



Trade Press - The CCEFP actively seeks out opportunities to inform the public about the Center's work in research, education and outreach. Projects and research taking place in the CCEFP are often featured in a variety of fluid power trade publications such as *Hydraulics & Pneumatics, Design News,* and *Diesel Progress* as well as several others. Publications that can be categorized under the trade press umbrella, specifically those whose readers have an interest in some aspect of fluid power, form a far-reaching network and also include those of trade associations, professional societies, specialty publications and online media. Their circulations range anywhere from approximately 2,000 to 100,000 readers. When articles about the CCEFP are carried in any of these publications, the Center is extending its network, reaching engineers and technicians in the fluid power industry and the industries it serves.

SUSTAINABILITY

We have formed the CCEFP Sustainability Task Force to create a plan to guide us through the transition from NSF ERC funding to independent sustainability. The members of the task force are:

- Kim Stelson - University of Minnesota, Chair
- Andrew Alleyne -University of Illinois, Urbana-Champaign
- Wayne Book -Georgia Institute of Technology
- Tom Bray - Milwaukee School of Engineering
- Ed Howe -Enfield Technologies
- Monika Ivantysynova -Purdue University
- Joe Kovach -Parker-Hannifin
- Eric Lanke - National Fluid Power Association
- Lonnie Love -Oak Ridge National Laboratory
- Bill Parks - Deltrol Fluid Products

A summary of the current plan for sustainability of the CCEFP appears below:

Executive summary

The Center for Compact and Efficient Fluid Power (CCEFP) has developed a plan to be sustainable as the NSF ERC funding comes to an end in 2016. This document presents an overview of that plan. The CCEFP will continue to focus on fundamental and applied research with close industry collaboration. The plan introduces the concept of Centers of Excellence (CoE) at partner universities that are closely aligned with the strategic research goals of the home university and the CCEFP's strategy. Alignment with the institution's strategic goals is critical for sustainability and will provide an environment that attracts highly skilled researchers and students. Although these CoEs could exist alone, they are stronger because of their membership in the CCEFP.

The Center for Compact and Efficient Fluid Power

The Center for Compact and Efficient Fluid Power (CCEFP) is an NSF funded Engineering Research Center. It is nearing the end of its sixth year of funding. It is critical that the center commits to a plan for sustainability. The center's lead university is the University of Minnesota. The center consists of seven universities. Besides the U of MN, the CCEFP partner institutions are Georgia Institute of Technology, University of Illinois Urbana-Champaign, Purdue University, Vanderbilt University, Milwaukee School of Engineering and North Carolina A&T.

Since the inception of the CCEFP, the Mission and Vision have remained the unchanged:

CCEFP Mission: **CHANGING THE WAY FLUID POWER IS RESEARCHED, APPLIED AND TAUGHT**
CCEFP Vision: **We are a sustainable organization that brings forward technologies (to industry) enabling fluid power to be compact, efficient and effective**.

- Compact means smaller and lighter for the same function.
- Efficient means saving energy.
- Effective means clean, quiet, safe and easy-to-use.

As the CCEFP moves toward sustainability without NSF ERC funding, the Mission and Vision of the Center will remain the same. The Vision brings together three critical success factors; compactness, efficiency and effectiveness. These factors will continue to guide the research activity as they have since the CCEFP was founded in 2006. By bringing together technology researchers and application experts from industry, we are able to direct research so it has the maximum impact on society. We have also confirmed that a focus on education is very important not only to society but also to our industry partners.

The Vision has been validated by our industry partners who continue to focus on compactness, efficiency and effectiveness to make their product more valuable to their markets. In light of the current demand on our energy resources, this vision is proper.

Situation analysis:

Current CCEFP funding comes primarily from three sources; NSF ERC funding and supplemental grants ($4.2 million), university matching funds ($800K) and industry membership dues ($700K). The center's Principal Investigators (PIs) have also received funding from associated projects that currently total $2.4 million. NSF ERC funding will decline beginning after year 8 and phase out after year 10.

An analysis of the CCEFP's Strengths, Weaknesses, Opportunities and Threats (SWOT) is a starting point to understand the center's current state and plan for a stronger future state. The SWOT analysis reveals an environment that leverages a broad set of skills and provides access to high quality future employees for industry. It also exposes some weaknesses that a future organization may help to address.

The plan for a future CCEFP must support the goals of the partner universities and colleges to be sustainable. It also needs to provide an environment that encourages the Principal Investigators (PIs) to engage. These key attributes are missing in the current organization and therefore the PIs engage at will. Close alignment with the institutions goals will help provide an environment that will encourage PI engagement. This is a critical weakness within the existing organization.

Once the NSF ERC funding is reduced and ultimately eliminated at the end of May 2016, the CCEFP needs to be financially sustainable. To achieve this, the CCEFP needs to develop a model that allows each member university to focus on their strategic plans which will encourage long term support. Doing so will maximize cooperation, maintain visibility locally and have positive impact on sustaining the CCEFP. The local awareness will provide individual visibility for the researchers. It is believed that this individual visibility will promote engagement in the CCEFP.

The CCEFP was founded on the NSF principles of blending fundamental and applied research. These principles have helped to engage significant industry involvement. Maintaining industry involvement is a strategic goal for the CCEFP as it plans for sustainability. There is another sector of membership that the center is beginning to focus on. This is the government sector that includes government agencies and departments including the EPA, Federal Research Laboratories, Department of Defense and the Department of Energy. This was identified as a gap in the CCEFP membership inventory and is being addressed.

Future CCEFP

The CCEFP, under the guidance of the NSF, has built an infrastructure to develop close relationships between the researchers and industry. It is believed that this needs to be a key feature to be preserved in a future state.

The NSF ERC funding is a key element that has supported the pre-competitive research which is very beneficial to the industry members. Through years of collaboration between universities and industry, close relationships have developed. It is essential that these relationships be preserved to support long term sustainability. Industry and researchers will have opportunities to secure government funding by jointly proposing projects. Funding requests proposed jointly by industry and academia are typically well received.

The future CCEFP needs to be supported by each partner university to increase the likelihood of being sustainable. A way to accomplish this is to align the work at each university with the strategy of that university. With this in mind, the future CCEFP will be composed of a network of Centers of Excellence (CoE) that may be capable of existing alone but are stronger because of their association with the CCEFP. Each CoE will support their institution's strategic research focus and will benefit from being associated with an organization that is broad reaching into industry and public sectors. This organization is the CCEFP.

Each Center of Excellence will be proposed by champions at the partner institutions. The final network of CoEs will be defined by the current Executive Committee of the CCEFP. Work is underway to define the focus of the CoEs. It is important that the CCEFP's focus on Compactness, Efficiency and Effectiveness is maintained. The mission and vision of each CoE will support both the goals of the CCEFP and their university's strategic plan. Figure 1 shows a possible organization of the future CCEFP.

This organization allows each university to support the strategic goals of their institution while gaining benefits from the CCEFP organization. It is expected that industry members will focus on specific CoEs. This focus will provide more value to both industry and the CoE.

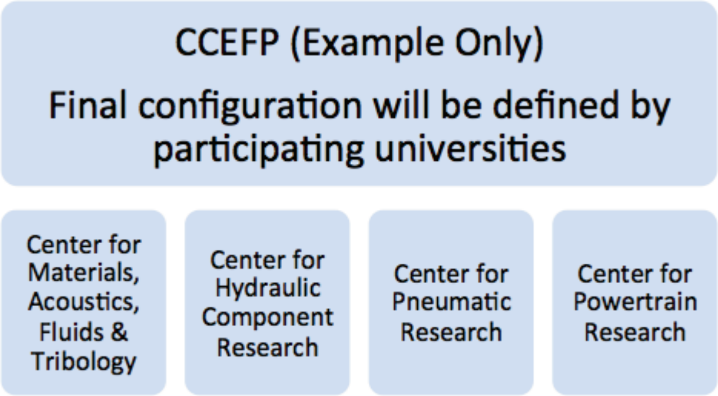


Figure 1: Possible CCEFP Organization

It is important that the CCEFP continues to encourage collaboration between researchers. The proposal template for the CoEs includes a section on collaboration which will be an important factor when considering the CoE selection. The CoEs are also encouraged to recruit researchers from other universities. The CCEFP will also be managed to foster collaborations between institutions and to draw on skills that are potentially outside of the current member universities.

There are also opportunities for “shared” CoEs. An example of this is the synergy between the University of MN and Vanderbilt University. Both universities have medical device research in the strategy. Georgia Tech has a strong robotics focus and the University of Illinois UC has researchers focused on othothsis. It is possible that a Center for Human Assistive Technologies could combine researchers from these and possibly other universities to develop a strong CoE. Another example of this is the tribology focus at Georgia Tech, Purdue, UIUC and MSOE.

The organization provides an environment to maintain the current industry partnerships and expand these to include broader involvement. It will also allow industry members to be more involved in their primary area of interest while the CCEFP continues to facilitate communications between the CoEs and industry.

The CCEFP will continue to recruit industry members. Industry members will be able to focus their interest and energy on one or more CoEs. With a clearer focus, industry will continue to influence research and likely partner even closer with the researchers.

It is envisioned that with more support from the universities, the CCEFP and CoEs will be able to recruit high quality students. Because industry will be able to focus energy on particular CoEs, there will be greater opportunity for interaction between industry members, PIs and students.

Organization and Management

The CCEFP organization will be patterned after the NSF ERC structure but will be modified to address lessons that have been learned. The proposed organizational structure will include features that will engage more industry representation than the previous CCEFP Organization. The reason for this is to gain more insight about perceived value by industry. It is also an attempt to help industry see higher value in research and counter the current demands by investors to focus on short term results. Industry will play an active role in Industrial Advisory Boards, CCEFP Governing Board, the CCEFP Technology Advisory Board and the E&O Advisory Board. The roles and makeup are developed in the full sustainability plan included in Appendix V of this report.

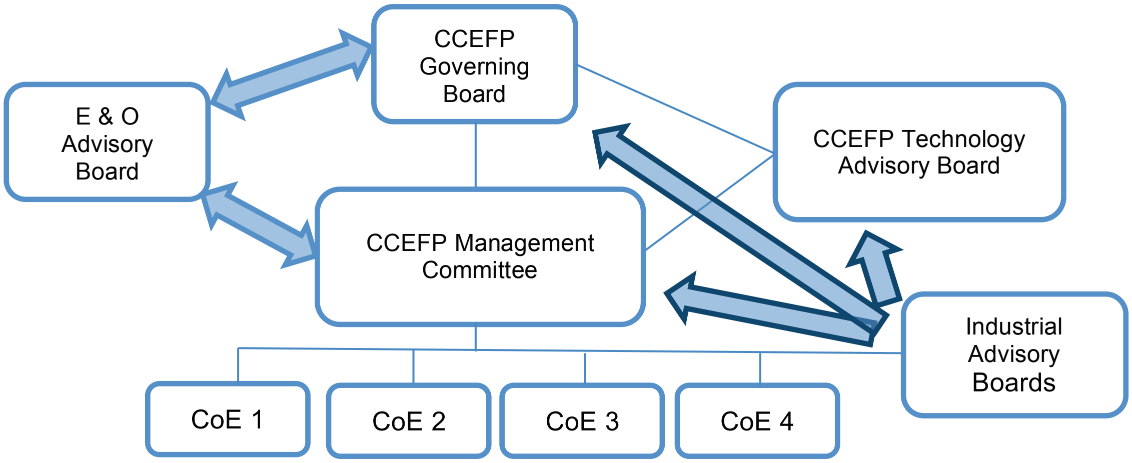


Figure 3 – CCEFP Organization

Financial Model

The financial model for the CCEFP is being developed. It is based on a tiered membership structure that would allow members to choose their level of support based on perceived benefits. The proposed membership matrix appears in the figure below.

Proposed Membership Matrix			
Base Annual Membership at Gold or Platinum Levels includes 1 CoE			
Company Size	**Membership Level**		
10% of Global Sales or Global Hydraulic Power Sales - whichever is greater	Silver	Gold	Platinum
Less than $25 million	$1,000	$5,000	$10,000
$25 - $100 million	$6,000	$15,000	$25,000
$100 - $500 million	$12,000	$40,000	$70,000
Over $500 million	$15,000	$50,000	$90,000
Addition CoE Memberships			
Less than $25 million	--	$2,500	$5,000
$25 - $100 million	--	$7,500	$15,000
$100 - $500 million	--	$20,000	$40,000
Over $500 million	--	$25,000	$50,000

The following table presents a high level financial model of the CCEFP. A Detailed development of this model is included in the complete sustainability plan which is located in Appendix V of this report.

Income	
Membership Dues	$1,135,000
Government Funded Research	$2,400,000
Matching funds (10% of Gov't Funding)	$240,000
Industry Funded Projects	$1,600,000
Total Income	$5,375,000
Operating Expenses	$944,556
Research Funding	$4,430,444

The transition to the new structure will begin in Year 8. During Year 7 the model will be developed with input from all stakeholders. It is expected that there will be adjustments based on this input. Beginning in Year 9, the NSF Funds will be allocated to the CoE's to fund the start up the new organization. We will begin transitions membership at that time as well.

Why will the CCEFP Succeed?

As the CCEFP transitions to this new structure, each member company will have an opportunity to be more involved in their specific areas of interest. The industry advisory boards at each CoE will have more influence on the research occurring. Active engagement by industry members will provide opportunities to develop even stronger relationships with researchers in the fields that will have the greatest impact on the industry member.

A more focused research strategy with active industry involvement will attract the best students. The CoE structure will provide industry members better access to these students and therefore it will also provide a channel to recruit new employees that have known skills which meet the organization's needs.

Close alignment with the strategic research goals at the member universities will provide motivation for the researchers to engage. Their engagement will be rewarded with recognition from their administration which will be high value to the researchers. This engagement will build a stronger CCEFP.

Because we have a minimum of two years to refine this plan, all stakeholders will have the opportunity to engage in the planning process. The CCEFP is actively engaging stakeholders to create a CCEFP that provides high value to them.

Over the next two years, while the CCEFP will continue to be funded primarily by the NSF, there is time to develop the CoEs and recruit members to support them. As NSF funding decreases, additional funding will be required. Industry and government agency relations that are being developed will provide a platform to continue to fund precompetitive research. The opportunity to more closely partner with researchers will provide opportunities for industry to gain government funding that might not be available to them without these university partnerships. Also, these relationships will reveal opportunities for industry to fund targeted research that builds on the research occurring within the CCEFP. In the near term, it is not necessary to significantly increase membership dues in the CCEFP. This will encourage existing industry members to engage in the development of this plan.

A more complete version of the sustainability plan appears in Appendix V.

Financial Tables

Table 8 shows the planned functional budget for Year 6 (NSF-generated Table 8, Figure 8a, Tables 9, 10 and 11 appear at the end of this section.) The research budget shows the following distribution between thrusts and test beds: Efficiency Thrust (34%), Compactness Thrust (29%), Effectiveness Thrust (18%), Test Beds (19%). The percentage distribution of the functional budget is shown in Figure 8a. The major expense is research, shown at 40.7% of the budget, with funding for education and outreach activities (including REU and RET) at 7.1%. While there has been a small decrease in number of member companies, In-kind contributions of equipment and software have increased in year 6 from $123,000 to $136,000, and our methods for tracking those contributions improved in year 6, with the introduction of a new data collection system that is discussed in volume two of this report (data management plan).

It is expected that this basic distribution will continue into the future with only minor modifications. It is expected that industry membership fees, associated projects from industry and government will continue to grow in year 7. Industry funding in year 6 remained steady, with 80% of membership dues received, and 20% anticipated before the end of year 6, providing $804,394 of income from membership dues and other cash contributions. Six new industry members joined in year 6: CNH America, Freudenberg - NOK, Nitta Moore, StorWatts, Walvoil Fluid Power and Woodward Inc. An additional three companies have paperwork underway to become members. The change in Industrial/Practitioner involvement from 54 in year five to 47 in year six is primarily related to involvement type changes which are detailed in section 1.2 of this volume. Membership growth is expected to continue in future years. Associated project funding has continued to grow each year with an increase to $2,311,570 in year 6. As seen in Table 9, year 6 funding was 19% higher than year 5.

Year 6: $2,311,570 (direct costs only)
Year 5: $1,885,000 (direct costs only)

Table 8b below shows the Year 6 budget distribution by university. The largest recipient of direct cash funding and associated project funding is the lead university with 33%. The difference between the lead and core university direct cash funding is largely due to the additional expenses of Center administration.

Table 8b: Proportional Distribution of Current Award Year Budget					
Institution	**Direct Cash (Unrestricted and Restricted)**	**Associated Projects**	**Total Cash and Associated Projects**	**% of Total Direct Cash**	**% of Total Assoc. Projects**
University of Minnesota	$2,471,476	$769,047	$3,240,523	48%	33%
Georgia Tech	$739,353	$64,638	$803,991	14%	3%
Milwaukee School of Engineering	$330,101	$383,500	$713,601	6%	17%
North Carolina A & T	$210,177	$27,176	$237,354	4%	1%
Purdue University	$641,923	$1,054,514	$1,696,438	12%	46%
UIUC	$362,676	$0	$362,676	7%	0%
Vanderbilt University	$317,950	$12,692	$330,642	6%	1%
Science Museum of Minnesota	$90,000	$0	$90,000	2%	0%
FolsomTechnologies International	$0	$0	$0	0%	0%
Grand Total	$5,163,656	$2,311,568	$7,475,224		

Table 8c: Current Award Year Education Budget, a part of the overall ERC budget, is show below as funds are distributed by program area.

Table 8c: Current Award Year Education Functional Budget					
Education Programs	**Direct Support**		**Direct Support Total**	**Associated Projects**	**Total Budget**
	Unrestricted Cash OR Core Projects	**Restricted Cash OR Sponsored Projects**			
Precollege Education Activities	$45,500	$0	**$45,500**	$0	**$45,500**
University Education	$44,600	$0	**$44,600**	$0	**$44,600**
Student Leadership Council	$18,500	$0	**$18,500**	$0	**$18,500**
Young Scholars	$0	$0	**$0**	$0	**$0**
REU	$181,254	$0	**$181,254**	$0	**$181,254**
RET	$51,083	$0	**$51,083**	$0	**$51,083**
Assessment	$45,000	$0	**$45,000**	$0	**$45,000**
Community College activities	$7,000	$0	**$7,000**	$0	**$7,000**
Other	$91,000	$0	**$91,000**	$0	**$91,000**
Education Program Total	**$483,937**	**$0**	**$483,937**	**$0**	**$483,937**

Table 9a shows the funding history of the Center and includes funding amounts on the base grant for years 1-6, plus supplements since inception. In year 6, two diversity graduate students received supplemental funding to total $39,989.

Table 9a: History of ERC Funding of the Center						
Award Number	**Award Type**	**Award Title**	**Award Duration**	**Amount**	**Status**	**Final Report Approved?**
0540834	Base	Engineering Research Center for Compact and Efficient Fluid Power	6 years	$21,480,000	In progress	N/A
0540834	REU Supplement	Engineering Research Center for Compact and Efficient Fluid Power	1 year	$65,801	Completed	N/A
0540834	NSF/GRDS Supplement	Engineering Research Center for Compact and Efficient Fluid Power	1 year	$44,814	Completed	N/A
0540834	NSF/SECO Supplement	Engineering Research Center for Compact and Efficient Fluid Power	2 years	$199,999	In progress	N/A
0540834	NSF/GRDS Supplement	Engineering Research Center for Compact and Efficient Fluid Power	1 year	$81,725	Completed	N/A
0540834	NSF/GRDS Supplement	Engineering Research Center for Compact and Efficient Fluid Power	1 year	$39,989	In progress	N/A

Table 9 (at the end of this section) shows the sources of support, and Table 9b below includes the cost sharing by institution. In Year 5, all Core Partner universities exceeded cost-sharing obligations, except Georgia Tech, who fell short by $16,436. CCEFP Core Partners provided $946,383 in cost-sharing cash toward the obligated $800,000.

Table 9b - Cost Sharing by Institution						
	Award Year 1 (FY07)		**Award Year 2 (FY08)**		**Award Year 3 (FY09)**	
Institution	**Committed**	**Actual**	**Committed**	**Actual**	**Committed**	**Actual**
U. of Minnesota	$180,180	$180,180	$182,000	$182,000	$220,469	$220,469
Georgia Tech	$112,860	$67,584	$129,000	$140,827	$133,000	$83,110
MSOE	$0	$0	$10,800	$18,086	$0	$0
Purdue	$112,860	$112,860	$129,000	$113,321	$133,000	$162,637
UIUC	$112,860	$33,529	$123,200	$77,249	$124,865	$201,233
Vanderbilt	$75,240	$75,240	$76,000	$157,021	$88,666	$112,359
	Award Year 4 (FY10)		**Award Year 5 (FY11)**		**Award Year 6 (FY12)**	
Institution	**Committed**	**Actual**	**Committed**	**Actual**	**Committed**	**Actual**
U. of Minnesota	$226,367	$187,032	$242,667	$327,140	$339,537	-
Georgia Tech	$142,995	$267,384	$152,000	$135,564	$130,232	-
MSOE	$0	-	$0	-	$0	-
Purdue	$142,995	$139,404	$152,000	$200,153	$152,557	-
UIUC	$142,995	$210,852	$119,541	$163,809	$92,093	-
Vanderbilt	$94,648	$69,213	$101,333	$119,717	$85,581	-
	Award Year 7 (FY13)		**Award Year 8 (FY14)**		**Cumulative Commitment**	
Institution	**Committed**	**Actual**	**Committed**	**Actual**		
U. of Minnesota	$339,537	-	$339,537	-	$2,070,294	
Georgia Tech	$130,232	-	$130,232	-	$1,060,551	
MSOE	$0	-	$0	-	$10,800	
Purdue	$152,557	-	$152,557	-	$1,127,526	
UIUC	$92,093	-	$92,093	-	$899,740	
Vanderbilt	$85,581	-	$85,581	-	$692,630	

Table 10 (at the end of this section) shows the annual expenditures and budgets, with Table 10a below showing unexpended residuals. Referring to the residual amounts in Table 10a, the carry-forward amount of $1,054,053, and $0 residuals, shows that all money was either committed or encumbered, at the start of year 6. The residual balance of -$92,217, after committed/encumbered/obligated funds, demonstrates that the Center continues to spend in a disciplined pattern as it starts year 7.

Table 10a: Unexpended Residual in the Current Award and Proposed Award Year

	Previous Award Year to Current Award Year	**Current Award Year to Proposed Award Year**
Total Unexpended Residual Funds	$1,054,053	$2,638,310.11
Committed, Encumbered, Obligated funds	$1,054,053	$2,730,526.72
Residual Funds Without Specified Use	$0	-$92,217

Table 11 details the modes of recent and historical support provided by Industry Members and non-member organizations alike.

Table 8: Current Award Year Functional Budget

Function	Direct Support		Direct Support Total	Associated Projects	Total Budget
	Unrestricted Cash (Core Projects)	Restricted Cash (Sponsored Projects)			
1: Efficiency	$961,792	$0	$961,792	$1,822,662	$2,784,454
2: Compactness	$805,424	$0	$805,424	$238,186	$1,043,610
3: Effectiveness	$497,107	$0	$497,107	$250,722	$747,829
Test Beds	$527,290	$0	$527,290	$0	$527,290
Research Total	**$2,791,613**	**$0**	**$2,791,613**	**$2,311,570**	**$5,103,183**
General Shared Equipment	$144,581	$0	$144,581	$0	$144,581
New Facilities/New Construction	$0	$0	$0	$0	$0
Leadership/Administration/Management	$614,753	$0	$614,753	$0	$614,753
Education Program Total	$483,937	$0	$483,937	$0	$483,937
Industrial Collaboration/Innovation Program	$378,700	$0	$378,700	$0	$378,700
Center Related Travel	$198,805	$0	$198,805	$0	$198,805
Residual Funds Remaining	$489,970	$0	$489,970	N/A	$489,970
Indirect Cost	$1,757,801	$0	$1,757,801	N/A	$1,757,801
Total	**$6,860,160**	**$0**	**$6,860,160**	**$2,311,570**	**$9,171,730**

Figure 8a: Functional Budget as a percentage of Direct Support

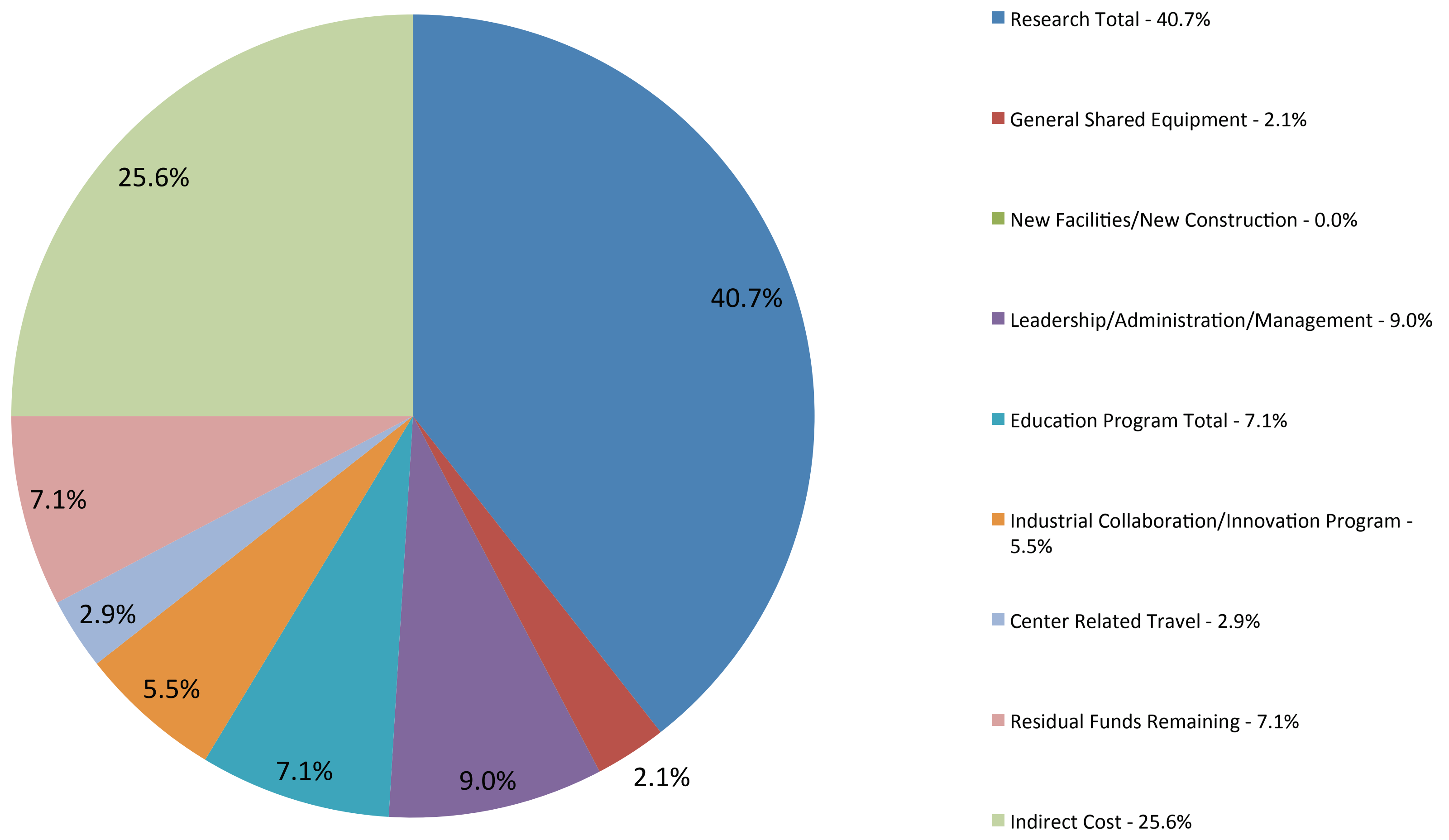


Table 9: Sources of Support

Sources of Support	Early Cumulative Total	Jun 1, 2007 - May 31, 2008	Jun 1, 2008 - May 31, 2009	Jun 1, 2009 - May 31, 2010	Jun 1, 2010 - May 31, 2011	Jun 1, 2011 - May 31, 2012			Cumulative Total [1]
						Received	Promised	Total	
Unrestricted Cash									
Government									
NSF Funding									
NSF ERC Base Award	$1,946,020	$3,250,000	$3,500,000	$3,750,000	$4,010,000	$4,000,000	$0	$4,000,000	$20,456,020
Other NSF (Not ERC Program)	$0	$0	$0	$0	$0	$0	$0	$0	$0
TOTAL NSF FUNDING	**$1,946,020**	**$3,250,000**	**$3,500,000**	**$3,750,000**	**$4,010,000**	**$4,000,000**	**$0**	**$4,000,000**	**$20,456,020**
Other U.S. Government (Not NSF)	$0	$0	$0	$0	$0	$0	$0	$0	$0
State Government	$0	$0	$0	$0	$0	$0	$0	$0	$0
Local Government	$0	$0	$0	$0	$0	$0	$0	$0	$0
Foreign Government	$0	$0	$0	$0	$0	$0	$0	$0	$0
Quasi-government research organization	$0	$0	$0	$0	$0	$0	$0	$0	$0
TOTAL GOVERNMENT FUNDING	**$1,946,020**	**$3,250,000**	**$3,500,000**	**$3,750,000**	**$4,010,000**	**$4,000,000**	**$0**	**$4,000,000**	**$20,456,020**
Industry									
U.S. Industry	$50,793	$633,000	$591,500	$579,415	$517,250	$529,167	$90,750	$619,917	$2,991,875
Foreign Industry	$60,000	$60,000	$141,000	$108,000	$119,000	$71,000	$50,000	$121,000	$609,000
Industrial Association	$0	$0	$0	$0	$51,000	$41,000	$0	$41,000	$92,000
TOTAL INDUSTRY FUNDING	**$110,793**	**$693,000**	**$732,500**	**$687,415**	**$687,250**	**$641,167**	**$140,750**	**$781,917**	**$3,692,875**
University									
U.S. University	$313,763	$650,000	$831,646	$913,885	$800,000	$800,000	$0	$800,000	$4,309,294
Foreign University	$0	$0	$0	$0	$0	$0	$0	$0	$0
TOTAL UNIVERSITY FUNDING	**$313,763**	**$650,000**	**$831,646**	**$913,885**	**$800,000**	**$800,000**	**$0**	**$800,000**	**$4,309,294**
Other									
Private Foundation	$0	$0	$0	$0	$1,000	$0	$0	$0	$1,000
Medical Facility	$0	$0	$0	$0	$0	$0	$0	$0	$0
Non Profit	$0	$0	$0	$0	$0	$0	$0	$0	$0
Venture Capitalist	$0	$0	$0	$0	$0	$0	$0	$0	$0
Other	$0	$0	$0	$0	$0	$0	$0	$0	$0
TOTAL OTHER FUNDING	**$0**	**$0**	**$0**	**$0**	**$1,000**	**$0**	**$0**	**$0**	**$1,000**
Total Unrestricted Cash	**$2,370,576**	**$4,593,000**	**$5,064,146**	**$5,351,300**	**$5,498,250**	**$5,441,167**	**$140,750**	**$5,581,917**	**$28,459,189**
Restricted Cash									
NSF Funding									
NSF ERC Program Special Purpose Awards and Supplements	$0	$65,801	$59,133	$44,814	$281,724	$39,989	$0	$39,989	$491,461
Other NSF (Not ERC Program)	$0	$0	$0	$0	$0	$0	$0	$0	$0
TOTAL NSF FUNDING	**$0**	**$65,801**	**$59,133**	**$44,814**	**$281,724**	**$39,989**	**$0**	**$39,989**	**$491,461**
Restricted Cash - Non Translational									
Government									
Other U.S. Government (Not NSF)	$0	$0	$0	$0	$0	$0	$0	$0	$0
State Government	$0	$0	$0	$0	$0	$0	$0	$0	$0
Local Government	$0	$0	$0	$0	$0	$0	$0	$0	$0
Foreign Government	$0	$0	$0	$0	$0	$0	$0	$0	$0

Sources of Support	Early Cumulative Total	Jun 1, 2007 - May 31, 2008	Jun 1, 2008 - May 31, 2009	Jun 1, 2009 - May 31, 2010	Jun 1, 2010 - May 31, 2011	Jun 1, 2011 - May 31, 2012			Cumulative Total [1]
						Received	Promised	Total	
Quasi-government research organization	$0	$0	$0	$0	$0	$0	$0	$0	$0
TOTAL GOVERNMENT FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Industry									
U.S. Industry	$0	$0	$0	$0	$0	$0	$0	$0	$0
Foreign Industry	$0	$0	$0	$0	$0	$0	$0	$0	$0
Industrial Association	$0	$0	$0	$0	$0	$0	$0	$0	$0
TOTAL INDUSTRY FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
University									
U.S. University	$0	$0	$0	$0	$0	$0	$0	$0	$0
Foreign University	$0	$0	$0	$0	$0	$0	$0	$0	$0
TOTAL UNIVERSITY FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Other									
Private Foundation	$0	$0	$0	$0	$0	$0	$0	$0	$0
Medical Facility	$0	$0	$0	$0	$0	$0	$0	$0	$0
Non Profit	$0	$0	$0	$0	$0	$0	$0	$0	$0
Venture Capitalist	$0	$0	$0	$0	$0	$0	$0	$0	$0
Other	$0	$0	$0	$0	$0	$0	$0	$0	$0
TOTAL OTHER FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Total Restricted Cash - Non Translational	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Restricted Cash - Translational									
Government									
Other U.S. Government (Not NSF)	$0	$0	$0	$0	$0	$0	$0	$0	$0
State Government	$0	$0	$0	$0	$0	$0	$0	$0	$0
Local Government	$0	$0	$0	$0	$0	$0	$0	$0	$0
Foreign Government	$0	$0	$0	$0	$0	$0	$0	$0	$0
Quasi-government research organization	$0	$0	$0	$0	$0	$0	$0	$0	$0
TOTAL GOVERNMENT FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Industry									
U.S. Industry	$0	$0	$0	$0	$0	$0	$0	$0	$0
Foreign Industry	$0	$0	$0	$0	$0	$0	$0	$0	$0
Industrial Association	$0	$0	$0	$0	$0	$0	$0	$0	$0
TOTAL INDUSTRY FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
University									
U.S. University	$0	$0	$0	$0	$0	$0	$0	$0	$0
Foreign University	$0	$0	$0	$0	$0	$0	$0	$0	$0
TOTAL UNIVERSITY FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Other									
Private Foundation	$0	$0	$0	$0	$0	$0	$0	$0	$0
Medical Facility	$0	$0	$0	$0	$0	$0	$0	$0	$0
Non Profit	$0	$0	$0	$0	$0	$0	$0	$0	$0
Venture Capitalist	$0	$0	$0	$0	$0	$0	$0	$0	$0
Other	$0	$0	$0	$0	$0	$0	$0	$0	$0
TOTAL OTHER FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Total Restricted Cash - Translational	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**

Sources of Support	Early Cumulative Total	Jun 1, 2007 - May 31, 2008	Jun 1, 2008 - May 31, 2009	Jun 1, 2009 - May 31, 2010	Jun 1, 2010 - May 31, 2011	Jun 1, 2011 - May 31, 2012			Cumulative Total [1]
						Received	Promised	Total	
Total Restricted Cash	**$0**	**$65,801**	**$59,133**	**$44,814**	**$281,724**	**$39,989**	**$0**	**$39,989**	**$491,461**
Residual Funds carried over from prior years [2]									
Government									
NSF Funding									
NSF ERC Base Award	$1,023,980	$279,300	$696,322	$316,642	$316,643	$589,405	N/A	$589,405	N/A
Other NSF (Not ERC Program)	$0	$49,656	$0	$0	$0	$0	N/A	$0	N/A
TOTAL NSF Residual Funds from Prior Years	**$1,023,980**	**$328,956**	**$696,322**	**$316,642**	**$316,643**	**$589,405**	**N/A**	**$589,405**	**N/A**
Other U.S. Government (Not NSF)	$0	$0	$0	$0	$0	$0	N/A	$0	N/A
State Government	$0	$0	$0	$0	$0	$0	N/A	$0	N/A
Local Government	$0	$0	$0	$0	$0	$0	N/A	$0	N/A
Foreign Government	$0	$0	$0	$0	$0	$0	N/A	$0	N/A
Quasi-government research organization	$0	$0	$0	$0	$0	$0	N/A	$0	N/A
TOTAL GOVT Residual Funds from Prior Years	**$1,023,980**	**$328,956**	**$696,322**	**$316,642**	**$316,643**	**$589,405**	**N/A**	**$589,405**	**N/A**
Industry									
U.S. Industry	$587,207	$599,662	$484,959	$297,485	$297,485	$464,648	N/A	$464,648	N/A
Foreign Industry	$0	$0	$0	$0	$0	$0	N/A	$0	N/A
Industrial Association	$0	$0	$0	$0	$0	$0	N/A	$0	N/A
TOTAL INDUSTRY Residual Funds from Prior Years	**$587,207**	**$599,662**	**$484,959**	**$297,485**	**$297,485**	**$464,648**	**N/A**	**$464,648**	**N/A**
University									
U.S. University	$298,502	$127,439	$281,567	$232,525	$232,757	$184,201	N/A	$184,201	N/A
Foreign University	$0	$0	$0	$0	$0	$0	N/A	$0	N/A
TOTAL UNIVERSITY Residual Funds from Prior Years	**$298,502**	**$127,439**	**$281,567**	**$232,525**	**$232,757**	**$184,201**	**N/A**	**$184,201**	**N/A**
Other									
Private Foundation	$0	$0	$0	$0	$0	$0	N/A	$0	N/A
Medical Facility	$0	$0	$0	$0	$0	$0	N/A	$0	N/A
Non Profit	$0	$0	$0	$0	$0	$0	N/A	$0	N/A
Venture Capitalist	$0	$0	$0	$0	$0	$0	N/A	$0	N/A
Other	$0	$0	$0	$0	$0	$0	N/A	$0	N/A
TOTAL OTHER Residual Funds from Prior Years	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**N/A**	**$0**	**N/A**
Total Residual Funds carried over from prior years [2]	**$1,909,689**	**$1,056,057**	**$1,462,848**	**$846,652**	**$846,885**	**$1,238,254**	**N/A**	**$1,238,254**	**N/A**
Associated Projects [3]									
NSF Funding									
NSF ERC Program	$0	$0	$0	$0	$0	$0	$0	$0	$0
Other NSF (Not ERC Program)	$113,333	$28,833	$99,326	$99,051	$157,667	$591,183	$0	$591,183	$1,089,393
TOTAL NSF FUNDING	**$113,333**	**$28,833**	**$99,326**	**$99,051**	**$157,667**	**$591,183**	**$0**	**$591,183**	**$1,089,393**
Associated Projects - Non Translational [3]									
Government									

Sources of Support	Early Cumulative Total	Jun 1, 2007 - May 31, 2008	Jun 1, 2008 - May 31, 2009	Jun 1, 2009 - May 31, 2010	Jun 1, 2010 - May 31, 2011	Jun 1, 2011 - May 31, 2012			Cumulative Total [1]
						Received	Promised	Total	
Other U.S. Government (Not NSF)	$653,318	$150,000	$734,017	$527,447	$181,485	$13,320	$0	$13,320	$2,259,587
State Government	$0	$0	$0	$0	$0	$0	$0	$0	$0
Local Government	$0	$0	$0	$0	$0	$0	$0	$0	$0
Foreign Government	$0	$0	$0	$0	$0	$0	$0	$0	$0
Quasi-government research organization	$0	$0	$0	$0	$57,276	$0	$0	$0	$57,276
TOTAL GOVERNMENT FUNDING	**$653,318**	**$150,000**	**$734,017**	**$527,447**	**$238,761**	**$13,320**	**$0**	**$13,320**	**$2,316,863**
Industry									
U.S. Industry	$457,629	$620,235	$663,806	$1,098,877	$350,123	$0	$0	$0	$3,190,670
Foreign Industry	$0	$0	$0	$0	$52,865	$78,000	$0	$78,000	$130,865
Industrial Association	$0	$0	$0	$0	$71,067	$0	$0	$0	$71,067
TOTAL INDUSTRY FUNDING	**$457,629**	**$620,235**	**$663,806**	**$1,098,877**	**$474,055**	**$78,000**	**$0**	**$78,000**	**$3,392,602**
University									
U.S. University	$0	$0	$0	$0	$0	$128,550	$0	$128,550	$128,550
Foreign University	$0	$0	$0	$0	$32,000	$13,714	$0	$13,714	$45,714
TOTAL UNIVERSITY FUNDING	**$0**	**$0**	**$0**	**$0**	**$32,000**	**$142,264**	**$0**	**$142,264**	**$174,264**
Other									
Private Foundation	$0	$0	$0	$0	$0	$0	$0	$0	$0
Medical Facility	$0	$0	$0	$0	$0	$0	$0	$0	$0
Non Profit	$0	$0	$0	$0	$0	$0	$0	$0	$0
Venture Capitalist	$0	$0	$0	$0	$0	$0	$0	$0	$0
Other	$5,000	$20,000	$141,620	$0	$1,202,686	$1,099,920	$0	$1,099,920	$2,469,226
TOTAL OTHER FUNDING	**$5,000**	**$20,000**	**$141,620**	**$0**	**$1,202,686**	**$1,099,920**	**$0**	**$1,099,920**	**$2,469,226**
Total Associated Projects - Non Translational	**$1,115,947**	**$790,235**	**$1,539,443**	**$1,626,324**	**$1,947,502**	**$1,333,504**	**$0**	**$1,333,504**	**$8,352,955**
Associated Projects - Translational [3]									
Government									
Other U.S. Government (Not NSF)	$0	$0	$0	$0	$0	$187,208	$0	$187,208	$187,208
State Government	$0	$0	$0	$0	$0	$0	$0	$0	$0
Local Government	$0	$0	$0	$0	$0	$0	$0	$0	$0
Foreign Government	$0	$0	$0	$0	$0	$0	$0	$0	$0
Quasi-government research organization	$0	$0	$0	$0	$0	$0	$0	$0	$0
TOTAL GOVERNMENT FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$187,208**	**$0**	**$187,208**	**$187,208**
Industry									
U.S. Industry	$0	$0	$0	$0	$0	$115,701	$0	$115,701	$115,701
Foreign Industry	$0	$0	$0	$0	$5,000	$83,974	$0	$83,974	$88,974
Industrial Association	$0	$0	$0	$0	$0	$0	$0	$0	$0
TOTAL INDUSTRY FUNDING	**$0**	**$0**	**$0**	**$0**	**$5,000**	**$199,675**	**$0**	**$199,675**	**$204,675**
University									
U.S. University	$0	$0	$0	$0	$0	$0	$0	$0	$0
Foreign University	$0	$0	$0	$0	$0	$0	$0	$0	$0
TOTAL UNIVERSITY FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Other									
Private Foundation	$0	$0	$0	$0	$0	$0	$0	$0	$0
Medical Facility	$0	$0	$0	$0	$0	$0	$0	$0	$0

Sources of Support	Early Cumulative Total	Jun 1, 2007 - May 31, 2008	Jun 1, 2008 - May 31, 2009	Jun 1, 2009 - May 31, 2010	Jun 1, 2010 - May 31, 2011	Jun 1, 2011 - May 31, 2012			Cumulative Total [1]
						Received	Promised	Total	
Non Profit	$0	$0	$0	$0	$0	$0	$0	$0	$0
Venture Capitalist	$0	$0	$0	$0	$0	$0	$0	$0	$0
Other	$0	$0	$0	$0	$0	$0	$0	$0	$0
TOTAL OTHER FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Total Associated Projects - Translational	**$0**	**$0**	**$0**	**$0**	**$5,000**	**$386,883**	**$0**	**$386,883**	**$391,883**
Total Associated Projects	**$1,229,280**	**$819,068**	**$1,638,769**	**$1,725,375**	**$2,110,169**	**$2,311,570**	**$0**	**$2,311,570**	**$9,834,231**
Value of New Construction									
Government									
NSF Funding									
NSF ERC Base Award	$0	$0	$0	$0	$0	$0	$0	$0	$0
Other NSF (Not ERC Program)	$0	$0	$0	$0	$0	$0	$0	$0	$0
TOTAL NSF FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Other U.S. Government (Not NSF)	$0	$0	$0	$0	$0	$0	$0	$0	$0
State Government	$0	$0	$0	$0	$0	$0	$0	$0	$0
Local Government	$0	$0	$0	$0	$0	$0	$0	$0	$0
Foreign Government	$0	$0	$0	$0	$0	$0	$0	$0	$0
Quasi-government research organization	$0	$0	$0	$0	$0	$0	$0	$0	$0
TOTAL GOVERNMENT FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Industry									
U.S. Industry	$0	$0	$0	$0	$0	$0	$0	$0	$0
Foreign Industry	$0	$0	$0	$0	$0	$0	$0	$0	$0
Industrial Association	$0	$0	$0	$0	$0	$0	$0	$0	$0
TOTAL INDUSTRY FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
University									
U.S. University	$0	$0	$0	$0	$0	$0	$0	$0	$0
Foreign University	$0	$0	$0	$0	$0	$0	$0	$0	$0
TOTAL UNIVERSITY FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Other									
Private Foundation	$0	$0	$0	$0	$0	$0	$0	$0	$0
Medical Facility	$0	$0	$0	$0	$0	$0	$0	$0	$0
Non Profit	$0	$0	$0	$0	$0	$0	$0	$0	$0
Venture Capitalist	$0	$0	$0	$0	$0	$0	$0	$0	$0
Other	$0	$0	$0	$0	$0	$0	$0	$0	$0
TOTAL OTHER FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Total Value of New Construction	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Value of Equipment									
Government									
NSF Funding									
NSF ERC Base Award	$0	$0	$0	$0	$0	$0	$0	$0	$0
Other NSF (Not ERC Program)	$0	$0	$0	$0	$0	$0	$0	$0	$0
TOTAL NSF FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Other U.S. Government (Not NSF)	$0	$0	$0	$0	$0	$0	$0	$0	$0

Sources of Support	Early Cumulative Total	Jun 1, 2007 - May 31, 2008	Jun 1, 2008 - May 31, 2009	Jun 1, 2009 - May 31, 2010	Jun 1, 2010 - May 31, 2011	Jun 1, 2011 - May 31, 2012			Cumulative Total [1]
						Received	Promised	Total	
State Government	$0	$0	$0	$0	$0	$0	$0	$0	$0
Local Government	$0	$0	$0	$0	$0	$0	$0	$0	$0
Foreign Government	$0	$0	$0	$0	$0	$0	$0	$0	$0
Quasi-government research organization	$0	$0	$0	$0	$0	$0	$0	$0	$0
TOTAL GOVERNMENT FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Industry									
U.S. Industry	$159,000	$75,000	$350,402	$0	$0	$31,753	$0	$31,753	$616,155
Foreign Industry	$0	$0	$0	$0	$0	$500	$0	$500	$500
Industrial Association	$0	$0	$0	$0	$0	$0	$0	$0	$0
TOTAL INDUSTRY FUNDING	**$159,000**	**$75,000**	**$350,402**	**$0**	**$0**	**$32,253**	**$0**	**$32,253**	**$616,655**
University									
U.S. University	$0	$0	$0	$0	$0	$0	$0	$0	$0
Foreign University	$0	$0	$0	$0	$0	$0	$0	$0	$0
TOTAL UNIVERSITY FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Other									
Private Foundation	$0	$0	$0	$0	$0	$0	$0	$0	$0
Medical Facility	$0	$0	$0	$0	$0	$0	$0	$0	$0
Non Profit	$0	$0	$0	$0	$0	$0	$0	$0	$0
Venture Capitalist	$0	$0	$0	$0	$0	$0	$0	$0	$0
Other	$0	$0	$0	$0	$0	$0	$0	$0	$0
TOTAL OTHER FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Total Value of Equipment	**$159,000**	**$75,000**	**$350,402**	**$0**	**$0**	**$32,253**	**$0**	**$32,253**	**$616,655**
Value of New Facilities in Existing Buildings									
Government									
NSF Funding									
NSF ERC Base Award	$0	$0	$0	$0	$0	$0	$0	$0	$0
Other NSF (Not ERC Program)	$0	$0	$0	$0	$0	$0	$0	$0	$0
TOTAL NSF FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Other U.S. Government (Not NSF)	$0	$0	$0	$0	$0	$0	$0	$0	$0
State Government	$0	$0	$0	$0	$0	$0	$0	$0	$0
Local Government	$0	$0	$0	$0	$0	$0	$0	$0	$0
Foreign Government	$0	$0	$0	$0	$0	$0	$0	$0	$0
Quasi-government research organization	$0	$0	$0	$0	$0	$0	$0	$0	$0
TOTAL GOVERNMENT FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Industry									
U.S. Industry	$0	$0	$0	$0	$0	$0	$0	$0	$0
Foreign Industry	$0	$0	$0	$0	$0	$0	$0	$0	$0
Industrial Association	$0	$0	$0	$0	$0	$0	$0	$0	$0
TOTAL INDUSTRY FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
University									
U.S. University	$57,591	$193,000	$375,000	$0	$0	$0	$0	$0	$625,591
Foreign University	$0	$0	$0	$0	$0	$0	$0	$0	$0
TOTAL UNIVERSITY FUNDING	**$57,591**	**$193,000**	**$375,000**	**$0**	**$0**	**$0**	**$0**	**$0**	**$625,591**
Other									

Sources of Support	Early Cumulative Total	Jun 1, 2007 - May 31, 2008	Jun 1, 2008 - May 31, 2009	Jun 1, 2009 - May 31, 2010	Jun 1, 2010 - May 31, 2011	Jun 1, 2011 - May 31, 2012			Cumulative Total [1]
						Received	Promised	Total	
Private Foundation	$0	$0	$0	$0	$0	$0	$0	$0	$0
Medical Facility	$0	$0	$0	$0	$0	$0	$0	$0	$0
Non Profit	$0	$0	$0	$0	$0	$0	$0	$0	$0
Venture Capitalist	$0	$0	$0	$0	$0	$0	$0	$0	$0
Other	$0	$0	$0	$0	$0	$0	$0	$0	$0
TOTAL OTHER FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Total Value of New Facilities in Existing Buildings	**$57,591**	**$193,000**	**$375,000**	**$0**	**$0**	**$0**	**$0**	**$0**	**$625,591**
Value of Visting Personnel									
Government									
NSF Funding									
NSF ERC Base Award	$0	$0	$0	$0	$0	$0	$0	$0	$0
Other NSF (Not ERC Program)	$0	$0	$0	$0	$0	$0	$0	$0	$0
TOTAL NSF FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Other U.S. Government (Not NSF)	$0	$0	$0	$0	$0	$0	$0	$0	$0
State Government	$0	$0	$0	$0	$0	$0	$0	$0	$0
Local Government	$0	$0	$0	$0	$0	$0	$0	$0	$0
Foreign Government	$0	$0	$0	$0	$0	$0	$0	$0	$0
Quasi-government research organization	$0	$0	$0	$0	$0	$0	$0	$0	$0
TOTAL GOVERNMENT FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Industry									
U.S. Industry	$0	$0	$22,500	$0	$0	$0	$0	$0	$22,500
Foreign Industry	$0	$0	$0	$0	$0	$0	$0	$0	$0
Industrial Association	$0	$0	$0	$0	$0	$0	$0	$0	$0
TOTAL INDUSTRY FUNDING	**$0**	**$0**	**$22,500**	**$0**	**$0**	**$0**	**$0**	**$0**	**$22,500**
University									
U.S. University	$0	$0	$16,200	$0	$0	$8,000	$0	$8,000	$24,200
Foreign University	$10,000	$39,500	$10,000	$0	$0	$0	$0	$0	$59,500
TOTAL UNIVERSITY FUNDING	**$10,000**	**$39,500**	**$26,200**	**$0**	**$0**	**$8,000**	**$0**	**$8,000**	**$83,700**
Other									
Private Foundation	$0	$0	$0	$0	$0	$0	$0	$0	$0
Medical Facility	$0	$0	$0	$0	$0	$0	$0	$0	$0
Non Profit	$0	$0	$0	$0	$0	$0	$0	$0	$0
Venture Capitalist	$0	$0	$0	$0	$0	$0	$0	$0	$0
Other	$0	$0	$0	$0	$0	$0	$0	$0	$0
TOTAL OTHER FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Total Value of Visting Personnel	**$10,000**	**$39,500**	**$48,700**	**$0**	**$0**	**$8,000**	**$0**	**$8,000**	**$106,200**
Value of Other Assets									
Government									
NSF Funding									
NSF ERC Base Award	$0	$0	$0	$0	$0	$0	$0	$0	$0
Other NSF (Not ERC Program)	$0	$0	$0	$0	$0	$0	$0	$0	$0
TOTAL NSF FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Other U.S. Government (Not NSF)	$0	$0	$0	$0	$0	$0	$0	$0	$0

Sources of Support	Early Cumulative Total	Jun 1, 2007 - May 31, 2008	Jun 1, 2008 - May 31, 2009	Jun 1, 2009 - May 31, 2010	Jun 1, 2010 - May 31, 2011	Jun 1, 2011 - May 31, 2012			Cumulative Total [1]
						Received	Promised	Total	
State Government	$0	$0	$0	$0	$0	$0	$0	$0	$0
Local Government	$0	$0	$0	$0	$0	$0	$0	$0	$0
Foreign Government	$0	$0	$0	$0	$0	$0	$0	$0	$0
Quasi-government research organization	$0	$0	$0	$0	$0	$0	$0	$0	$0
TOTAL GOVERNMENT FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Industry									
U.S. Industry	$0	$0	$0	$0	$219,621	$106,408	$0	$106,408	$326,029
Foreign Industry	$0	$0	$0	$0	$9,000	$37,833	$24,475	$62,308	$71,308
Industrial Association	$0	$0	$0	$0	$0	$0	$0	$0	$0
TOTAL INDUSTRY FUNDING	**$0**	**$0**	**$0**	**$0**	**$228,621**	**$144,241**	**$24,475**	**$168,716**	**$397,337**
University									
U.S. University	$0	$0	$0	$0	$0	$0	$0	$0	$0
Foreign University	$0	$0	$0	$0	$0	$0	$0	$0	$0
TOTAL UNIVERSITY FUNDING	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
Other									
Private Foundation	$0	$0	$0	$0	$0	$0	$0	$0	$0
Medical Facility	$0	$0	$0	$0	$0	$0	$0	$0	$0
Non Profit	$0	$0	$0	$0	$0	$0	$0	$0	$0
Venture Capitalist	$0	$0	$0	$0	$0	$0	$0	$0	$0
Other	$0	$0	$0	$169,032	$0	$0	$0	$0	$169,032
TOTAL OTHER FUNDING	**$0**	**$0**	**$0**	**$169,032**	**$0**	**$0**	**$0**	**$0**	**$169,032**
Total Value of Other Assets	**$0**	**$0**	**$0**	**$169,032**	**$228,621**	**$144,241**	**$24,475**	**$168,716**	**$566,369**
Total In-Kind Support, All Sources	**$226,591**	**$307,500**	**$774,102**	**$169,032**	**$228,621**	**$184,494**	**$24,475**	**$208,969**	**$1,914,815**
Total Cash Support, All Sources [2]	**$4,280,265**	**$5,714,858**	**$6,586,127**	**$6,242,766**	**$6,626,859**	**$6,719,410**	**$140,750**	**$6,860,160**	**$28,950,650**
Percent Non-ERC Program Cash	**31%**	**37%**	**35%**	**34%**	**30%**	**31%**	**100%**	**33%**	**28%**
Total Cash + In-Kind	**$4,506,856**	**$6,022,358**	**$7,360,229**	**$6,411,798**	**$6,855,480**	**$6,903,904**	**$165,225**	**$7,069,129**	**$30,865,465**
Grand Total (Cash + In-Kind + Associated Projects)	**$5,736,136**	**$6,841,426**	**$8,998,998**	**$8,137,173**	**$8,965,649**	**$9,215,474**	**$165,225**	**$9,380,699**	**$40,699,696**

[1] - No Residual amounts are included in the Cumulative Total column because the funds are by definition included in the year in which they were received.

[2] - Cash Total = The sum of Unrestricted Cash, Restricted Cash, and Residual Funds for a particular NSF Award Year, but NOT Support for Associated Projects. This cash amount in Table 9 is also the total for the 'Expenditure' column pertaining to the same Award Year in Table 10: Annual Expenditures and Budgets.

[3] - Associated project support is the sum of the received and promised amounts from the prior year. Actual amounts are not collected for associated project support.

Explanation of Residual Funds entry in Direct Sources of Support - Cash
charged until year 5 - June 1, 2010-May 31, 2011.

Table 10: Annual Expenditures and Budgets

Total Direct Center Cash Support	Early Cumulative Total [1]	Jun-01-2007 - May-31-2008	Jun-01-2008 - May-31-2009	Jun-01-2009 - May-31-2010	Jun-01-2010 - May-31-2011	Jun-01-2011 - May-31-2012	Next Award Year
Direct Cash Support (All Sources)	**$2,370,576**	**$4,658,801**	**$5,123,279**	**$5,396,114**	**$5,779,974**	**$5,621,906**	**N/A**
Residual Funds from Prior Year (All Sources)	**$1,909,689**	**$1,056,057**	**$1,462,848**	**$846,652**	**$846,885**	**$1,238,254**	**N/A**
Total Direct Center Cash Support	**$4,280,265**	**$5,714,858**	**$6,586,127**	**$6,242,766**	**$6,626,859**	**$6,860,160**	**N/A**

Expenses Proposed and Residual Budget	Early Cumulative Total [1]	Jun-01-2007 - May-31-2008	Jun-01-2008 - May-31-2009	Jun-01-2009 - May-31-2010	Jun-01-2010 - May-31-2011	Jun-01-2011 - May-31-2012	Proposed Budget - Next Award Year
Salaries & Benefits							
A. Senior Personnel: PI/PD, Co-PIs, Faculty and Other Senior Associates	$219,229	$357,473	$477,455	$484,549	$505,207	$500,000	$500,000
B. Other Personnel:	$833,328	$1,974,012	$1,592,092	$1,919,364	$1,853,739	$1,852,600	$1,882,600
Postdoctoral associates	$106,172	$196,473	$115,001	$67,797	$19,180	$23,000	$23,000
Other professionals (technician, programmer, etc.)	$17,301	$248,840	$121,572	$232,601	$113,991	$30,000	$30,000
Graduate Students	$326,502	$870,142	$710,796	$892,055	$1,117,358	$1,200,000	$1,200,000
Undergraduate students	$57,618	$153,555	$125,435	$157,422	$59,537	$30,000	$60,000
Secretarial - clerical	N/A	N/A	N/A	N/A	$188,104	$200,000	$200,000
Other	$325,735	$505,002	$519,288	$569,489	$355,569	$369,600	$369,600
C. Fringe Benefits	$224,701	$493,148	$541,702	$591,497	$587,333	$595,000	$595,000
Total Salaries & Benefits (A+B+C)	**$1,277,258**	**$2,824,633**	**$2,611,249**	**$2,995,410**	**$2,946,279**	**$2,947,600**	**$2,977,600**
Other Expenses							
D. Equipment	$99,085	$450,188	$187,609	$95,831	$147,311	$144,581	$144,581
E. Travel	N/A	N/A	N/A	N/A	$253,621	$198,805	$198,805
F. Participant Support	N/A	N/A	N/A	N/A	$161,046	$232,337	$232,337
G. Other Direct Costs	$347,923	$1,045,745	$752,196	$811,591	$629,139	$1,518,945	$1,518,945
H. Direct Costs Total (A through G):	**$1,724,266**	**$4,320,566**	**$3,551,054**	**$3,902,832**	**$4,137,396**	**$5,042,268**	**$5,072,268**
I. Indirect Costs	**$646,310**	**$1,165,595**	**$1,080,129**	**$1,262,004**	**$1,251,209**	**$1,555,167**	**$1,555,167**
J. Direct and Indirect Costs Total (A through I):	**$2,370,576**	**$5,486,161**	**$4,631,183**	**$5,164,836**	**$5,388,605**	**$6,597,435**	**$6,627,435**
K. Residual Funds Remaining	**$1,909,689**	**$1,056,057**	**$1,312,927**	**$0**	**$1,238,254**	**$262,725**	**$0**
TOTAL Expenditures and Budgets (J+K)	**$4,280,265**	**$6,542,218**	**$5,944,110**	**$5,164,836**	**$6,626,859**	**$6,860,160**	**$6,627,435**
Current Year Support)	**$4,280,265**	**$5,714,858**	**$6,586,127**	**$6,242,766**	**$6,626,859**	**$6,860,160**	**N/A**
Prior Award Year Residual Funds spent in Current Award Year							
ERC Program	$0	$1,023,980	$279,300	$279,300	$316,643	$589,405	$0
Other NSF	$0	$0	$0	$0	$0	$0	$0
Other Federal	$0	$0	$0	$0	$0	$0	$0
Industry	$0	$587,207	$1,250,042	$1,250,042	$297,485	$464,648	$0
Other	$0	$297,496	$756,115	$0	$232,757	$184,201	$0
Prior Award Year Residual Funds spent in Current Award Year	**$0**	**$1,908,683**	**$2,285,457**	**$1,529,342**	**$846,885**	**$1,238,254**	**$0**

[1] - For Centers in operation for more than five years.

Table 11: Modes of Support by Industry and Other Practitioner Organizations

	Jun 1, 2010 - May 31, 2011						Jun 1, 2011 - May 31, 2012						
		Sponsored Projects		Associated Projects				Sponsored Projects		Associated Projects			
Organization	Fees and Contributions	Non-translational	Translational	Non-translational	Translational	In-Kind Support	Fees and Contributions	Non-translational	Translational	Non-translational	Translational	In-Kind Support	Promised Support
Industrial/Practitioner Member Organizations													
Afton Chemical Corp.	$10,000	$0	N/A	$0	N/A	$0	$10,000	$0	$0	$0	$0	$0	$0
Air Logic	$1,000	$0	N/A	$0	N/A	$0	$1,000	$0	$0	$0	$0	$0	$0
Bobcat	$15,000	$0	N/A	$0	N/A	$0	$15,000	$0	$0	$0	$0	$0	$0
Bosch Rexroth Corporation	$50,000	$0	N/A	$0	N/A	$9,000	$0	$0	$0	$0	$1,974	$35,140	$74,475
Caterpillar, Inc.	$50,000	$0	N/A	$76,797	N/A	$0	$50,000	$0	$0	$0	$0	$0	$0
CNH America, Inc.	$0	$0	N/A	$0	N/A	$0	$40,000	$0	$0	$0	$17,231	$0	$0
Concentric AB/Haldex	$6,000	$0	N/A	$0	N/A	$0	$6,000	$0	$0	$0	$0	$0	$0
Deltrol Fluid Products	$5,000	$0	N/A	$0	N/A	$0	$0	$0	$0	$0	$0	$0	$5,000
Donaldson Company	$0	$0	N/A	$0	N/A	$0	$0	$0	$0	$0	$0	$0	$12,000
Eaton Corporation	$50,000	$0	N/A	$0	N/A	$0	$50,000	$0	$0	$0	$64,225	$14,232	$0
Enfield Technologies	$5,000	$0	N/A	$0	N/A	$0	$5,000	$0	$0	$0	$0	$1,000	$0
Evonik Industries	$10,000	$0	N/A	$0	N/A	$0	$10,000	$0	$0	$0	$0	$0	$0
Exxon Mobil	$40,000	$0	N/A	$0	N/A	$0	$40,000	$0	$0	$0	$0	$0	$0
Freudenberg - NOK	$0	$0	N/A	$0	N/A	$0	$6,000	$0	$0	$0	$0	$0	$0
G.W. Lisk Company	$15,000	$0	N/A	$0	N/A	$0	$15,000	$0	$0	$0	$0	$0	$0
Gates Corporation	$40,000	$0	N/A	$0	N/A	$0	$0	$0	$0	$0	$0	$0	$40,000
Hagglunds Drives, Inc. . Sold to Bosch Rexroth	$6,000	$0	N/A	$0	N/A	$0	$0	$0	$0	$0	$0	$0	$0
Heco Gear, Inc.	$2,000	$0	N/A	$0	N/A	$0	$2,000	$0	$0	$0	$0	$0	$0
High Country Tek, Inc.	$1,000	$0	N/A	$0	N/A	$0	$1,000	$0	$0	$0	$0	$0	$0
Hoowaki, LLC	$1,000	$0	N/A	$0	N/A	$0	$1,000	$0	$0	$0	$0	$0	$0
Husco International, Inc.	$40,000	$0	N/A	$5,000	N/A	$0	$40,000	$0	$0	$0	$0	$0	$0
Hydac Corporation	$5,000	$0	N/A	$0	N/A	$2,400	$0	$0	$0	$0	$0	$0	$0
Hydraquip Corporation	$6,000	$0	N/A	$0	N/A	$0	$0	$0	$0	$0	$0	$0	$0
Kepner Products, Co.	$1,000	$0	N/A	$0	N/A	$0	$0	$0	$0	$0	$0	$0	$0
Linde Hydraulics Corp.	$5,000	$0	N/A	$1,000	N/A	$0	$5,000	$0	$0	$0	$0	$0	$0
Main Manufacturing Products, Inc.	$0	$0	N/A	$0	N/A	$0	$1,000	$0	$0	$0	$0	$0	$0
Master Pneumatic-Detroit, Inc.	$1,000	$0	N/A	$0	N/A	$0	$1,000	$0	$0	$0	$0	$0	$0
Mico, Inc.	$1,000	$0	N/A	$0	N/A	$0	$1,000	$0	$0	$0	$0	$0	$0
Moog, Inc.	$15,000	$0	N/A	$0	N/A	$0	$15,000	$0	$0	$0	$0	$0	$0
MTS Systems Corporation	$15,000	$0	N/A	$0	N/A	$0	$0	$0	$0	$0	$0	$0	$15,000
National Fluid Power Association	$50,000	$0	N/A	$71,067	N/A	$0	$40,000	$0	$0	$0	$0	$0	$0
National Tube Supply Company	$1,000	$0	N/A	$0	N/A	$0	$1,000	$0	$0	$0	$0	$0	$0
Netshape Technologies	$11,250	$0	N/A	$0	N/A	$0	$15,000	$0	$0	$0	$0	$0	$3,750
Nexen Group, Inc.	$1,000	$0	N/A	$0	N/A	$0	$1,000	$0	$0	$0	$0	$0	$0
Nitta Corporation	$0	$0	N/A	$0	N/A	$0	$1,000	$0	$0	$0	$0	$0	$0
Parker Hannifin Corporation	$50,000	$0	N/A	$0	N/A	$36,000	$50,000	$0	$0	$0	$0	$7,765	$0
PHD, Inc.	$6,000	$0	N/A	$0	N/A	$0	$0	$0	$0	$0	$0	$0	$0
PIAB Vacuum Products	$1,000	$0	N/A	$0	N/A	$0	$1,000	$0	$0	$0	$0	$0	$0
Poclain Hydraulics	$6,000	$0	N/A	$0	N/A	$0	$15,000	$0	$0	$0	$0	$0	$0
Quality Control Corporation	$1,000	$0	N/A	$0	N/A	$0	$1,000	$0	$0	$0	$0	$0	$0
R.T. Dygert International	$5,000	$0	N/A	$0	N/A	$0	$0	$0	$0	$0	$0	$0	$0
Racine Federated Inc. (formerly Hedland Flow Meters)	$1,000	$0	N/A	$0	N/A	$4,592	$1,000	$0	$0	$0	$1,974	$0	$0
Ross Controls	$5,000	$0	N/A	$0	N/A	$0	$5,000	$0	$0	$0	$0	$0	$0
Sauer-Danfoss	$50,000	$0	N/A	$8,000	N/A	$70,837	$50,000	$0	$0	$0	$1,974	$6,345	$0
Shell Global Solutions	$12,000	$0	N/A	$0	N/A	$0	$12,000	$0	$0	$0	$0	$0	$0
Simerics, Inc.	$1,000	$0	N/A	$0	N/A	$0	$1,000	$0	$0	$0	$0	$0	$0
StorWatts Inc.	$0	$0	N/A	$0	N/A	$0	$1,000	$0	$0	$0	$0	$0	$0

Organization	Jun 1, 2010 - May 31, 2011						Jun 1, 2011 - May 31, 2012						Promised Support
		Sponsored Projects		Associated Projects				Sponsored Projects		Associated Projects			
	Fees and Contributions	Non-translational	Translational	Non-translational	Translational	In-Kind Support	Fees and Contributions	Non-translational	Translational	Non-translational	Translational	In-Kind Support	
Sun Hydraulics	$15,000	$0	N/A	$0	N/A	$832	$6,000	$0	$0	$0	$0	$500	$0
Takako Industries	$1,000	$0	N/A	$0	N/A	$0	$1,000	$0	$0	$0	$0	$2,693	$0
Tennant	$12,000	$0	N/A	$0	N/A	$0	$12,000	$0	$0	$0	$0	$0	$0
The Lubrizol Corporation	$5,000	$0	N/A	$0	N/A	$0	$5,000	$0	$0	$0	$7,917	$0	$0
Trelleborg Sealing Solutions	$6,000	$0	N/A	$0	N/A	$0	$15,000	$0	$0	$0	$0	$0	$0
Veljan Hydrair Private Limited	$5,000	$0	N/A	$0	N/A	$0	$0	$0	$0	$0	$0	$0	$0
Woodward, Inc.	$0	$0	N/A	$0	N/A	$0	$79,167	$0	$0	$0	$0	$0	$0
Total Members	**$641,250**	**$0**	**N/A**	**$161,864**	**N/A**	**$123,661**	**$628,167**	**$0**	**$0**	**$0**	**$95,295**	**$67,675**	**$150,225**
Non-Member Organizations: Funders of Sponsored Projects, Funders of Associated Projects, and Contributing Organizations													
Bimba Manufacturing Company	$6,000	$0	N/A	$0	N/A	$200	$0	$0	$0	$0	$0	$2,319	$0
Casappa S.p.A.	$0	$0	N/A	$37,962	N/A	$0	$0	$0	$0	$0	$82,000	$0	$0
DARPA	$0	$0	N/A	$116,000	N/A	$0	$0	$0	$0	$0	$182,000	$0	$0
Deere & Co.	$0	$0	N/A	$48,252	N/A	$0	$0	$0	$0	$0	$0	$0	$0
Deere and Company	$15,000	$0	N/A	$72,450	N/A	$0	$0	$0	$0	$0	$0	$0	$15,000
Dynasonics	$0	$0	N/A	$0	N/A	$2,535	$0	$0	$0	$0	$0	$0	$0
Festo Corporation	$12,000	$0	N/A	$0	N/A	$0	$0	$0	$0	$0	$0	$500	$0
Ford	$0	$0	N/A	$0	N/A	$101,000	$0	$0	$0	$0	$0	$0	$0
International Fluid Power Society	$1,000	$0	N/A	$0	N/A	$0	$1,000	$0	$0	$0	$0	$0	$0
Laboratoire de Mecanique; INSA de Lyon	$0	$0	N/A	$57,276	N/A	$0	$0	$0	$0	$0	$0	$0	$0
National Defense Science and Engineering Fellowship Grant (NDSEG)	$0	$0	N/A	$13,320	N/A	$0	$0	$0	$0	$13,320	$0	$0	$0
National Institutes of Health (NIH)	$0	$0	N/A	$41,667	N/A	$0	$0	$0	$0	$0	$5,208	$0	$0
No Magic, Inc.	$0	$0	N/A	$0	N/A	$0	$0	$0	$0	$0	$0	$6,000	$0
Oak Ridge National Laboratory	$0	$0	N/A	$10,667	N/A	$0	$0	$0	$0	$0	$0	$0	$0
Phoenix Integration	$0	$0	N/A	$0	N/A	$0	$0	$0	$0	$0	$0	$100,000	$0
Precision Associates	$0	$0	N/A	$0	N/A	$925	$0	$0	$0	$0	$0	$0	$0
Purdue Research Park Trask Funds	$0	$0	N/A	$37,576	N/A	$0	$0	$0	$0	$0	$0	$0	$0
Ralph Rivera	$0	$0	N/A	$0	N/A	$0	$0	$0	$0	$0	$0	$0	$0
The Martin Company	$0	$0	N/A	$36,630	N/A	$0	$0	$0	$0	$0	$12,692	$0	$0
The Timken Company	$0	$0	N/A	$45,288	N/A	$0	$0	$0	$0	$0	$0	$0	$0
The Toro Company	$12,000	$0	N/A	$0	N/A	$0	$12,000	$0	$0	$0	$0	$0	$0
Total Oil Company	$0	$0	N/A	$13,903	N/A	$0	$0	$0	$0	$20,000	$0	$0	$0
United Technologies Research Center	$0	$0	N/A	$57,706	N/A	$0	$0	$0	$0	$0	$9,688	$0	$0
University of MN; IonE and IREE	$0	$0	N/A	$45,832	N/A	$0	$0	$0	$0	$0	$0	$0	$0
University of Stuttgart/German Research Foundation	$0	$0	N/A	$31,968	N/A	$0	$0	$0	$0	$0	$0	$0	$0
Vanderbilt University	$0	$0	N/A	$16,667	N/A	$0	$0	$0	$0	$0	$0	$0	$0
Vex Robotics	$0	$0	N/A	$0	N/A	$300	$0	$0	$0	$0	$0	$0	$0
Total Non-Members	**$46,000**	**$0**	**N/A**	**$683,164**	**N/A**	**$104,960**	**$13,000**	**$0**	**$0**	**$91,320**	**$291,588**	**$108,819**	**$15,000**
Total	**$687,250**	**$0**	**N/A**	**$845,028**	**N/A**	**$228,621**	**$641,167**	**$0**	**$0**	**$91,320**	**$386,883**	**$176,494**	**$165,225**

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5.4 RESOURCES AND UNIVERSITY COMMITMENT

The CCEFP lead and partner universities are fully committed to the mission of the Center. This commitment can be seen in tangible investments in headquarters space, research facilities and equipment and communication networks. Intangible commitments can also be seen in the collaborative university research culture.

CCEFP university investments in personnel and infrastructure have slowed due to economic hardships experienced due to the recession. In previous years, CCEFP hired six faculty members: Zongliang Jiang (NCAT), Ashlie Martini (PU), Zongxuan Sun (UM), Jun Ueda (GT), Andrea Vacca (PU) and Robert Webster (VU). In the last year, the CCEFP faculty-hiring rate has increased considerably with four new members being added to our ranks. These are: Randy Ewoldt (UIUC), Michael Leamy (GT), Pietro Valdastri (VU) and James Van de Ven (UM). Thus, CCEFP is well positioned to fulfill its commitment to hire a total of twelve faculty members by adding two new faculty members in the future.

The CCEFP researchers are fully committed to supporting post-docs as part of the research and education mission of the center. In the last year, three post-docs have been supported, two at Minnesota and one at Illinois. As the prominence of our research increases, CCEFP is expected to attract more high-quality researchers to post-doc positions.

CCEFP university administrators have been fully supportive of the center. The CCEFP Director has a formal meeting semiannually with the Dean or Associate Deans of the Institute of Technology at the University of Minnesota. Less formal meetings occur with much greater frequency. Through the Council of Deans, an administrative structure exists to handle any major issues, but good cooperation between universities at lower levels has meant that this structure has not been needed. Administrative agreements between universities have been handled with some delays, but no major difficulties. These include intellectual property agreements, sub-contracts funded by NSF and industry, and billing. CCEFP universities actively promote cross-disciplinary research. Being part of an ERC research team is an asset, not a liability, in tenure and promotion.

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SUMMARY
PROPOSAL BUDGET

YEAR 7

ORGANIZATION **University of Minnesota**	**FOR NSF USE ONLY** PROPOSAL NO.
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR Kim A. Stelson	AWARD NO. 0540834

DURATION (MONTHS)	
Proposed	Granted

A. SENIOR PERSONNEL: PI/PD, Co-PI´S, Faculty and Other Senior Associates
(List each separately with title, A.7. show number in brackets)

0.	First Name	M	Last Name	Title	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By Proposer	Funds Granted by NSF
1.	Kim	A	Stelson	Dr.	0.00	0.00	2.00	31,642	
2.	Perry		Li	Dr.	0.00	0.00	2.50	22,231	
3.	Paul		Imbertson	Dr.	0.00	0.00	2.00	20,786	
4.	Thomas		Chase	Dr.	0.00	0.00	1.50	10,000	
5.	David		Kittelson	Dr.	0.00	0.00	1.00	15,533	
6.	Zongxuan		Sun	Dr.	0.00	0.00	1.00	15,080	
7.	Kittleson		David	Dr.	0.00	0.00	1.00	14,450	
8.	William		Durfee	Dr.	0.00	0.00	1.00	10,768	
(6)	TOTAL SENIOR PERSONNEL (1-6)							140,490	

	CAL	ACAD	SUMR	Funds Requested By Proposer	Funds Granted by NSF
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. 0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00		
2. 1) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	12.00	0.00	0.00	$10,000	
3. 9) GRADUATE STUDENTS	12.00			$250,000	
4. 3) UNDERGRADUATE STUDENTS	12.00			$31,200	
5. 2) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)	12.00			$50,000	
6. 3) OTHER	12.00			$191,907	
TOTAL SALARIES AND WAGES (A+B)				$673,597	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				$242,495	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A+B+C)				$916,092	
D. PERMANENT EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000) 20000 0 0					
TOTAL EQUIPMENT 20000				$20,000	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				$20,000	
2. FOREIGN				$6,000	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $0					
2. TRAVEL $0					
3. SUBSISTENCE $0					
4. OTHER $0					
(0) TOTAL NUMBER OF PARTICIPANTS $0				$0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				$10,000	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				$10,000	
3. CONSULTANT SERVICES Systems Engineering				$10,000	
4. COMPUTERS SERVICES				$0	
5. SUBAWARDS				$2,668,748	
6. OTHER				$0	
TOTAL OTHER DIRECT COSTS				$2,698,748	
H. TOTAL DIRECT COSTS (A THROUGH G) Rate				$3,660,840	
I. INDIRECT COSTS (SPECIFY RATE AND BASE) 0					
TOTAL INDIRECT COSTS				$339,160	
J. TOTAL DIRECT AND INDIRECT COSTS (H+I)				$4,000,000	$0
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.D.7.j.)				$0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$4,000,000	
M. COST SHARING: PROPOSED LEVEL AGREED LEVEL IF DIFFERENT $				$800,000	

Grad fringe and eqpt exempt idc	Direct costs IDC	$491,085.50	
	Less Grad fringe, equipment Ex	$151,925.12	49.50%
	Total IDC	$339,160.38	
Equip. exempt idc			

PI/PD NAME Kim A. Stelson	DATE 4/9/12	**FOR NSF USE ONLY** INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME InstRepFullName	DATE	Date Checked	Date Rate of Sheet	Initials-ORG

*SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.B)

SUMMARY
PROPOSAL BUDGET

YEAR 8

FOR NSF USE ONLY

ORGANIZATION
University of Minnesota

PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR
Kim A. Stelson

PROPOSAL NO.

DURATION (MONTHS): Proposed | Granted

AWARD NO.
0540834

A. SENIOR PERSONNEL: PI/PD, Co-PI´S, Faculty and Other Senior Associates
(List each separately with title, A.7. show number in brackets)

0.	First Name	M	Last Name	Title	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By Proposer	Funds Granted by NSF
1.	Kim	A	Stelson	Dr.	0.00	0.00	2.00	31,642	
2.	Perry		Li	Dr.	0.00	0.00	2.50	22,231	
3.	Paul		Imbertson	Dr.	0.00	0.00	2.00	20,786	
4.	Thomas		Chase	Dr.	0.00	0.00	1.50	10,000	
5.	David		Kittelson	Dr.	0.00	0.00	1.00	15,533	
6.	Zongxuan		Sun	Dr.	0.00	0.00	1.00	15,080	
7.	Kittleson		David	Dr.	0.00	0.00	1.00	14,450	
8.	William		Durfee	Dr.	0.00	0.00	1.00	10,768	
(6) TOTAL SENIOR PERSONNEL (1-6)								140,490	

	CAL	ACAD	SUMR	Funds Requested By Proposer	Funds Granted by NSF
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. 0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00		
2. 1) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	12.00	0.00	0.00	$10,000	
3. 9) GRADUATE STUDENTS	12.00			$250,000	
4. 3) UNDERGRADUATE STUDENTS	12.00			$31,200	
5. 2) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)	12.00			$50,000	
6. 3) OTHER	12.00			$191,907	
TOTAL SALARIES AND WAGES (A+B)				$673,597	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				$242,495	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A+B+C)				$916,092	

		Funds Requested By Proposer	Funds Granted by NSF
D. PERMANENT EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000)			
	20000		
	0		
	0		
TOTAL EQUIPMENT	20000	$20,000	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)		$20,000	
2. FOREIGN		$6,000	
F. PARTICIPANT SUPPORT COSTS			
1. STIPENDS	$0		
2. TRAVEL	$0		
3. SUBSISTENCE	$0		
4. OTHER	$0		
(0) TOTAL NUMBER OF PARTICIPANTS	$0	$0	
G. OTHER DIRECT COSTS			
1. MATERIALS AND SUPPLIES		$10,000	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION		$10,000	
3. CONSULTANT SERVICES	Systems Engineering	$10,000	
4. COMPUTERS SERVICES		$0	
5. SUBAWARDS		$2,668,748	
6. OTHER		$0	
TOTAL OTHER DIRECT COSTS		$2,698,748	
H. TOTAL DIRECT COSTS (A THROUGH G)	Rate	$3,660,840	

I. INDIRECT COSTS (SPECIFY RATE AND BASE) 0

	Direct costs IDC	$491,085.50	
Grad fringe and eqpt exempt idc	Less Grad fringe, equipment Ex	$151,925.12	49.50%
	Total IDC	$339,160.38	
Equip. exempt idc			

		Funds Requested By Proposer	Funds Granted by NSF
TOTAL INDIRECT COSTS		$339,160	
J. TOTAL DIRECT AND INDIRECT COSTS (H+I)		$4,000,000	$0
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.D.7.j.)		$0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)		$4,000,000	
M. COST SHARING: PROPOSED LEVEL	AGREED LEVEL IF DIFFERENT $	$800,000	

PI/PD NAME Kim A. Stelson	DATE 4/9/12	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME InstRepFullName	DATE	Date Checked	Date Rate of Sheet	Initials-ORG

*SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.B)

SUMMARY
PROPOSAL BUDGET

YEAR 9

FOR NSF USE ONLY

ORGANIZATION **University of Minnesota**	PROPOSAL NO.	DURATION (MONTHS) Proposed	Granted
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR Kim A. Stelson	AWARD NO. 0540834	Funds Granted by NSF	

A. SENIOR PERSONNEL: PI/PD, Co-PI´S, Faculty and Other Senior Associates
(List each separately with title, A.7. show number in brackets)

0.	First Name	M	Last Name	Title	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By Proposer	Funds Granted by NSF
1.	Kim	A	Stelson	Dr.	0.00	0.00	2.00	20,000	
2.	Perry		Li	Dr.	0.00	0.00	2.50	15,000	
3.	Paul		Imbertson	Dr.	0.00	0.00	2.00	15,000	
4.	Thomas		Chase	Dr.	0.00	0.00	1.50	7,500	
5.	David		Kittelson	Dr.	0.00	0.00	1.00	7,500	
6.	Zongxuan		Sun	Dr.	0.00	0.00	1.00	7,500	
7.	Kittleson		David	Dr.	0.00	0.00	1.00	5,000	
8.	William		Durfee	Dr.	0.00	0.00	1.00	5,000	
(6) TOTAL SENIOR PERSONNEL (1-6)								82,500	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)									
1. 0) POST DOCTORAL ASSOCIATES					0.00	0.00	0.00		
2. 1) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)					12.00	0.00	0.00	$78,000	
3. 9) GRADUATE STUDENTS					12.00			$172,000	
4. 3) UNDERGRADUATE STUDENTS					12.00			$25,505	
5. 2) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)					12.00				
6. 3) OTHER					12.00			$90,000	
TOTAL SALARIES AND WAGES (A+B)								$448,005	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)								$161,282	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A+B+C)								$609,287	

D. PERMANENT EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000)				
	20000			
	0			
	0			
TOTAL EQUIPMENT	20000		$20,000	
E. TRAVEL	1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)		$25,000	
	2. FOREIGN		$4,000	
F. PARTICIPANT SUPPORT COSTS				
1. STIPENDS		$0		
2. TRAVEL		$0		
3. SUBSISTENCE		$0		
4. OTHER		$0		
(25) TOTAL NUMBER OF PARTICIPANTS		$0	$0	
G. OTHER DIRECT COSTS				
1. MATERIALS AND SUPPLIES			$10,000	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION			$5,000	
3. CONSULTANT SERVICES	Program Evaluation of E&O (25K); Systems Eng ($5K); Prof. Svcs (30K) Western		$0	
4. COMPUTERS SERVICES			$0	
5. SUBAWARDS			$1,784,200	
6. OTHER			$0	
TOTAL OTHER DIRECT COSTS			$1,799,200	
H. TOTAL DIRECT COSTS (A THROUGH G)		Rate	$2,457,487	
I. INDIRECT COSTS (SPECIFY RATE AND BASE)		0		
	Grad fringe and eqpt exempt idc	Direct costs IDC $333,276.97		
	stipends, reduced idc 25%	Less Grad fringe, equipment Ex $110,764.17 49.50%		
	Equip. exempt idc	Total IDC $222,512.79		
TOTAL INDIRECT COSTS			$222,513	
J. TOTAL DIRECT AND INDIRECT COSTS (H+I)			$2,680,000	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.D.7.j.)			$0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)			$2,680,000	
M. COST SHARING: PROPOSED LEVEL		AGREED LEVEL IF DIFFERENT $	$536,000	

PI/PD NAME Kim A. Stelson	DATE 4/9/12	**FOR NSF USE ONLY** INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME InstRepFullName	DATE	Date Checked	Date Rate of Sheet	Initials-ORG

*SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.B)

SUMMARY
PROPOSAL BUDGET

YEAR 10

FOR NSF USE ONLY

ORGANIZATION **University of Minnesota**	PROPOSAL NO.	DURATION (MONTHS) Proposed	Granted
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR Kim A. Stelson	AWARD NO. 0540834	Funds Granted by NSF	

A. SENIOR PERSONNEL: PI/PD, Co-PI´S, Faculty and Other Senior Associates
(List each separately with title, A.7. show number in brackets)

0.	First Name	M	Last Name	Title	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By Proposer	Funds Granted by NSF
1.	Kim	A	Stelson	Dr.	0.00	0.00	2.00	20,000	
2.	Perry		Li	Dr.	0.00	0.00	2.50	15,000	
3.	Paul		Imbertson	Dr.	0.00	0.00	2.00	15,000	
4.	Thomas		Chase	Dr.	0.00	0.00	1.50	7,508	
5.	David		Kittelson	Dr.	0.00	0.00	1.00	7,500	
6.	Zongxuan		Sun	Dr.	0.00	0.00	1.00	7,500	
7.	Kittleson		David	Dr.	0.00	0.00	1.00	5,000	
8.	William		Durfee	Dr.	0.00	0.00	1.00	5,000	
(6) TOTAL SENIOR PERSONNEL (1-6)								82,508	

	CAL	ACAD	SUMR	Funds Requested By Proposer	Funds Granted by NSF
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. 0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00		
2. 1) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	12.00	0.00	0.00	$75,320	
3. 9) GRADUATE STUDENTS	12.00			$130,000	
4. 3) UNDERGRADUATE STUDENTS	12.00			$25,505	
5. 2) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)	12.00				
6. 3) OTHER	12.00			$90,000	
TOTAL SALARIES AND WAGES (A+B)				$403,333	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				$145,200	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A+B+C)				$548,533	
D. PERMANENT EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000) 20000 0 0					
TOTAL EQUIPMENT 20000				$20,000	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				$25,000	
2. FOREIGN				$4,000	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $0					
2. TRAVEL $0					
3. SUBSISTENCE $0					
4. OTHER $0					
(25) TOTAL NUMBER OF PARTICIPANTS $0				$0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				$10,000	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				$5,000	
3. CONSULTANT SERVICES Program Evaluation of E&O (25K); Systems Eng ($5K); Prof. Svcs (30K) Western				$0	
4. COMPUTERS SERVICES				$0	
5. SUBAWARDS				$968,464	
6. OTHER				$0	
TOTAL OTHER DIRECT COSTS				$983,464	
H. TOTAL DIRECT COSTS (A THROUGH G)	Rate			$1,580,997	
I. INDIRECT COSTS (SPECIFY RATE AND BASE) 0 **Grad fringe and eqpt exempt idc** Direct costs IDC $303,203.78 Less Grad fringe, equipment Ex $88,600.58 49.50% Total IDC $214,603.19 **Equip. exempt idc**					
TOTAL INDIRECT COSTS				$214,603	
J. TOTAL DIRECT AND INDIRECT COSTS (H+I)				$1,795,600	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.D.7.j.)				$0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$1,795,600	
M. COST SHARING: PROPOSED LEVEL	AGREED LEVEL IF DIFFERENT $			$359,120	

PI/PD NAME Kim A. Stelson	DATE 4/9/12	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME InstRepFullName	DATE	Date Checked	Date Rate of Sheet	Initials-ORG

*SIGNATURES REQUIRED ONLY FOR REVISED BUDGET (GPG III.B)

APPENDIX I

Glossary of Acronyms and Special Terms

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GLOSSARY OF ACRONYMS AND SPECIAL TERMS

ABET	Accreditation Board for Engineering and Technology
AC	alternating current
AGEP	Alliances for Graduate Education and the Professoriate
AISES	American Indian Science and Engineering Society
ASEE	American Society for Engineering Education
ASME	American Society of Mechanical Engineers
CAREI	Center for Applied Research and Educational Improvement
CCEFP	Center of Compact and Efficient Fluid Power
CFD	Computational Fluid Dynamics
CNT	carbon nano-tubes
DC	direct current
DOHF	Design Optimization and Hybrid Fabrication
E & O	Education and Outreach
EAB	Education Advisory Board
EC	Executive Committee
EON	Education and Outreach Network
ERC	Engineering Research Center
ESEM	Environmental Scanning Electron Microscope
FDLTCC	Fon du Lac Tribal and Community College
FIRST	For Inspiration and Recognition of Science and Technology
FLUENT ®	Commercial Computational Fluid Dynamics Code
FP	fluid power
FPE	free piston engine
FPEF	Fluid Power Educational Foundation
FY	fiscal year
gidaa	gidakiimanaaniwigamig (Our Earth Lodge, in Anishinaabe)
GT	Georgia Institute of Technology
H & P	hydraulics and pneumatics
HBCU	Historically Black College and University
HCCI	homogeneous charge compression ignition
HMT	hydro-mechanical drive train
HP	horsepower
HuMVIIS	Human-Machine Virtualization Interaction & Integration Systems Laboratory
IAB	Industrial Advisory Board

IC	internal combustion
kW	kilowatt
LSAMP	Louis Stokes Alliance for Minority Participation
ME	Mechanical Engineering
MSOE	Milwaukee School of Engineering
MW	megawatt
NCAT	North Carolina Agricultural and Technical State University
NCED	National Center for Earth-Surface Dynamics
NFPA	National Fluid Power Association
NSF	National Science Foundation
OMG SysML	modeling language for OMG technology
PC	Project Champion
PFPD	Portable Fluid Power Demonstration
PIV	particle image velocimetry
PLTW	Project Lead The Way
PWM	pulse width modulation
RET	Research Experiences for Teachers
REU	Research Experiences for Undergraduates
SAB	Scientific Advisory Board
SACNAS	Society for Advancement of Chicanos and Native Americans in Science
SAM	strategic action mapping
SLC	Student Leadership Council
SMM	Science Museum of Minnesota
STEM	Science Technology Engineering and Mathematics
SURE	Summer Undergraduate Research in Engineering/Science
SWOT	Strengths, Weaknesses, Opportunities and Threats
TB	test bed
TCUP	Tribal Colleges and Universities Program
TPT	Twin Cities Public Television
UCD	user-centered design
UIUC	University of Illinois at Urbana-Champaign
UMN	University of Minnesota
VaNTH	Multidisciplinary ERC consisting of Vanderbilt, Northwestern and Texas-Harvard/MIT
W	watt

APPENDIX II

Agreements and Certifications

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Engineering Research Center for
Compact and Efficient Fluid Power Membership Agreement

This Agreement (the "Agreement") is made this 2nd day of August, 2006, between the Regents of the University of Minnesota (hereinafter "Lead University"), on behalf of the Engineering Research Center for Compact and Efficient Fluid Power (hereinafter "Center") located at the Lead University, and _________________ (hereinafter, "Member").

WHEREAS, Lead University will operate the Center in cooperation with six other universities, namely, University of Illinois at Urbana-Champaign, Purdue University, Vanderbilt University, Georgia Institute of Technology, Milwaukee School of Engineering and North Carolina Agricultural and Technical University (hereinafter, each university individually is "University", and the seven universities collectively are "Universities").

WHEREAS, the parties to this Agreement, along with each of the Universities, intend to join together in a cooperative effort to support an Engineering Research Center for Compact and Efficient Fluid Power (the "Center") to maintain a mechanism whereby the Universities' environments can be used to perform research in the area of fluid power.

The parties hereby agree to the following terms and conditions:

A. The Center will be administered by certain faculty, staff and students at the Lead University. The parties understand that for the first five (5) years, the Center will be supported jointly by industrial firms, federal laboratories, the Grant and the Universities. At the end of the initial five (5) year term, the National Science Foundation (the "NSF") will conduct a review and may extend its support for an additional five (5) years. If the review is not successful, the NSF support will be phased out over a period not to exceed two (2) years after the initial five (5) year term.

B. Any individual, company, federal research and development organization, or any government-owned contractor operated laboratory may become a Member of the Center, consistent with applicable state and federal laws and statutes. Federal research and development organizations and government-owned contractor operated laboratories may become Members of the Center on terms and conditions other than those in this agreement upon approval by the Lead University and two-thirds of the Industrial Advisory Board (the "IAB"). The establishment and terms and conditions of the IAB are set forth more fully below.

C. Each of the non-lead Universities shall enter into a sub-award or subcontract with the Lead University that obligates the non-lead Universities and their researchers to comply with the obligations of Universities and researchers set forth in this Agreement.

D. Members will be required to remit a pledge at stratified levels according to Member annual U.S. Fluid Power Related Revenues. The annual fees are as follows:

Member's Annual U.S. Fluid Power Related Revenues:	**Sustaining Required Pledge (one lump sum)**	**Sustaining Required Pledge (each year for 5 years)**	**Principal Required Pledge (one lump sum)**	**Principal Required Pledge (each year for 5 years)**	**Supporter Required Pledge (one lump sum)**	**Supporter Required Pledge (each year for 5 years)**
Less than $25 million	$50,000	$10,000	$25,000	$5,000	$5,000	$1,000
$25 - $100 million	$150,000	$30,000	$75,000	$15,000	$30,000	$6,000
$100 -$500 million	$400,000	$80,000	$200,000	$40,000	$60,000	$12,000
Over $500 million	$500,000	$100,000	$250,000	$50,000	$75,000	$15,000

Each Member agrees to contribute the amount set forth in the above table in support of the Center and thereby will become either a Sustaining Member, Principal Member or a Supporter Member, based on the fees outlined in the table above. Payment of these membership fees shall be made to the Center as one lump sum, on a per year basis, which shall be due and payable by October 01 of each year. Checks should be made payable to University of Minnesota and mailed to Regents of the University of Minnesota, NW 5957, P.O. Box 1450, Minneapolis, MN 55485-5957. Members acknowledge that research of the type to be done by the Center takes time and research results may not be immediately obvious. The pledge of support is for a period of five years; however, a Member may withdraw from the Center on one year's prior written notice to the Lead University.

The Center shall provide each Member with periodic reports of the progress of research supported by the Center. The Center shall invite each Member to attend an annual meeting of the Center, at which the results of Center research will be presented and displayed. The Center shall produce a Newsletter which periodically informs each Member of noteworthy research and developments. In addition, Members will be invited to actively interact with researchers conducting projects of particular interest to them, and such Members will receive early, confidential information directly from the researchers about the progress of those projects.

E. The IAB is an advisory board. The organization, governance and operation of the IAB within the Center will be specified in detail by Center bylaws that will be adopted at the first IAB meeting. The bylaws, when adopted, shall control the functions of the IAB, shall reflect the terms of this Agreement, and shall be consistent with the NSF grant and applicable federal regulations and policies.

F. The IAB will be comprised of one representative from each Sustaining Member and Principal Member. The IAB will effect all changes in the Center bylaws. The IAB will make recommendations to the Universities and Center researchers concerning (a) the research projects to be carried out by the Center, (b) the apportionment of resources to such research projects, and (c) other matters specified in the Center bylaws. The organization and function of the IAB will be specified in the Center bylaws. The overall administrative functions and operations of the Center shall be the responsibility of the Lead University. The Lead University's Center Director retains final authority and will not be bound by IAB recommendations specific to selection of research projects and apportionment of resources.

G. The students, faculty and staff conducting research through the Center (the "Researchers") shall have the right to publish the results of any research performed through the Center, subject to the limitations set forth in this Paragraph. In order to protect potentially patentable Intellectual Property, the Center shall notify all Members in writing of the potential publication of any paper or presentation containing information on the research performed through the Center ("Publication Materials") and shall provide all Members with an opportunity to review, on a confidential basis (e.g., on a secure website), any Publication Materials. The Center shall effect such notification and make all Publication Materials available for review not less than forty-five (45) days prior to the expected date of publication. Members shall have the right to delay publication for a period not to exceed ninety (90) days from the date the publication or presentation is made available to each Member, provided that Member submits to the publishing University and Researcher a written request to delay publication in order to consider obtaining patent protection within thirty (30) days from the date the proposed publication or presentation is made available to the Member.

H. Each University hereby grants all Members a perpetual, irrevocable, non-exclusive, royalty-free license to use any non-patented discovery or invention developed under the Center.

I. Pursuant to 35 U.S.C. § 200 *et seq.* (the "Bayh-Dole Act"), the University or Universities whose researchers are inventors under U.S. Patent law (the "Inventing University") shall have the right to retain title to all patents developed from this work, subject to the rights of the U.S. Government as set forth in the Bayh-Dole Act and regulations. The provisions of Part 730, "Intellectual Property", of the NSF Grants Policy Manual shall also govern rights and responsibilities regarding intellectual property created with NSF funding. If any Member exercises its rights under Paragraph K of this Agreement, the Inventing University or Inventing Universities shall exercise its right to retain title.

J. University employees shall promptly disclose to their University (which shall promptly notify the Center) any invention made with support of the Center. The Center shall promptly provide all Members with confidential notice of the invention and of their right to exercise the options provided under this Paragraph K. Within 90 days of receipt of notice, any Member may direct that a patent application or application for other intellectual property protection be filed. If a Member so directs, other Members shall then be provided an additional 60-day option period to elect whether to share equally, among those who elect to exercise the option, all costs incurred in connection with such preparation, filing, prosecution, and maintenance of U.S. and foreign application(s) directed to said invention.

Those Members that elect to share such costs shall cooperate with Inventing University to assure that such application(s) will cover, to the best of Members' knowledge, all items of interest and importance. The Inventing University shall keep the Members that are sharing in payment of costs advised as to all developments with respect to such application(s) and shall promptly supply to those Members copies of all papers received and filed in connection with the prosecution thereof in sufficient time for those Members to comment thereon.

K. If a Member elects not to exercise its option described above in Paragraph J, or decides to discontinue the financial support of the prosecution or maintenance of the protection, the Member shall have no rights in the invention. If no Members elect to exercise their option, or if all Members discontinue their support, then the Inventing University shall be free to file or continue prosecuting or maintaining any such application(s), and to maintain any protection issuing thereon in the U.S. and in any foreign country at that University's sole expense.

If only one Member bears the costs of protection, the Inventing University shall grant that Member the first option to a royalty bearing exclusive license to the invention. If only one Member is interested in a license for a particular field of use, the Inventing University shall grant that Member an option to a royalty bearing exclusive license for that field of use. In either case, if the Member is a Sustaining Member, then the Sustaining Member shall have an option to obtain a royalty-free, non-exclusive license, without a right to sublicense, rather than a royalty bearing exclusive license; further, when a Sustaining Member elects to obtain an exclusive license, the royalty shall be at a reduced rate to be negotiated at a discount from a commercially reasonable royalty. If the Member is either a Supporter Member or a Principal Member, the exclusive license shall bear a full reasonable royalty to be negotiated on commercially reasonable terms. Any exclusive licensee under this Paragraph will have a right to sublicense on terms and conditions to be mutually agreed upon. The option shall extend for a time period of (180) days from the date of filing the first patent application, which period may be extended by mutual agreement.

If more than one Member bears the costs of prosecution, the Inventing University shall grant to each of those Members options to a license to the invention on terms and conditions to be mutually agreed upon. The license shall be exclusive as to the rest of the world, but non-exclusive as among those Members which bear the cost of prosecution, provided that, where only one Member seeks a license for a particular field of use, the preceding paragraph, and not this paragraph, shall apply. The Inventing University shall grant all Sustaining Members that have borne the cost of prosecution of the patent a royalty-free license. The Inventing University shall grant all Principal Members that have borne the cost of prosecution a royalty-bearing license, but the royalty amount will be a reduced rate. The Inventing University shall grant all Supporter Members that have borne the cost of prosecution a royalty-bearing license, the royalty to be negotiated on commercially reasonable terms, but in any event the royalty amount will be higher than the amount paid by Principal Members. Except in cases of fully exclusive licenses as provided in the preceding paragraph (either for all uses or for particular fields of use), there shall be no right to sublicense; provided, however, that with the consent of the Inventing University and of all Members that have entered into licenses, either the University or a Member may sublicense the invention on such terms as the parties may agree.

L. Background Patent Rights means patent rights that result from research conducted at any of the Universities before the creation of the Center, but that are used, in whole or in part, in the research to be conducted through the Center. To the extent necessary to practice an invention conceived or first reduced to practice with funding from the Center, and to the extent that a University has legal authority to do so, a University that owns Background Patent Rights shall offer Members that have exercised the option to obtain a license to the invention, a non-exclusive, royalty-bearing license to use such Background Patent Rights, the terms of which will be negotiated in good faith on commercially reasonable terms.

M. Each University shall ensure that it has obtained all necessary rights to the Intellectual Property from its Researchers to grant the rights provided under this Agreement.

N. Any royalties and fees received by any of the Universities under this Agreement, over and above expenses incurred, will be distributed as or in accordance with the policies of the University or Universities that have taken title to the invention. A portion of net income from inventions will be devoted to research in the Center's fields of research.

O. Each party recognizes that the Center will be funded by NSF for, at the most, ten (10) years, subject to NSF continued approval and support. It is hoped that, during that 10 year period, the Center may become self-supporting. Any disposition of funds and Intellectual Property upon the conclusion of the funding, or upon the possible termination of operations of the Center shall be the responsibility of the Lead University and of any Universities that have taken title to Center inventions, and shall be in full compliance with the laws, regulations and rules governing NSF supported research programs.

P. CONTACTS for this Agreement are as follows:

Lead University Addresses	**LEAD UNIVERSITY** (Name, phone, email)	**MEMBER** (Name, phone, email)
Technical: Mechanical Engineering 111 Church Street SE Minneapolis, MN 55455	Prof. Kim Stelson 612-625-6528 kstelson@umn.edu	
Contractual/Administrative: 200 Oak Street SE, Suite 450 Minneapolis, MN 55455	Sponsored Projects Admin- Amy Rollinger 612-625-1359 amyg@umn.edu	
Financial: Mechanical Engineering 111 Church St. SE Minneapolis, MN 55455	Lisa Wissbaum 612-624-4993 mailto:lwissbaum0022@umn.edu	

Q. This Agreement is the complete and exclusive statement of the understanding between the Parties regarding the subject matter hereof, and it supersedes all prior written or contemporaneous communications.

R. This Agreement shall be governed and construed in accordance with the laws of the State of Minnesota.

REGENTS OF THE
UNIVERSITY OF MINNESOTA
on behalf of
The Engineering Resource Center

Name
Kevin McKoskey, CRA
Senior Associate Director

Title

Date: ______________________

MEMBER

____
Name

____
Title

Date: ______________________

NGEDOCS: 1150312.9

OMB No. 0990-0263
Approved for use through 1/31/2012

Protection of Human Subjects
Assurance Identification/IRB Certification/Declaration of Exemption
(Common Rule)

Policy: Research activities involving human subjects may not be conducted or supported by the Departments and Agencies adopting the Common Rule (56FR28003, June 18, 1991) unless the activities are exempt from or approved in accordance with the Common Rule. See section 101(b) of the Common Rule for exemptions. Institutions submitting applications or proposals for support must submit certification of appropriate Institutional Review Board (IRB) review and approval to the Department or Agency in accordance with the Common Rule.

Institutions must have an assurance of compliance that applies to the research to be conducted and should submit certification of IRB review and approval with each application or proposal unless otherwise advised by the Department or Agency.

1. Request Type
[] ORIGINAL
[X] CONTINUATION
[] EXEMPTION

2. Type of Mechanism
[X] GRANT [] CONTRACT [] FELLOWSHIP
[] COOPERATIVE AGREEMENT
[] OTHER:

3. Name of Federal Department or Agency and, if known, Application or Proposal Identification No.
National Science Foundation #0540834

4. Title of Application or Activity
Assessment of gait using novel fluid-power assistive ankle-foot-orthoses (AFOs)

5. Name of Principal Investigator, Program Director, Fellow, or Other
Kim Stelson, Sc.D. (Minnesota)
Elizabeth Hsiao-Wecksler, Ph.D.

6. Assurance Status of this Project *(Respond to one of the following)*

[X] This Assurance, on file with Department of Health and Human Services, covers this activity:
Assurance Identification No. FWA00008584, the expiration date March 08, 2013 IRB Registration No. **00000018**

[ ] This Assurance, on file with *(agency/dept)*__________, covers this activity.
Assurance No.__________, the expiration date __________ IRB Registration/Identification No.__________ *(if applicable)*

[ ] No assurance has been filed for this institution. This institution declares that it will provide an Assurance and Certification of IRB review and approval upon request.

[ ] Exemption Status: Human subjects are involved, but this activity qualifies for exemption under Section 101(b), paragraph__________.

7. Certification of IRB Review (Respond to one of the following IF you have an Assurance on file)

[X] This activity has been reviewed and approved by the IRB in accordance with the Common Rule and any other governing regulations.
by: [ ] Full IRB Review on (date of IRB meeting) __________ or [X] Expedited Review on June 21,2010
[ ] If less than one year approval, provide expiration date __________

[ ] This activity contains multiple projects, some of which have not been reviewed. The IRB has granted approval on condition that all projects covered by the Common Rule will be reviewed and approved before they are initiated and that appropriate further certification will be submitted.

8. Comments

IRB#08710 Assessment of gait using novel fluid-power assistive ankle-foot-orthoses (AFOs)

9. The official signing below certifies that the information provided above is correct and that, as required, future reviews will be performed until study closure and certification will be provided.

10. Name and Address of Institution

University of Illinois at Urbana-Champaign
Institutional Review Board
528 E. Green Street, Suite 203
Champaign, IL 61820

11. Phone No. *(with area code)* **(217) 333-2670**

12. Fax No. *(with area code)* **(217) 333-0405**

13. Email: **irb@illinois.edu**

14. Name of Official
Sue Keehn

15. Title
Director, Institutional Review Board

16. Signature

17. Date
6/21/10

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CCEFP INDUSTRY MEMBERSHIP LIST

Private Sector Firms

- Afton Chemical Corp.
- Air Logic
- Bobcat Co.
- Caterpillar Inc.
- CNH America, Inc.
- Concentric AB/Haldex
- Eaton Corp.
- Enfield Technologies
- Evonik Industries
- Exxon Mobil
- Freudenberg-NOK
- G.W. Lisk Co., Inc.
- HECO Gear, Inc.
- High Country Tek, Inc.
- Hoowaki, LLC
- HUSCO International, Inc.
- Linde Hydraulics Corp.
- Main Mfg Products
- Master Pneumatic-Detroit, Inc.
- MICO, Inc.
- Moog Inc.
- National Fluid Power Assoc.
- National Tube Supply Co.
- Netshape Technologies, Inc.
- Nexen Group, Inc.
- Nitta Moore
- Parker Hannifin Corp.
- PIAB Vacuum Products
- Poclain Hydraulics
- Quality Control Corp.
- Racine Federated Inc. (formerly Hedland Flow Meters)
- Ross Controls
- Sauer-Danfoss
- Shell Global Systems
- Simerics
- StorWatts
- Sun Hydraulics Corp.
- Takako Industries
- Tennant Co.
- The Lubrizol Corporation
- Trelleborg Sealing Solutions U.S. Inc.
- Woodward

Non-Private Sector Firms

- Fluid Power Educational Foundation

Kevin McKoskey
Senior Associate Director

Table 9b - Cost Sharing by Institution

	Award Year 1 (FY07)		Award Year 2 (FY08)		Award Year 3 (FY09)	
Institution	**Committed**	**Actual**	**Committed**	**Actual**	**Committed**	**Actual**
U. of Minnesota	$180,180	$180,180	$182,000	$182,000	$220,469	$220,469
Georgia Tech	$112,860	$67,584	$129,000	$140,827	$133,000	$83,110
MSOE	$0	$0	$10,800	$18,086	$0	$0
Purdue	$112,860	$112,860	$129,000	$113,321	$133,000	$162,637
UIUC	$112,860	$33,529	$123,200	$77,249	$124,865	$201,233
Vanderbilt	$75,240	$75,240	$76,000	$157,021	$88,666	$112,359

	Award Year 4 (FY10)		Award Year 5 (FY11)		Award Year 6 (FY12)	
Institution	**Committed**	**Actual**	**Committed**	**Actual**	**Committed**	**Actual**
U. of Minnesota	$226,367	$187,032	$242,667	$327,140	$339,537	-
Georgia Tech	$142,995	$267,384	$152,000	$135,564	$130,232	-
MSOE	$0	-	$0	-	$0	-
Purdue	$142,995	$139,404	$152,000	$200,153	$152,557	-
UIUC	$142,995	$210,852	$119,541	$163,809	$92,093	-
Vanderbilt	$94,648	$69,213	$101,333	$119,717	$85,581	-

	Award Year 7 (FY13)		Award Year 8 (FY14)		Cumulative Commitment
Institution	**Committed**	**Actual**	**Committed**	**Actual**	
U. of Minnesota	$339,537	-	$339,537	-	$2,070,294
Georgia Tech	$130,232	-	$130,232	-	$1,060,551
MSOE	$0	-	$0	-	$10,800
Purdue	$152,557	-	$152,557	-	$1,127,526
UIUC	$92,093	-	$92,093	-	$899,740
Vanderbilt	$85,581	-	$85,581	-	$692,630

Kevin McKoskey
Senior Associate Director

Administrative

UNIVERSITY OF MINNESOTA
BOARD OF REGENTS POLICY

INSTITUTIONAL CONFLICT OF INTEREST
Adopted: June 10, 2005

INSTITUTIONAL CONFLICT OF INTEREST

SECTION I. SCOPE.

This policy governs institutional conflict of interest at the University of Minnesota (University) and applies to members of the Board of Regents (Board), University officials, department/unit heads, and other individuals as required by administrative policies and procedures.

SECTION II. DEFINITIONS.

Subd. 1. Institutional Conflict of Interest. *Institutional conflict of interest* shall mean a situation in which the research, teaching, outreach, or other activities of the University may be compromised because of an external financial or business relationship held at the institutional level that may bring financial gain to the institution, any of its units, or the individuals covered by this policy. **Subd. 2. University Official.** *University official* shall mean persons holding the following positions, including those holding these positions in a temporary capacity:

(a) chancellors and vice chancellors;
(b) deans, associate deans, and assistant deans;
(c) division I athletic director;
(d) general counsel;
(e) president and president's chief of staff;
(f) provosts, vice provosts, associate vice provosts, and assistant vice provosts; and
(g) senior vice presidents, vice presidents, associate vice presidents, and assistant vice presidents.

SECTION III. GUIDING PRINCIPLES.

The following principles shall guide the University in addressing institutional conflict of interest:

(a) Because it is critical to the mission and reputation of the University to maintain the public's trust, University research, teaching, outreach, and other activities must not be compromised or perceived as biased by financial and business considerations.

(b) Because of its numerous and complex relationships with public and private entities, the University must be aware of any relationships involving financial gain that may compromise or

appear to compromise its integrity.
(c) The University shall establish and maintain an oversight process to manage, reduce, or eliminate institutional conflict of interest.

SECTION IV. RESERVATION OF AUTHORITY.

The Board reserves authority to review and approve plans for managing, reducing, or eliminating institutional conflict of interest involving:

(a) external relationships with an unusually significant financial impact that present a potential conflict;
(b) potential conflicts involving the president;
(c) potential conflicts that raise serious policy issues or have a significant public impact on the mission and reputation of the University; or
(d) potential conflicts arising in matters that otherwise require Board review and action under Board of Regents Policy: *Reservation and Delegation of Authority.*

In these instances of conflict of interest, the president shall consult with the Board.

SECTION V. ASSURANCE, DELEGATION OF AUTHORITY, AND REPORTING.

The president or delegate shall:

(a) implement an oversight process and administrative policies and procedures to address institutional conflict of interest and to identify situations in which institutional conflict of interest may arise;
(b) recommend and implement plans to manage, reduce, or eliminate institutional conflict of interest;
(c) develop and present conflict of interest plans to the Board for review and action as required under Section IV;
(d) ensure that individuals covered by this policy who act on behalf of the institution adhere to these policies and procedures, follow applicable conflict management plans, and do not engage in activities in which there is an actual conflict of interest; and
(e) report to the Board annually all institutional conflict of interest matters that do not meet the thresholds identified in Section IV.

SECTION VI. DISCLOSURES.

Subd. 1. Regents. Regents shall file a financial disclosure statement annually and report conflicts of interest as required by Board of Regents Policy: *Code of Ethics.*

Subd. 2. University Officials. University officials shall, upon appointment and annually on September 30 thereafter, file a financial disclosure statement with the president or delegate, disclosing significant economic interests and how those interests may relate to their institutional responsibilities. Such disclosure shall be made in addition to any reporting requirement for individual conflicts of interest.

Subd. 3. Department/Unit Heads. Annually and under circumstances described in administrative policy, department/unit heads shall disclose relevant financial and business interests by filing a *Report of External Professional Activities*.

Subd. 4. Other Individuals. The president or delegate may designate other individuals who shall file a financial disclosure statement.

SUPERSEDES: FINANCIAL DISCLOSURE FOR SENIOR UNIVERSITY OFFICIALS, DATED NOVEMBER 10, 1995.

CERTIFIED BY AOR

Kevin McKoskey, CRA
Senior Grants Manager
Office of Sponsored Projects Administration

Response of the University of Minnesota to NSF's
Request for Conflict of Interest Related Information

NSF has requested specific conflict of interest policy information from the ERC lead institution regarding ERC faculty or student involvement in start-up firms or small businesses. In particular, NSF requests that the lead university's oversight policies with respect to COI for the following circumstances be explained:

- Situations where ERC faculty or students spin-out start-up firms;
- Situations where it is necessary for the ERC to purchase products from a firm for which ERC faculty (or hi/her spouse or children") have fiduciary interests.

The following is the University of Minnesota's response.

The University has recently revised its conflict of interest policy, now titled: *Individual Conflicts of Interest***.** This policy has University wide application. The policy is risk based. More restrictive standards apply to individuals who are involved in one or more of the five higher risk areas which include individuals:

1. involved in human subjects research subject to review by the Institutional Review Board (IRB) where the IRB has determined that research conducted by the covered individual involves "more than minimal" risk to subjects;
2. involved in clinical health care;
3. involved in technology commercialization;
4. in a position to exert control over the content of University curriculum that could benefit the commercial interests of a business entity and, at the same time, create opportunity for or further an existing financial relationship between the covered individual and that business entity; or
5. in a position to take any other action on behalf of the University that could benefit the commercial interests of a business entity and, at the same time, create opportunity for or further an existing financial relationship between the covered individual and that business entity.

The University has an annual mandatory reporting process that applies to all faculty and staff, those responsible for the design, conduct and reporting of research, as well as those who are considered "key personnel" on research protocols. These individuals are required to annually report all business and financial interests and engagement in outside consulting and other outside commitments. In addition to annual reporting, these individuals are also required to prepare a new report within 30 days of a substantial change in a business or financial interest that relates to the individual's university expertise or responsibilities, or a change in their University responsibilities that relates to an existing business or financial interest.

The report form is called the Report of External Professional Activities (REPA). The REPA asks a number of detailed questions to include:

- whether the individual completing the form will take administrative action on behalf of the University related to the business in which the individual has a business or significant financial interest. This question elicits information regarding purchasing relationships.

The questions on the REPA also inquire about the filer's equity interests. Where faculty spin-out start up firms, they typically have an equity interest in the firm that equals or exceeds the University's thresholds for reporting.

When REPA filers report the circumstances described above, a conflict of interest review is initiated. That review begins with an administrative review and ends with review and consideration by a formally convened conflict of interest committee. If the committee determines that a conflict of interest exists, a conflict management plan is developed and that plan remains in effect so long as the conflict exists. Throughout the review process, coordination takes place between the Conflict of Interest Program and the Office for Technology Commercialization.

Students are covered by the University's conflict of interest policies and procedures if they:

- have a leadership role on University research (PI or CoI); or
- have responsibility for the design, conduct or reporting or University research, or are considered "key personnel" on University research.

The following are links to the:

- University's of Minnesota's Board of Regents Policy: *Individual Conflicts of Interest.*

  http://www1.umn.edu/regents/policies/administrative/Individual_COI.htm.

- University of Minnesota's administrative policy: *Individual Conflicts of Interest.*

  http://www.policy.umn.edu/Policies/Operations/Compliance/CONFLICTINTEREST.html.

- *Appendix to policy: Conflicts of Interest Categories.*

  http://www.policy.umn.edu/Policies/Operations/Compliance/CONFLICTINTEREST_APPD.html. See item 4A.

Table 10a: Unexpended Residual in the Current Award and Proposed Award Year

	Previous Award Year to Current Award Year	Current Award Year to Proposed Award Year
Total Unexpended Residual Funds	$1,054,053	$2,638,310.11
Committed, Encumbered, Obligated funds	$1,054,053	$2,730,526.72
Residual Funds Without Specified Use	$0	-$92,217

Kevin McKoskey
Senior Associate Director

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APPENDIX III

Table 7: Personnel

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Table 7: ERC Personnel

Personnel Type	Total [1]	Gender			Citizenship Status									Ethnicity: Hispanic			Disability
					Race—U.S. citizens and permanent residents only												
		Male	Female	Gender Not Reported	AI/AN	NH/PI	B/AA	W	A	More than one race reported, minority	Race Not Reported	Citizenship Foreign/ Temp Visa	Citizenship Not Reported	U.S. Citizen/ Perm Resident	Citizenship Foreign/ Temp Visa	Citizenship Not Reported	
Total All Institutions																	
Total [2]	296	187	70	39	65	0	12	130	11	2	11	37	28	5	4	0	5
Leadership/Administration																	
Directors	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Thrust Leaders	4	3	1	0	0	0	0	3	0	1	0	0	0	0	0	0	0
Research Thrust Management and Strategic Planning	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Industrial Liaison Officer (ILO)	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Education Program Leaders	2	1	1	0	0	0	0	2	0	0	0	0	0	0	0	0	0
Administrative Director	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Staff	12	9	2	1	0	0	1	7	1	0	1	1	1	0	0	0	0
Subtotal	**22**	**16**	**5**	**1**	**0**	**0**	**1**	**15**	**2**	**1**	**1**	**1**	**1**	**0**	**0**	**0**	**0**
Research Under Strategic Research Plan																	
Senior Faculty	17	16	1	0	0	0	2	10	3	0	2	0	0	1	0	0	0
Junior Faculty	8	6	1	1	0	0	0	3	1	0	0	3	1	0	0	0	0
Research Staff	6	7	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0
Industry Researchers	2	1	0	1	0	0	0	0	0	0	1	0	1	0	0	0	0
Total Postdocs	3	3	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0
Total Doctoral Students	52	43	7	2	5	0	0	18	2	0	2	23	2	0	3	0	1
Total Master's Students	26	19	4	3	0	0	0	18	2	0	1	3	2	0	1	0	1
Total Undergraduate Students	76	38	22	18	35	0	4	18	2	0	2	5	12	0	0	0	0
Subtotal	**193**	**133**	**35**	**25**	**40**	**0**	**6**	**74**	**10**	**0**	**8**	**37**	**18**	**1**	**4**	**0**	**2**
Curriculum Development and Outreach																	
Senior Faculty	13	10	4	0	2	0	1	8	2	0	1	0	0	0	0	0	0
Junior Faculty	6	4	1	1	0	0	0	2	1	0	0	2	1	0	0	0	0
Research Staff	15	6	12	0	2	0	0	12	0	0	2	0	2	0	0	0	2
Total Doctoral Students	8	7	1	0	0	0	0	6	0	0	0	2	0	0	1	0	1
Total Master's Students	4	1	0	3	1	0	0	0	0	0	0	1	2	0	0	0	0
Total Undergraduate Students	93	41	28	24	49	0	8	21	1	1	0	1	12	3	0	0	1
Subtotal	**143**	**69**	**46**	**28**	**54**	**0**	**9**	**49**	**4**	**1**	**3**	**6**	**17**	**3**	**1**	**0**	**4**
ERC REU Students																	
ERC's Own REU Students	19	14	12	2	0	0	6	18	1	0	0	1	2	2	1	0	0
Subtotal	**28**	**14**	**12**	**2**	**0**	**0**	**6**	**18**	**1**	**0**	**0**	**1**	**2**	**2**	**1**	**0**	**0**
Precollege (K-12)																	
Teachers (non-RET)	15	8	7	0	4	0	1	9	0	0	1	0	0	1	0	0	0
Teachers (RET)	6	6	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0
Subtotal	**21**	**14**	**7**	**0**	**4**	**0**	**1**	**15**	**0**	**0**	**1**	**0**	**0**	**1**	**0**	**0**	**0**
University of Minnesota - Lead Institution																	
Total [2]	81	52	18	11	9	0	3	32	4	0	3	17	13	1	0	0	2
Leadership/Administration																	
Directors	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Research Thrust Management and Strategic Planning	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Industrial Liaison Officer (ILO)	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Education Program Leaders	2	1	1	0	0	0	0	2	0	0	0	0	0	0	0	0	0
Administrative Director	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Staff	8	6	2	0	0	0	1	4	1	0	1	1	0	0	0	0	0
Subtotal	**14**	**10**	**4**	**0**	**0**	**0**	**1**	**9**	**2**	**0**	**1**	**1**	**0**	**0**	**0**	**0**	**0**
Research Under Strategic Research Plan																	
Senior Faculty	4	4	0	0	0	0	0	3	1	0	0	0	0	0	0	0	0
Junior Faculty	2	1	0	1	0	0	0	0	1	0	0	0	1	0	0	0	0

Personnel Type	Total [1]	Gender			Citizenship Status									Ethnicity: Hispanic			Disability
					Race—U.S. citizens and permanent residents only												
		Male	Female	Gender Not Reported	AI/AN	NH/PI	B/AA	W	A	More than one race reported, minority	Race Not Reported	Citizenship Foreign/ Temp Visa	Citizenship Not Reported	U.S. Citizen/ Perm Resident	Citizenship Foreign/ Temp Visa	Citizenship Not Reported	
Research Staff	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Total Postdocs	2	2	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
Total Doctoral Students	14	13	1	0	0	0	0	2	1	0	0	11	0	0	0	0	0
Total Master's Students	8	6	1	1	0	0	0	6	0	0	1	1	0	0	0	0	0
Total Undergraduate Students	12	6	1	5	1	0	0	4	0	0	0	2	5	0	0	0	0
Subtotal	**43**	**33**	**3**	**7**	**1**	**0**	**0**	**16**	**3**	**0**	**1**	**16**	**6**	**0**	**0**	**0**	**0**
Curriculum Development and Outreach																	
Senior Faculty	5	4	1	0	0	0	0	4	1	0	0	0	0	0	0	0	0
Junior Faculty	2	1	0	1	0	0	0	0	1	0	0	0	1	0	0	0	0
Research Staff	8	1	7	0	1	0	0	5	0	0	1	0	1	0	0	0	1
Total Doctoral Students	2	2	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0
Total Master's Students	2	1	0	1	1	0	0	0	0	0	0	1	0	0	0	0	0
Total Undergraduate Students	20	11	5	4	7	0	2	3	0	0	0	1	7	1	0	0	1
Subtotal	**39**	**20**	**13**	**6**	**9**	**0**	**2**	**13**	**2**	**0**	**1**	**3**	**9**	**1**	**0**	**0**	**2**
ERC REU Students																	
ERC's Own REU Students	2	2	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0
Subtotal	**2**	**2**	**0**	**0**	**0**	**0**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**
Georgia Institute of Technology - Core Partner																	
Total [2]	29	23	5	1	0	0	0	23	0	0	1	4	1	0	0	0	0
Leadership/Administration																	
Thrust Leaders	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Staff	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Subtotal	**2**	**2**	**0**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Research Under Strategic Research Plan																	
Senior Faculty	4	4	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0
Junior Faculty	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Research Staff	2	2	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
Total Postdocs	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Total Doctoral Students	9	6	2	1	0	0	0	5	0	0	1	2	1	0	0	0	0
Total Master's Students	3	3	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
Total Undergraduate Students	5	3	2	0	0	0	0	5	0	0	0	0	0	0	0	0	0
Subtotal	**25**	**20**	**4**	**1**	**0**	**0**	**0**	**19**	**0**	**0**	**1**	**4**	**1**	**0**	**0**	**0**	**0**
Curriculum Development and Outreach																	
Senior Faculty	2	2	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
Total Doctoral Students	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Total Undergraduate Students	3	2	1	0	0	0	0	3	0	0	0	0	0	0	0	0	0
Subtotal	**6**	**4**	**2**	**0**	**0**	**0**	**0**	**6**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
ERC REU Students																	
ERC's Own REU Students	2	1	1	0	0	0	0	2	0	0	0	0	0	0	0	0	0
Subtotal	**2**	**1**	**1**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Purdue University - Core Partner																	
Total [2]	33	24	4	5	0	0	0	16	3	0	1	8	5	0	2	0	0
Leadership/Administration																	
Thrust Leaders	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Staff	2	1	0	1	0	0	0	1	0	0	0	0	1	0	0	0	0
Subtotal	**3**	**1**	**1**	**1**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**
Research Under Strategic Research Plan																	
Junior Faculty	3	2	1	0	0	0	0	2	0	0	0	1	0	0	0	0	0
Total Doctoral Students	11	11	0	0	0	0	0	5	0	0	1	5	0	0	2	0	0
Total Master's Students	7	5	0	2	0	0	0	3	1	0	0	1	2	0	0	0	0

Personnel Type	Total [1]	Gender			Citizenship Status									Ethnicity: Hispanic			Disability
		Male	Female	Gender Not Reported	Race—U.S. citizens and permanent residents only							Citizenship Foreign/ Temp Visa	Citizenship Not Reported	U.S. Citizen/ Perm Resident	Citizenship Foreign/ Temp Visa	Citizenship Not Reported	
					AI/AN	NH/PI	B/AA	W	A	More than one race reported, minority	Race Not Reported						
Total Undergraduate Students	3	2	1	0	0	0	0	0	2	0	0	1	0	0	0	0	0
Subtotal	**24**	**20**	**2**	**2**	**0**	**0**	**0**	**10**	**3**	**0**	**1**	**8**	**2**	**0**	**2**	**0**	**0**
Curriculum Development and Outreach																	
Junior Faculty	2	2	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0
Total Doctoral Students	2	2	0	0	0	0	0	1	0	0	0	1	0	0	1	0	0
Total Master's Students	2	0	0	2	0	0	0	0	0	0	0	0	2	0	0	0	0
Total Undergraduate Students	5	4	1	0	0	0	0	4	1	0	0	0	0	0	0	0	0
Subtotal	**11**	**8**	**1**	**2**	**0**	**0**	**0**	**6**	**1**	**0**	**0**	**2**	**2**	**0**	**1**	**0**	**0**
ERC REU Students																	
ERC's Own REU Students	4	3	1	0	0	0	0	3	1	0	0	0	0	0	0	0	0
Subtotal	**4**	**3**	**1**	**0**	**0**	**0**	**0**	**3**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
University of Illinois at Urbana-Champaign - Core Partner																	
Total [2]	14	9	4	1	0	0	0	8	2	1	0	2	1	0	0	0	1
Leadership/Administration																	
Thrust Leaders	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Subtotal	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Research Under Strategic Research Plan																	
Senior Faculty	2	1	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0
Total Doctoral Students	6	5	1	0	0	0	0	4	1	0	0	1	0	0	0	0	1
Total Master's Students	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Total Undergraduate Students	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Subtotal	**10**	**7**	**3**	**0**	**0**	**0**	**0**	**6**	**2**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**1**
Curriculum Development and Outreach																	
Senior Faculty	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Total Doctoral Students	2	2	0	0	0	0	0	2	0	0	0	0	0	0	0	0	1
Total Undergraduate Students	3	1	1	1	0	0	0	2	0	0	0	0	1	0	0	0	0
Subtotal	**6**	**3**	**2**	**1**	**0**	**0**	**0**	**4**	**1**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**1**
ERC REU Students																	
ERC's Own REU Students	3	1	1	1	0	0	0	2	0	0	0	0	1	0	0	0	0
Subtotal	**3**	**1**	**1**	**1**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**
Vanderbilt University - Core Partner																	
Total [2]	11	8	2	1	0	0	1	7	0	0	0	2	1	0	1	0	0
Leadership/Administration																	
Thrust Leaders	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Subtotal	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Research Under Strategic Research Plan																	
Senior Faculty	2	2	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
Junior Faculty	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Total Doctoral Students	4	3	1	0	0	0	0	2	0	0	0	2	0	0	1	0	0
Total Master's Students	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Subtotal	**8**	**7**	**1**	**0**	**0**	**0**	**0**	**6**	**0**	**0**	**0**	**2**	**0**	**0**	**1**	**0**	**0**
Curriculum Development and Outreach																	
Senior Faculty	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Total Doctoral Students	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Total Undergraduate Students	2	1	0	1	0	0	1	0	0	0	0	0	1	0	0	0	0
Subtotal	**4**	**2**	**1**	**1**	**0**	**0**	**1**	**2**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**
ERC REU Students																	
ERC's Own REU Students	2	1	0	1	0	0	1	0	0	0	0	0	1	0	0	0	0

Personnel Type	Total [1]	Gender			Citizenship Status									Ethnicity: Hispanic			Disability
					Race—U.S. citizens and permanent residents only												
		Male	Female	Gender Not Reported	AI/AN	NH/PI	B/AA	W	A	More than one race reported, minority	Race Not Reported	Citizenship Foreign/ Temp Visa	Citizenship Not Reported	U.S. Citizen/ Perm Resident	Citizenship Foreign/ Temp Visa	Citizenship Not Reported	
Subtotal	**2**	**1**	**0**	**1**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**
Bemidji State University - Collaborating (Outreach) Institutions																	
Total [2]	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Curriculum Development and Outreach																	
Total Undergraduate Students	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal	**1**	**0**	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Case Western Reserve University - Collaborating (Outreach) Institutions																	
Total [2]	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Curriculum Development and Outreach																	
Total Undergraduate Students	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Subtotal	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Clarkson University - Collaborating (Outreach) Institutions																	
Total [2]	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Curriculum Development and Outreach																	
Total Undergraduate Students	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Subtotal	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Eolos Wind Energy Research Consortium - Collaborating (Outreach) Institutions																	
Total [2]	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Research Under Strategic Research Plan																	
Research Staff	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Subtotal	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Hennepin Technical College - Collaborating (Outreach) Institutions																	
Total [2]	5	5	0	0	0	0	0	0	0	0	3	0	2	0	0	0	0
Research Under Strategic Research Plan																	
Senior Faculty	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Total Undergraduate Students	4	4	0	0	0	0	0	0	0	0	2	0	2	0	0	0	0
Subtotal	**5**	**5**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**3**	**0**	**2**	**0**	**0**	**0**	**0**
Michigan Technological University - Collaborating (Outreach) Institutions																	
Total [2]	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Curriculum Development and Outreach																	
Total Undergraduate Students	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Subtotal	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Milwaukee School of Engineering - Collaborating (Outreach) Institutions																	
Total [2]	22	15	6	1	0	0	1	17	1	0	1	1	1	1	1	0	1
Leadership/Administration																	
Staff	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Subtotal	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Research Under Strategic Research Plan																	
Senior Faculty	1	1	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0
Research Staff	3	3	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
Industry Researchers	2	1	0	1	0	0	0	0	0	0	1	0	1	0	0	0	0
Total Master's Students	6	4	2	0	0	0	0	4	1	0	0	1	0	0	1	0	1
Total Undergraduate Students	9	5	4	0	0	0	0	9	0	0	0	0	0	0	0	0	0
Subtotal	**21**	**14**	**6**	**1**	**0**	**0**	**1**	**16**	**1**	**0**	**1**	**1**	**1**	**1**	**1**	**0**	**1**
Curriculum Development and Outreach																	
Research Staff	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Total Undergraduate Students	3	1	2	0	0	0	0	3	0	0	0	0	0	0	0	0	0
Subtotal	**4**	**2**	**2**	**0**	**0**	**0**	**0**	**4**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Personnel Type	Total [1]	Gender			Citizenship Status									Ethnicity: Hispanic			Disability
					Race—U.S. citizens and permanent residents only							Citizenship Foreign/ Temp Visa	Citizenship Not Reported	U.S. Citizen/ Perm Resident	Citizenship Foreign/ Temp Visa	Citizenship Not Reported	
		Male	Female	Gender Not Reported	AI/AN	NH/PI	B/AA	W	A	More than one race reported, minority	Race Not Reported						
ERC REU Students																	
ERC's Own REU Students	2	0	2	0	0	0	0	2	0	0	0	0	0	0	0	0	0
Subtotal	**2**	**0**	**2**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
National Center for Earth-surface Dynamics - Collaborating (Outreach) Institutions																	
Total [2]	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Curriculum Development and Outreach																	
Research Staff	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Subtotal	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
North Carolina Agriculture and Technical State University - Collaborating (Outreach) Institutions																	
Total [2]	15	10	4	1	5	0	4	0	1	0	1	3	1	0	0	0	0
Research Under Strategic Research Plan																	
Senior Faculty	3	3	0	0	0	0	1	0	1	0	1	0	0	0	0	0	0
Junior Faculty	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Total Doctoral Students	8	5	2	1	5	0	0	0	0	0	0	2	1	0	0	0	0
Total Undergraduate Students	1	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Subtotal	**13**	**9**	**3**	**1**	**5**	**0**	**2**	**0**	**1**	**0**	**1**	**3**	**1**	**0**	**0**	**0**	**0**
Curriculum Development and Outreach																	
Senior Faculty	2	2	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0
Junior Faculty	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Total Undergraduate Students	3	1	2	0	0	0	3	0	0	0	0	0	0	0	0	0	0
Subtotal	**6**	**4**	**2**	**0**	**0**	**0**	**4**	**0**	**0**	**0**	**1**	**1**	**0**	**0**	**0**	**0**	**0**
ERC REU Students																	
ERC's Own REU Students	3	1	2	0	0	0	3	0	0	0	0	0	0	0	0	0	0
Subtotal	**3**	**1**	**2**	**0**	**0**	**0**	**3**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Science Museum of Minnesota - Collaborating (Outreach) Institutions																	
Total [2]	5	4	1	0	0	0	0	5	0	0	0	0	0	0	0	0	1
Curriculum Development and Outreach																	
Research Staff	5	4	1	0	0	0	0	5	0	0	0	0	0	0	0	0	1
Subtotal	**5**	**4**	**1**	**0**	**0**	**0**	**0**	**5**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**
St. Cloud State University - Collaborating (Outreach) Institutions																	
Total [2]	5	0	4	1	5	0	0	0	0	0	0	0	0	0	0	0	0
Research Under Strategic Research Plan																	
Total Undergraduate Students	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal	**1**	**0**	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Curriculum Development and Outreach																	
Research Staff	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Total Undergraduate Students	3	0	2	1	3	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal	**4**	**0**	**3**	**1**	**4**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
STEM Education Center - Collaborating (Outreach) Institutions																	
Total [2]	2	0	2	0	0	0	0	2	0	0	0	0	0	0	0	0	0
Curriculum Development and Outreach																	
Senior Faculty	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Junior Faculty	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Subtotal	**2**	**0**	**2**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
University of Florida - Collaborating (Outreach) Institutions																	
Total [2]	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Curriculum Development and Outreach																	
Total Undergraduate Students	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Subtotal	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Personnel Type	Total [1]	Gender			Citizenship Status									Ethnicity: Hispanic			Disability
					Race—U.S. citizens and permanent residents only												
		Male	Female	Gender Not Reported	AI/AN	NH/PI	B/AA	W	A	More than one race reported, minority	Race Not Reported	Citizenship Foreign/ Temp Visa	Citizenship Not Reported	U.S. Citizen/ Perm Resident	Citizenship Foreign/ Temp Visa	Citizenship Not Reported	
University of Minnesota - Morris - Collaborating (Outreach) Institutions																	
Total [2]	17	2	9	6	13	0	1	0	0	0	0	0	3	0	0	0	0
Curriculum Development and Outreach																	
Total Undergraduate Students	17	2	9	6	13	0	1	0	0	0	0	0	3	0	0	0	0
Subtotal	**17**	**2**	**9**	**6**	**13**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**3**	**0**	**0**	**0**	**0**
University of Missouri-Columbia - Collaborating (Outreach) Institutions																	
Total [2]	2	2	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
Curriculum Development and Outreach																	
Total Undergraduate Students	2	2	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
Subtotal	**2**	**2**	**0**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
University of North Dakota - Collaborating (Outreach) Institutions																	
Total [2]	6	3	3	0	5	0	1	0	0	0	0	0	0	2	0	0	0
Curriculum Development and Outreach																	
Total Undergraduate Students	6	3	3	0	5	0	1	0	0	0	0	0	0	2	0	0	0
Subtotal	**6**	**3**	**3**	**0**	**5**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**0**
Humboldt State University - Non-ERC Institutions Providing REU Students																	
Total [2]	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
ERC REU Students																	
ERC's Own REU Students	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Subtotal	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Louisana State University - Non-ERC Institutions Providing REU Students																	
Total [2]	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
ERC REU Students																	
ERC's Own REU Students	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Subtotal	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Loyola University Chicago - Non-ERC Institutions Providing REU Students																	
Total [2]	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
ERC REU Students																	
ERC's Own REU Students	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Subtotal	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Minneapolis Community and Technical College - Non-ERC Institutions Providing REU Students																	
Total [2]	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
ERC REU Students																	
ERC's Own REU Students	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Subtotal	**1**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
New Mexico State University - Non-ERC Institutions Providing REU Students																	
Total [2]	1	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0
ERC REU Students																	
ERC's Own REU Students	1	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0
Subtotal	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**
Princeton University - Non-ERC Institutions Providing REU Students																	
Total [2]	2	1	1	0	0	0	0	2	0	0	0	0	0	0	0	0	0
ERC REU Students																	
ERC's Own REU Students	2	1	1	0	0	0	0	2	0	0	0	0	0	0	0	0	0
Subtotal	**2**	**1**	**1**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Texas A and M University - Non-ERC Institutions Providing REU Students																	
Total [2]	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
ERC REU Students																	

Personnel Type	Total [1]	Gender			Citizenship Status									Ethnicity: Hispanic			Disability
					Race—U.S. citizens and permanent residents only												
		Male	Female	Gender Not Reported	AI/AN	NH/PI	B/AA	W	A	More than one race reported, minority	Race Not Reported	Citizenship Foreign/ Temp Visa	Citizenship Not Reported	U.S. Citizen/ Perm Resident	Citizenship Foreign/ Temp Visa	Citizenship Not Reported	
ERC's Own REU Students	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Subtotal	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
University of Texas at El Paso - Non-ERC Institutions Providing REU Students																	
Total [2]	1	1	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0
ERC REU Students																	
ERC's Own REU Students	1	1	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0
Subtotal	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**1**	**0**	**0**
Yale University - Non-ERC Institutions Providing REU Students																	
Total [2]	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
ERC REU Students																	
ERC's Own REU Students	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Subtotal	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Fond du Lac Tribal and Community College - Community College																	
Total [2]	2	2	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0
Curriculum Development and Outreach																	
Total Undergraduate Students	2	2	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0
Subtotal	**2**	**2**	**0**	**0**	**1**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Lac Courte Oreilles Ojibwa Community College - Community College																	
Total [2]	2	2	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
Research Under Strategic Research Plan																	
Total Undergraduate Students	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal	**1**	**1**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Curriculum Development and Outreach																	
Total Undergraduate Students	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal	**1**	**1**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Leech Lake Tribal College - Community College																	
Total [2]	4	1	0	3	4	0	0	0	0	0	0	0	0	0	0	0	0
Research Under Strategic Research Plan																	
Total Undergraduate Students	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal	**1**	**0**	**0**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Curriculum Development and Outreach																	
Senior Faculty	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Total Undergraduate Students	3	0	0	3	3	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal	**4**	**1**	**0**	**3**	**4**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Salish Kootenai College - Community College																	
Total [2]	16	7	1	8	16	0	0	0	0	0	0	0	0	0	0	0	0
Curriculum Development and Outreach																	
Senior Faculty	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Total Undergraduate Students	15	6	1	8	15	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal	**16**	**7**	**1**	**8**	**16**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Brentwood High School - Pre-college Partner																	
Total [2]	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Precollege (K-12)																	
Teachers (RET)	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Subtotal	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Circle of Life School - Pre-college Partner																	
Total [2]	2	2	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0
Precollege (K-12)																	

Personnel Type	Total [1]	Gender			Citizenship Status									Ethnicity: Hispanic			Disability
					Race—U.S. citizens and permanent residents only												
		Male	Female	Gender Not Reported	AI/AN	NH/PI	B/AA	W	A	More than one race reported, minority	Race Not Reported	Citizenship Foreign/ Temp Visa	Citizenship Not Reported	U.S. Citizen/ Perm Resident	Citizenship Foreign/ Temp Visa	Citizenship Not Reported	
Teachers (non-RET)	2	2	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0
Subtotal	**2**	**2**	**0**	**0**	**1**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Cloquet High School - Pre-college Partner																	
Total [2]	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Precollege (K-12)																	
Teachers (non-RET)	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Subtotal	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Gibbon, Fairfax, Winthrop School - Pre-college Partner																	
Total [2]	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Precollege (K-12)																	
Teachers (RET)	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Subtotal	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Independence High School - Pre-college Partner																	
Total [2]	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Precollege (K-12)																	
Teachers (RET)	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Subtotal	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
KidWind - Pre-college Partner																	
Total [2]	2	1	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0
Precollege (K-12)																	
Teachers (non-RET)	2	1	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0
Subtotal	**2**	**1**	**1**	**0**	**1**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Mahtomedi High School - Pre-college Partner																	
Total [2]	2	1	1	0	0	0	0	2	0	0	0	0	0	0	0	0	0
Precollege (K-12)																	
Teachers (non-RET)	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Teachers (RET)	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Subtotal	**2**	**1**	**1**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
McCutcheon High School - Pre-college Partner																	
Total [2]	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Precollege (K-12)																	
Teachers (RET)	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Subtotal	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Ojibwe School - Pre-college Partner																	
Total [2]	2	1	1	0	2	0	0	0	0	0	0	0	0	1	0	0	0
Precollege (K-12)																	
Teachers (non-RET)	2	1	1	0	2	0	0	0	0	0	0	0	0	1	0	0	0
Subtotal	**2**	**1**	**1**	**0**	**2**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**
Ponemah Elementary School - Pre-college Partner																	
Total [2]	1	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Precollege (K-12)																	
Teachers (non-RET)	1	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Subtotal	**1**	**0**	**1**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Red Lake Middle School - Pre-college Partner																	
Total [2]	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Precollege (K-12)																	
Teachers (non-RET)	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Subtotal	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**

Personnel Type	Total [1]	Gender			Citizenship Status									Ethnicity: Hispanic			Disability
					Race—U.S. citizens and permanent residents only												
		Male	Female	Gender Not Reported	AI/AN	NH/PI	B/AA	W	A	More than one race reported, minority	Race Not Reported	Citizenship Foreign/ Temp Visa	Citizenship Not Reported	U.S. Citizen/ Perm Resident	Citizenship Foreign/ Temp Visa	Citizenship Not Reported	
South Ridge School (formerly Albrook School) - Pre-college Partner																	
Total [2]	5	2	3	0	0	0	0	5	0	0	0	0	0	0	0	0	0
Precollege (K-12)																	
Teachers (non-RET)	5	2	3	0	0	0	0	5	0	0	0	0	0	0	0	0	0
Subtotal	**5**	**2**	**3**	**0**	**0**	**0**	**0**	**5**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Tippecanoe School Corporation - Pre-college Partner																	
Total [2]	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Precollege (K-12)																	
Teachers (RET)	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Subtotal	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
North Star STEM Alliance - LSAMP																	
Total [2]	23	8	11	4	14	0	3	0	0	0	0	1	5	0	0	0	0
Research Under Strategic Research Plan																	
Total Undergraduate Students	23	8	11	4	14	0	3	0	0	0	0	1	5	0	0	0	0
Subtotal	**23**	**8**	**11**	**4**	**14**	**0**	**3**	**0**	**0**	**0**	**0**	**1**	**5**	**0**	**0**	**0**	**0**
The All Nations Louis Stokes Alliance for Minority Participation - LSAMP																	
Total [2]	2	2	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
Research Under Strategic Research Plan																	
Total Undergraduate Students	2	2	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal	**2**	**2**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
New Baccalaureate Degrees and STEM Program Improvement at Salish Kootenai College - TCUP																	
Total [2]	15	6	1	8	15	0	0	0	0	0	0	0	0	0	0	0	0
Research Under Strategic Research Plan																	
Total Undergraduate Students	15	6	1	8	15	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal	**15**	**6**	**1**	**8**	**15**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Northstar STEM Program - Alliances with NSF Diversity Awardees																	
Total [2]	2	0	2	0	0	0	0	0	0	0	1	0	1	0	0	0	0
Curriculum Development and Outreach																	
Research Staff	2	0	2	0	0	0	0	0	0	0	1	0	1	0	0	0	0
Subtotal	**2**	**0**	**2**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**1**	**0**	**0**	**0**	**0**

[1] The Total column will not equal the sum of the values in each row. This is because an individual will be reported more than once across Gender, Citizenship Status, Ethnicity: Hispanic, and Disability.

[2] If ERC Personnel were entered at the individual level the Total row may not equal the sum of the line items. This is because an individual may be reported in more than one personnel category but is only counted once for the

Legend
AI/AN: American Indian or Alaska Native
NH/PI: Native Hawaiian or Other Pacific Islander
B/AA: Black/African American
W: White
A: Asian, e.g., Asian Indian, Chinese, Filipino, Japanese, Korean, Vietnamese, Other Asian
More than one race reported, minority - Personnel reporting a) two or more race categories and b) one or more of the reported categories includes American Indian or Alaska Native, Black or African American, or Native Hawaiian or
More than one race reported, non-minority - Personnel reporting a) both White and Asian and b) no other categories in addition to White and Asian
US/Perm: U.S. citizens and legal permanent residents
Non-US: Non-U.S. citizens/Non-legal permanent residents

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APPENDIX IV

Proposed By-Laws

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Proposed CCEFP BY-LAWS

Initial issue date: *pending approval*
Revised date:

1.0 ORGANIZATION

The U.S. National Science Foundation has established the Center for Compact and Efficient Fluid Power (CCEFP) aimed at developing new fluid power systems with significantly improved efficiency, compactness and environmental performance. The CCEFP includes university research that targets technology barrier issues facing the industry, as well as, outreach activities to promote program growth, education and technology transfer. A consortium of seven universities, industry members and affiliations, the CCEFP administration is headquartered at the University of Minnesota although the organizational structure is designed to operate in a collaborate manner "without walls" and thus represent all university participants within the consortium.

The CCEFP will maintain a minimal staff required to effectively administer the overall Center funds. Current University of Minnesota personnel and work study students will supplement full-time CCEFP staff. Total CCEFP support staff will be approved by the Center Director. Key leadership positions within the CCEFP are as follows:

1.1 CENTER DIRECTOR: Responsible for the overall management of the CCEFP.

1.2 RESEARCH Co-DEPUTY DIRECTORS: Responsible for research related activities of the CCEFP.

1.3 RESEARCH THRUST LEADERS: Responsible for the research projects underway within each of the key research thrust areas.

1.4 EDUCATION Co-DIRECTORS: Responsible for education related activities of the CCEFP.

1.5 ADMINISTRATIVE DIRECTOR: Responsible for the administrative related activities of the CCEFP.

1.6 INDUSTRY LIAISON DIRECTOR: Responsible for the industry related activities of the CCEFP.

1.7 OUTREACH DIRECTOR: Responsible for the public outreach related activities of the CCEFP.

1.8 COMMUNICATIONS DIRECTOR: Responsible for the communications related activities of the CCEFP.

2.0 PURPOSE

The vision of the CCEFP is to transform fluid power so that it is compact, efficient and effective. This will benefit humanity by significantly reducing energy consumption and spawning whole new industries. A coordinated research, education, outreach and diversity program will facilitate this transformation.

The Major goals of the CCEFP are:

1. Increase efficiency in existing fluid power applications.
2. Expand fluid power use in transportation.
3. Create portable, un-tethered human-scale fluid power applications.
4. Ubiquity - making fluid power clean, quiet, safe and easy to use.

The CCEFP consortium is charged with conducting research on long range technology development issues as identified by its Strategic Plan and to promote the associated outcomes via outreach. The goal is to remove the technical barriers that may exist in areas such as (but not limited to):

- Efficient fluid power components
- Efficient fluid power systems;
- Efficient control and energy management
- Compact fluid power supplies
- Compact fluid power energy storage
- Compact integration of fluid power components and systems
- Safe and easy to use fluid power
- Quiet fluid power
- Leak-free fluid power systems

3.0 MEMBERSHIP

Membership and participation in the consortium will be in accordance with the following criteria:

3.1 CORE UNIVERSITIES: University members who are primarily tasked with conducting CCEFP sponsored research. These partner institutions must also provide a 20% match to NSF funding. Matching funds may be either in-kind or monetary in nature and will remain locally at the university providing the match. These funds are intended to support CCEFP related activities. In consideration of this match, Core University members obtain the same IP access rights as Company Members at the Sustaining Member level. The CCEFP core university members are:

- University of Minnesota
- University of Illinois Urbana-Champaign
- Georgia Institute of Technology
- Purdue University
- Vanderbilt University

3.2 OUTREACH UNIVERSITIES: University members who are primarily tasked with, but not limited to, supporting public outreach activities related to CCEFP sponsored research. The CCEFP envisions its outreach university members to be full research partners. Outreach universities are not required to provide any matching funds. The CCEFP outreach university members are:

- Milwaukee School of Engineering
- North Carolina A&T State University

3.3 OTHER ORGANIZATIONS: The CCEFP actively seeks out strategic partners with common interests to help realize its vision. Typically these include either organizations that represent fluid power related companies or organizations whose primary mission is to increase awareness of fluid power through educational efforts. While these types of partners do enjoy CCEFP membership benefits, such as access to center related intellectual property, their members do not. The following organizations are current CCEFP strategic partners:

- National Fluid Power Association
- Project Lead the Way
- Science Museum of Minnesota

3.4 INDUSTRY MEMBERS: Membership in the CCEFP is open to all companies worldwide. It is possible to join in one of three membership categories…Supporter, Principal or Sustaining. To become a member or to maintain membership a company must pay annual dues. The amount of dues is dependant upon the company's annual US fluid power related revenues, as well as, the membership level desired and is shown in the table below.

Proposed Membership Matrix			
Base Annual Membership at Gold or Platinum Levels includes 1 CoE			
Company Size		**Membership Level**	
10% of Global Sales or Global Hydraulic Power Sales - whichever is greater	Silver	Gold	Platinum
Less than $25 million	$1,000	$5,000	$10,000
$25 - $100 million	$6,000	$15,000	$25,000
$100 - $500 million	$12,000	$40,000	$70,000
Over $500 million	$15,000	$50,000	$90,000
Addition CoE Memberships			
Less than $25 million		$2,500	$5,000
$25 - $100 million		$7,500	$15,000
$100 - $500 million		$20,000	$40,000

Over $500 million		$25,000	$50,000

3.5 MEMBER BENEFITS: CCEFP membership brings along numerous tangible and intangible benefits including:

3.5.1 Communications: Access to quarterly newsletters, frequent electronic news blast updates, bi-weekly webcasts on Center projects, dedicated CCEFP website with detailed information and an invitation to attend the annual industry conference at a reduced membership rate.

3.5.2 Student interaction: Invitations to attend student retreats and activities, student-industry social events at conferences and student internships.

3.5.3 Industrial Advisory Board: Membership at the ‘Principal’ or ‘Sustaining’ levels will include a seat on the Industrial Advisory Board (IAB). The IAB provides strategic industry input into the Center Executive Committee.

3.5.4 Non-patented discoveries: Membership includes a perpetual, irrevocable nonexclusive, royalty-free license to use any non-patented discovery or invention.

3.5.5 Discoveries to be patented**:** University employees will promptly disclose to their University, which in turn will notify the Center, of any invention made with the support of the Center. The Center will promptly provide all its Members with confidential notice of the invention. Members may then direct that a patent application or application for other intellectual property protection be filed. Other Members will be alerted to this decision and can elect whether to share equally in the costs of the preparation and filing of the patent. Membership status at the time of disclosure establishes access. Membership level at the time of disclosure establishes royalty rates. Further details regarding access, licensing terms and special circumstances for CCEFP generated intellectual property is covered by the CCEFP Membership Agreement (http://ccefp.org/get-involved/become-a-member).

3.6 Operating terms following the initial 5 year funding period.

3.6.1 Following the Center’s initial 5 years of operation, Members join the Center and/or continue their membership on an annual, year-to-year basis and are not required to make 5 year pledges of support. Payment and acceptance of annual membership fees signifies extension of the Membership Agreement for an additional year, subject to the terms set forth in the by-laws.

3.6.2. In its discretion, and after consultation with the IAB, the Lead University may increase annual fees by up to 5% per year.

3.6.3 Membership level will be determined on the basis of global sales, not U.S. sales.

3.6.4 For ease of administration, and in its sole discretion, the lead University may establish membership years on a basis other than October 1, may establish different membership years for different Members, and may establish membership fees on a pro-rata basis for new Members or for Members that are changing to a new membership year (e.g., to a year that ends May 30 rather than September 30).

3.6.5 In their discretion, Core Universities may establish programs to grant greater benefits for Members at the Sustaining or Principal Member level. This may include establishment of "faculty champion" programs (a mutually selected faculty principal investigator who serves as a liaison to the Member) and providing greater prominence on the CCEFP web site for Sustaining and Principal Members.

3.6.6 Additional Universities may join the Center; a University may cease to be a Center Member if it no longer participates actively in Center research. All Members will be notified of any changes in University membership promptly.

3.6.7 The technology licensing office of the Inventing University, in its discretion, may subject any license of a patent owned by the Inventing University to a grant-back of rights for university research purposes. Such grant-backs are standard terms for license of university-owned patents.

3.6.8 The lead University in its discretion, after consultation with the IAB, may permit federal research and development organizations and government owned, contractor operated laboratories to become Members on terms and conditions other than those in the Membership Agreement, provided that Members' rights in Intellectual Property are not adversely affected.

4.0 MANAGEMENT BOARDS AND COMMITTEES

4.1 Executive Committee (EC)

Roles & Responsibilities

- Establishing and maintaining the CCEFP's strategic plan.
- Evaluating current research projects and determining their future place in ERC activities.
- Selection of new projects and determining where Center funds will be allocated.

Membership

- CCEFP Director
- Deputy Co-Directors
- Four industry representatives from the Industry Advisory Board (IAB)
- Three Thrust area leaders
- One representative from each core university otherwise not represented.
- One member from the Student Advisory Council

4.2 Management Committee (MC)

Roles & Responsibilities

- Day to day operation of the CCEFP

Membership

- Same as the EC without the industry and student representatives

4.3 Scientific Advisory Board (SAB)

Roles & Responsibilities

- Review CCEFP strategic plan and provide feedback for improvements
- Review individual research projects and provide feedback for improvement

- Provide input on latest research trends
- Attend annual industry meetings and NSF site visits

Membership

- ~12 to 15_experts from academia, renowned research laboratories or industry

4.4 Industry Advisory Board (IAB)

Roles & Responsibilities

- The IAB has a Chairman and Vice Chairman, elected from its membership.
- The IAB holds four seats on the ERC Executive Committee.
- The members of the IAB make recommendations to the Executive Committee, through their representatives, on the following:
    - Overall strategic planning for the ERC (updated annually)
    - Current project evaluations
    - Recommendations for new research
    - Recommendations for allocation of seed funding of additional projects (a portion of the ERC budget is designated for funding of this sort)
- Where appropriate, the IAB may choose to assign representatives from its membership to focused sub committees which will investigate areas of common interest and report back to the IAB with their recommendations.
- A task force of representatives, referred to as Project Champions, from the IAB (or their designates) will serve as industry experts for each specific research project within the ERC. Membership on the task forces will be coordinated with representatives' interests and expertise.

Membership

- Each company supporting the ERC at the principal or sustaining membership level will be eligible to hold (1) seat on the IAB.
- Each representative should be in a position to make decisions for his/her company.
- Each principal or sustaining company will decide for itself how its seat on the IAB will be handled.
- NFPA will hold one seat on the Industry Advisory Board.

4.5 Education Advisory Board (EAB)

Roles & Responsibilities

- Evaluate current ERC educational programs and make recommendations to the Executive Committee for strategic direction and programming decisions.

Membership

- Chairman assigned by the Education & Outreach Co-Directors
- Professional educators including college professors and high school teachers
- Industry representatives.

4.6 Student Leadership Council (SLC)

Roles & Responsibilities

- Act as a liaison between the CCEFP and the Center Students
- Promote collaboration between the Students at the CCEFP Institutions
- Enhance communication between the advisors and Students of the ERC
- Encourage the study of engineering, math, and natural sciences for the future benefit of fluid power.
- Prepare an annual student perspective of the CCEFP's Strengths, Weaknesses, Opportunities, Threats (SWOT) analysis and present it to National Science Foundation representatives..

Membership

- President
- Vice President
- Secretary
- Treasurer
- Webmaster
- Industry Liaison & Communications
- Student Retreat Coordinator
- Executive Committee Representative
- Other students

5.0 FUNDING

5.1 RESEARCH CONTRACTS: Funds for university research contracts are derived from the NSF grant award, industry membership dues and core university matching funds. The initial NSF award of $3,000,000 is increased by $250,000 per to a maximum of $4,000,000 in year four. This funding level is maintained until year eight. The final three years of NSF funding is reduced by 1/3rd each year whereupon it is anticipated that the Center will have identified alternate sources of funding. Overall industry members' dues will fluctuate based upon the numbers of members and their membership level identified in Table 3.4 above. A 20% match to NSF funding will be provided by all core universities listed in paragraph 3.1 above.

5.2 SPONSORED RESEARCH: The CCEFP strongly endorses and encourages industry sponsored research. The infrastructure, expertise and momentum of the base research underway will provide excellent opportunities for company sponsored research. If you are interested in learning more contact the CCEFP at the following link. http://ccefp.org/get-involved/sponsored-research

5.3 AFFLIATED RESEARCH: Center related research backed by alternate funding sources is also strongly encouraged. Combining the CCEFP's expertise and resources with your own can create an extremely compelling proposal. To learn more on how best to leverage the CCEFP for affiliated research opportunities contact the CCEFP at http://ccefp.org/contact-us

6.0 ANTI-TRUST GUIDELINES

It is the intention of the Center for Compact and Efficient Fluid Power (CCEFP) that all activities conducted by its Industrial Advisory Board (IAB), Committees and other working groups will be in conformance with all Federal Antitrust Laws.

Areas of particular concern include:

- Any effort undertaken whether expressed or implied, that could be considered to restrain trade or act as a barrier to commerce to any individual or group of individuals will be avoided.
- Meetings of members will be structured. There should be proper notification, agenda, and observance of rules of procedure and minutes of the meeting. Adherence to the business items on the agenda will avoid any appearance of conflict.
- Members must take special care to avoid making statements or engaging in conduct prohibited by CCEFP policy and by-laws. Should members have any doubt concerning the propriety of any matters under discussion at such meetings, they must immediately disassociate themselves from the discussion and, if necessary, leave the meeting.

Responsibility for compliance rests with every member of the CCEFP IAB and committees along with any invited guests(s) or participants(s). Suspected violations of this notice should be communicated to your company representative or responsible CCEFP employee.

APPENDIX V

Strategic Sustainability Plan

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Center for Compact and Efficient Fluid Power
Strategic Sustainability Plan

CENTER FOR COMPACT AND EFFICIENT FLUID POWER

Executive summary

The Center for Compact and Efficient Fluid Power (CCEFP) has developed a plan to be sustainable as the NSF ERC funding comes to an end in 2016. This document presents a plan that provides a path to success while continuing to focus on fundamental and applied research with close industry collaboration. It introduces a concept of Centers of Excellence (CoE) at partner universities that are closely aligned with the strategic research goals of the home university. Alignment with the institution's strategic goals is critical for sustainability and will provide an environment that attracts highly skilled researchers and students. These CoEs could exist alone but are stronger because of their membership in the CCEFP.

The Center for Compact and Efficient Fluid Power

The Center for Compact and Efficient Fluid Power (CCEFP) is an NSF funded Engineering Research Center. It is nearing the end of its sixth year of funding. It is critical that the center commits to a plan for sustainability. The center's lead university is the University of Minnesota. The center consists of seven universities. Besides the U of MN, the CCEFP partner institutions are Georgia Tech, U of Illinois Urbana-Champaign, Purdue University, Vanderbilt University, Milwaukee School of Engineering and North Carolina A&T.

Since the inception of the CCEFP, the Mission and Vision have remained the unchanged:

CCEFP Mission: **CHANGING THE WAY FLUID POWER IS RESEARCHED, APPLIED AND TAUGHT**

CCEFP Vision: **We are a sustainable organization that brings forward technologies enabling fluid power to be compact, efficient and effective.**

- Compact means smaller and lighter for the same function.
- Efficient means saving energy.
- Effective means clean, quiet, safe and easy-to-use.

As the CCEFP moves toward sustainability without NSF ERC funding, the Mission and Vision of the Center will remain the same. The Vision brings together three critical success factors; compactness, efficiency and effectiveness. These factors will continue to guide the research activity as they have since the CCEFP was founded in 2006. By bringing together technology research and application experts from industry, we are able to direct research so it has the maximum impact on society. We have also confirmed that a focus on education is very important not only to society but also to our industry partners.

The Vision has been validated by our industry partners who continue to focus on compactness, efficiency and effectiveness to make their product more valuable to their markets. In light of the current demand on our energy resources, this vision is proper.

Situation analysis:

Current CCEFP funding comes primarily from three sources; NSF ERC funding and supplemental grants ($4.2 million), university matching funds ($800K) and industry membership dues ($750K). The center's Principal Investigators (PIs) have also received funding from associated projects that currently total $2.4 million. NSF ERC funding will decline beginning after year 8 and phase out after year 10. NSF ERC funding will decline beginning after year 8 and phase out after year 10 as shown in Figure 1.

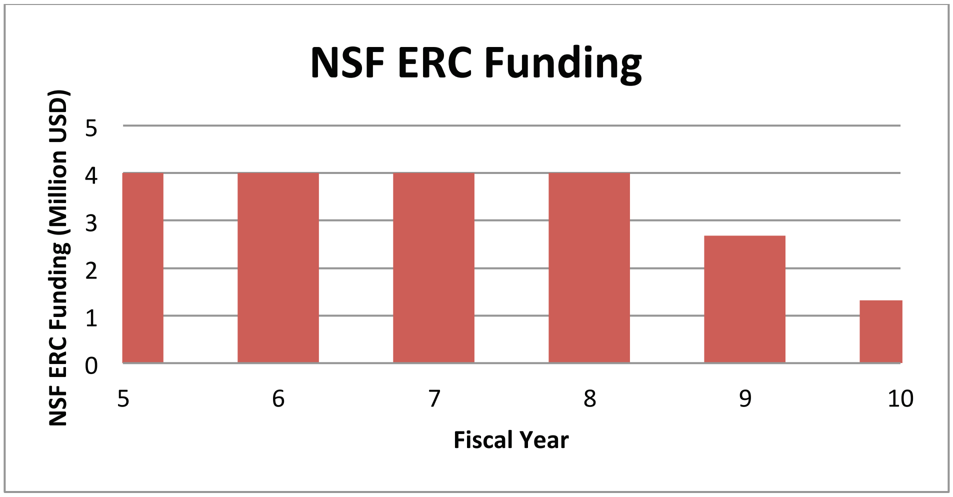


Figure 1 – NSF ERC Funding

The plan for a future CCEFP must support the goals of the partner universities and colleges to be sustainable. It also needs to provide an environment that encourages the Principal Investigators (PIs) to engage. These key attributes are missing in the current organization and therefore the PIs engage at will. Close alignment with the institutions goals will help provide an environment that will encourage PI engagement.

Once the NSF ERC funding is reduced and ultimately eliminated at the end of May 2016, the CCEFP needs to be financially sustainable. To achieve this, the CCEFP needs to develop a model that allows each university to focus on their strategic plans which will encourage long term support. Doing so will maximize cooperation, maintain visibility locally and have positive impact on sustaining the CCEFP. The local awareness will provide individual visibility for the researchers. It is believed that this individual visibility will promote engagement in the CCEFP.

The CCEFP was founded on the NSF principles of blending fundamental and applied research. These principles have helped to engage significant industry involvement. Maintaining industry involvement is a strategic goal for the CCEFP as it plans for sustainability.

An analysis of the CCEFP’s Strengths, Weaknesses, Opportunities and Threats (SWOT) is a starting point to understand the center’s current state and plan for a stronger future state. The SWOT analysis reveals an environment that leverages a broad set of skills and provides access to high quality future employees for industry. It also exposes some weaknesses that a future organization may help to address.

Future CCEFP

The CCEFP, under the guidance of the NSF, has built an infrastructure to develop close relationships between the researchers and industry. It is believed that this needs to be a key feature that should be preserved in a future state. Currently there are approximately fifty (50) industry members that contribute at levels between $1000 and $50,000 annual membership dues.

The NSF ERC funding is a key element that has funded the pre-competitive research which is very beneficial to the industry members. Through years of collaboration between universities and industry, close relationships have developed. It is essential that these relationships are preserved to support long term sustainability.

The future CCEFP needs to be supported by each partner university to increase the likelihood of being sustainable. A way to accomplish this is to align the work at each university with the strategy of that university. With this in mind, the future CCEFP will be composed of a network of Centers of Excellence (CoE) that may be capable of existing alone but are stronger because of their association with the CCEFP. Each CoE will support their institution's strategic research focus and will benefit from being associated with an organization that is broad reaching into industry and public sectors. This organization is the CCEFP.

Each Center of Excellence will be proposed by champions at the partner institutions. The final network of CoEs will be defined by the current Executive Committee of the CCEFP. Work is underway to define the focus of the CoEs. It is important that the CCEFP's focus on Compactness, Efficiency and Effectiveness is maintained. The mission and vision of each CoE will support both the goals of the CCEFP and their university's strategic plan. An example of the possible organization is shown in Figure 2.

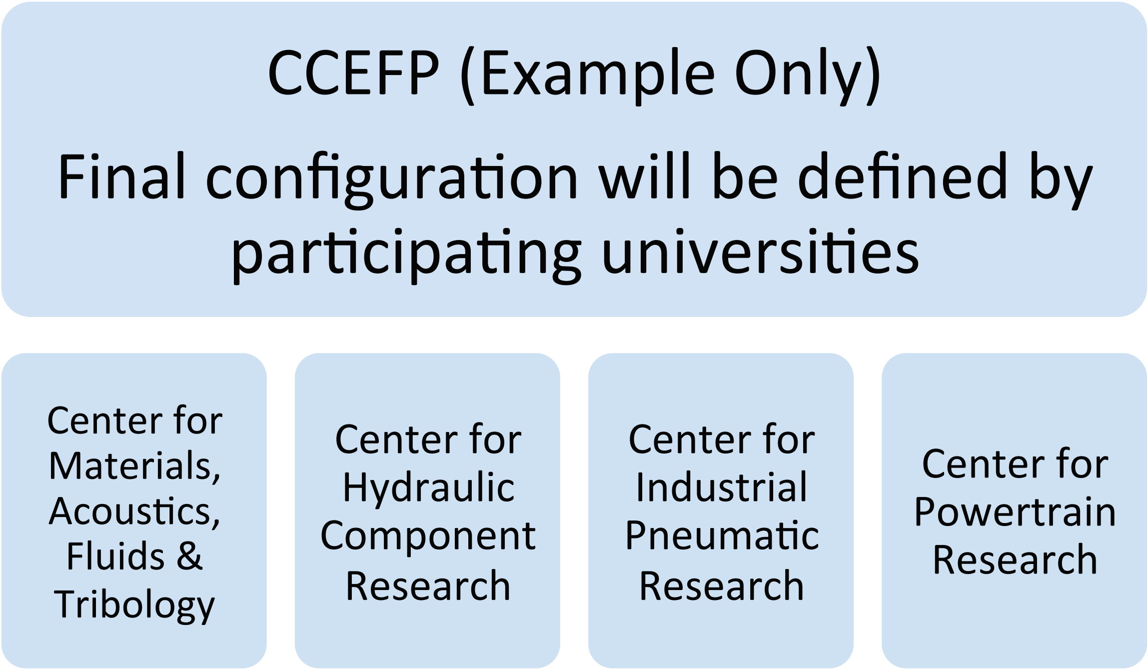


Figure 2 – Possible CCEFP Organization

This organization allows each university to support the strategies of their institution while gaining benefits from the CCEFP organization. It is expected that industry members will focus on specific CoEs. This focus will provide more value to both industry and the CoE home university.

The organization provides an environment to maintain the current industry partnerships and expand these to include broader involvement. It will also allow industry members to be more focused in their primary area of interest. The CCEFP will continue to facilitate communications between the universities and industry.

It is imperative is to preserve and extend collaboration. This collaboration should be across institutions as well as between researchers. It will be natural for collaboration to occur between researchers in a CoE. However, collaboration between universities has to potential of producing even more significant results. The CoEs are encouraged to recruit researchers from other universities. The CCEFP will be managed to foster collaborations between institutions and to draw on skills outside the current member universities.

Appendix 4 includes a partial inventory of the specialties and skills currently associated with the CCEFP. It is expected that these sets of expertise will be represented in the final set of Centers of Excellence that will make up the future CCEFP. It may also be appropriate to recruit other skills into the organization to enable future research.

The CCEFP will continue to recruit industry members. Industry members will be able to focus their interest and energy on one or more CoEs. With a clearer focus, industry will continue to influence research and likely partner even closer with the researchers.

It is envisioned that with more support from the universities, the CCEFP and CoEs will be able to recruit high quality students. Because industry will be able to focus energy on particular CoEs, there will be greater opportunity for interaction between industry members, PIs and students.

Organization and Management

The CCEFP organization will be patterned after the NSF ERC structure but will be modified to address lessons that have been learned. The proposed organizational structure appears in figure 3.

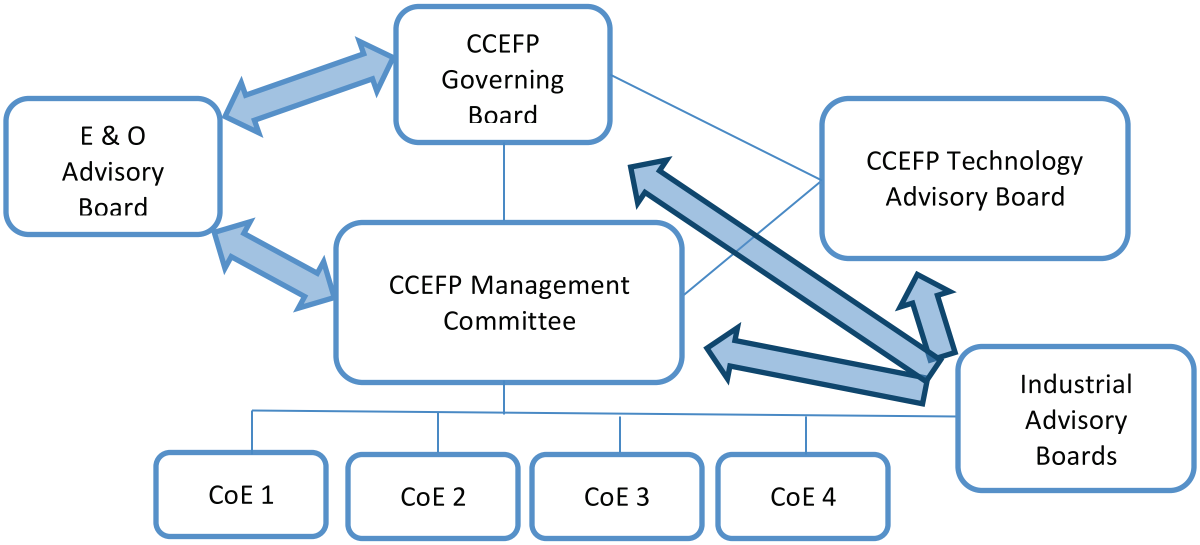


Figure 3 – CCEFP Organization

The Governing Board, Management Committee, Technology Advisory Board, Industrial Advisory Board and E&O Advisory Board each have critical roles in managing the CCEFP.

CCEFP Governing Board:

The charter of the Governing Board is to assure that the CCEFP is operating in a fashion that best protects the interests of the stakeholders. It will assure that there is proper leadership in place and resolve conflicts on within the Management Committee. It will take input and provide direction with regard to the goals and functions within the CCEFP. It will approve the strategic plan and assure that an effective organizational model is in place. The Governing Board will include balanced representation from industry, government agencies, universities and other stakeholder groups as required.

Management Committee

The day to day operations the CCEFP will be the responsibility of the Management Committee. The Management Committee will be chaired by the Center Director who will be appointed by the Dean of the University of MN's College of Science and Engineering. A representative from each of the Centers of Excellence will have a seat on the Management Committee of the CCEFP.

The Management Committee will assure that the CCEFP is properly managed and coordinated. It will have the authority to manage the CCEFP budget. It will assure that budgets are properly allocated, and that the research is progressing acceptably. The Management Committee will assure that each Center of Excellence is treated fairly. The Management Committee will have both policy and financial authority.

Another key responsibility of the Management Committee is to provide an environment that encourages the engagement of PI's. Researchers will be recruited and will agree to participate in the center based on the guidelines set by the Management Committee. This means that the Management Committee is responsible to develop an environment that attracts top researchers to the CCEFP.

Technology Advisory Board

The Technology Advisory Board is made up of high level technologists, such as Chief Technology Officers, from all stake holder groups. These representatives should have knowledge of the strategic technology plan (technology roadmap) within their organizations. The role of the Technology Advisory Board is to provide advice for setting direction of research initiatives and promote the long term value of research within their various representative groups. It is necessary to include industry representation on this board to assure that the CCEFP is focused on research that has high value in the market and to share the value of the CCEFP research activities more effectively within industry.

Industrial Advisory Boards

Each CoE will have an associated Industrial Advisory Board. This board will meet at least twice a year at the home university of the CoE. The purpose of these meetings will be to review progress on the CoEs research and develop further relationships with the researchers. This will also be a time to conduct meetings to address the advisory board business.

Education and Outreach Advisory Board

The E& O activities are very important to the industry members. At the time of this writing, the model being considered appears in Appendix 5.

Operating Model and Services Provided

The value of the CCEFP administrative function is to deliver services that were developed under NSF funding across the group of Centers of Excellence. This sort of infrastructure and support would not be feasible in a single CoE.

The CCEFP will provide the following services:

- Recruit investment to fund the center and researchers. This may be in several forms:
    - Develop strategic relationships with Industry
    - Recruit industry members
    - Development of relationships with government agencies
- Coordinate industry member involvement.
- Provide support for the preparation of proposals to gain funding.
- Manage the mix of pre-competitive and sponsored research.
- Work with outside partners to develop relationships with researchers.
- Identify opportunities for research collaboration between CoEs.
- Help attract high quality students.
- Help to develop licensing opportunities for CCEFP inventions as well as market CCEFP developed IP to industry members.
- Publicize the CCEFP and its members.
- Manage industry communications.
- Manage education opportunities across the center.
- Coordinate internships to place our students in industry.
- As CoEs need capital, the CCEFP will work with the development offices to create plans for raising necessary funds.
- Provide financial administration.

Industry Membership Structure

Industry membership dues in the CCEFP will be based on participation with the CoEs. The base membership in the CCEFP at the Gold or Platinum levels will include the right to participate in the IAB associated with one CoE. Participation with additional CoEs will be based on a tiered membership structure. A proposed membership structure appears in figure 4:

	Proposed Membership Matrix			
	Base Annual Membership at Gold or Platinum Levels includes 1 CoE			
	Company Size		**Membership Level**	
	10% of Global Sales or Global Hydraulic Power Sales - whichever is greater	Silver	Gold	Platinum
Size 1 - S1	Less than $25 million	$1,000	$5,000	$10,000
Size 2 - S2	$25 - $100 million	$6,000	$15,000	$25,000
Size 3 - S3	$100 - $500 million	$12,000	$40,000	$70,000
Size 4 - S4	Over $500 million	$15,000	$50,000	$90,000
	Addition CoE Memberships			
Size 1 - S1	Less than $25 million		$2,500	$5,000
Size 2 - S2	$25 - $100 million		$7,500	$15,000
Size 3 - S3	$100 - $500 million		$20,000	$40,000
Size 4 - S4	Over $500 million		$25,000	$50,000

Note: Fees will be adjusted annually.

Figure 4 Industry Dues Structure

CoE Membership in the CCEFP

A CoE selected to join the CCEFP will agree to the CCEFP CoE Membership by-laws. These by-laws will be patterned after the existing CCEFP by-laws. However lessons learned and modification based on the new structure will be included. A copy of the by-laws are included

Each member university will contribute to support the administrative cost of the CCEFP and pay for services supplied. This will be in the form of directing the Industry Membership dues and other funding as required to pay these costs. The Management Committee will agree on the final organization and cost structure of the CCEFP.

Financial Structure

By the end of FY 8 (May 31, 2014) the CCEFP must have adequate funding for precompetitive research to sustain its Industry Membership Base. It is expected that approximately 20 precompetitive research projects are required to sustain the current interest. Each project typically requires a $100K - $200K budget

CCEFP Annual Operating Budget (2011):

Management and Administrative: $1,222,575
E&O: $731,929
Research: $3,208,787
Total: $5,163,286

Transition

It is likely that this cost structure will be carried forward through 2013. There is an effort ongoing to provide these services to a broader organization at the University of MN. As this consolidation occurs, it is expected that the costs for administrative functions be reduced. The financial accounting for this will need to be determined.

Funding Beginning 2014

The current industry membership dues provide an income of approximately $750,000. The model below predicts that this level of funding will be maintained or increased.

Fundamental Research Funding: It is likely that 4 centers will emerge from the existing structure. It is reasonable that each center will be able to attract $1,500,000 in research funding annually. It is envisioned that approximately 50% of this would be Pre-competitive and 50% would be sponsored research. We should target about 40% -60% of total center research funding to be pre-competitive research to attract Industry Members. If we can achieve this, we will have the following mix:

Funding Model

It is envisioned that research funding will be from multiple sources:

- Federal Grants: The expectation is that each center will secure $600,000 of pre-competitive research funding.
- Industry sponsored research: The CCEFP will recruit industry members and facilitate (broker) sponsored research opportunities. This is expected to provide approximately $750,000 of funding annually.
- Industry membership. The CCEFP Membership is currently approximately $750K / year. The goal is grow this to approximately $1 million.
    - It is possible that the number of industry members may decrease but that the financial contribution will stay similar or increase relative to the current income.

Financial Model

See appendix 6 for details

Income	
Membership Dues	$1,135,000
Government Funded Research	$2,400,000
Matching funds (10% of Gov't Funding)	$240,000
Industry Funded Projects	$1,600,000
Total Income	$5,375,000
Operating Expenses	$944,556
Research Funding	$4,430,444

The Next Steps

1. Engage Industry to get feedback and refine this plan,
2. Develop proposals for CoEs. Once the needs of the CoEs are understood, it is the responsibility of the CCEFP Governing Board and Management Committee to define and allocate funding for the final organization of the CCEFP.
3. Validate that adequate pre-competitive funding can be generated.
4. Develop operating covenants that define responsibilities of members.
5. Confirm financial model for the CCEFP

Why will the CCEFP Succeed?

As the CCEFP transitions to this new structure, each member company will have an opportunity to be more involved in their specific areas of interest. The industry advisory boards at each CoE will have more influence on the research occurring. Active engagement by industry members will provide opportunities to develop even stronger relationships with researchers in the fields that will have the greatest impact on the industry member.

A more focused research strategy with active industry involvement will attract the best students. The CoE structure will provide industry members better access to these students and therefore it will also provide a channel to recruit new employees that have known skills which meet the organization's needs.

Close alignment with the strategic research goals at the member universities will provide motivation for the researchers to engage. Their engagement will be rewarded with recognition from their administration which will be high value to the researchers. This engagement will build a stronger CCEFP.

Because we have a minimum of two years to refine this plan, all stakeholders will have the opportunity to engage in the planning process. The CCEFP will actively engage stakeholders to create a CCEFP that provides high value to them.

Over the next two years, while the CCEFP will continue to be funded primarily by the NSF, there is time to develop the CoEs and recruit members to support them. As NSF funding decreases, additional funding will be required. Industry and government agency relations that are being developed will provide a platform to continue to fund precompetitive research. The opportunity to more closely partner with researchers will provide opportunities for industry to gain government funding that might not be available to them without these university partnerships. Also, these relationships will reveal opportunities for industry to fund targeted research that builds on the research occurring within the CCEFP. In the near term, it is not necessary to significantly increase membership dues in the CCEFP. This will encourage existing industry members to engage in the development of this plan.

Appendix 1 CCEFP SWOT

CCEFP SWOT:

Strengths:

- Broad Industry Participation at high levels in the organizations.
- Industry has the ability to influence the direction of the research.
- Broad expertise amongst PI's
- Many vehicles to facilitate communication exist to enhance industry involvement.
- Center produces high quality graduates that are recruited by industry.
- Provides a forum for Researchers to interact with industry.
- Systems approach assures that relevant research is being done.
- The center provides a platform for interdisciplinary research and enables networking and collaboration across a broad group of Principal Investigators (PI's).

Weaknesses:

- PIs across the multiple Universities have different priorities.
- Since the PIs are generally self-sufficient, if the Center does not bring significant value to the PIs they can (and do) disengage.
- Industry and Funding Sources may have different technical needs than the Center can provide.
- Possibly missing the right mix of industry members.
- Broad industry participation makes common interests hard to identify.

Opportunities:

- High energy costs
- Energy conservation is becoming more important to society
- Leverage the University of MN's and other University's broader focus on Energy
- Create an organization that engages the PI's

Threats

- NSF Funding Loss
- Federal Research budgets being cut
- University funding by the State
- Short term focus by industry
- Lack of member university cooperation
- Lack of progress toward new product technologies
- The economy

Influence on SWOT – Future State

Strengths:

- We will maintain and broaden our exposure to industry and industries exposure to CCEFP.
- Industry members will be able to influence the research being done
- PI expertise will be focused on areas of their interest and in strategic support of their organization's goals.
- We will maintain a very proactive communication strategy with industry
- Center will continue to produce high quality graduates that are recruited by industry.
- This organization will broaden the PI's ability to interact with industry
- Systems approach assures that relevant research is being done.
- The CCEFP Center of Excellence model provides more opportunity for interdisciplinary research and enables networking and collaboration across a broad group of Principal Investigators (PI's).

Weaknesses:

- The CCEFP composed of multiple Centers of Excellence allows each university to focus on its strengths and strategic goals.
- With management support of the broader organization at the Member University, there will be motivation for PI's to engage.
- The CoE concept will allow industry members to focus their energy on areas of specific interest. This will provide more value to industry while helping to focus research activities.

Opportunities:

- Energy costs are on the rise... This makes energy related research more attractive
- This provides a broad focus on Energy which continues to be increasingly important to society
- Leverage each universities Strategic Research Focus

Threats

- This organization allows for consolidation of expenses and allow for more to be done with less cost.
  With Federal and State Research budgets being cut, a broad set of expertise and association with prominent universities and close Industry alliances may improve the likelihood of funding.

Appendix 2 - Current CCEFP Industry Members

Company name	**Website**
Afton Chemical Corp.	www.aftonchemical.com
Air Logic	www.air-logic.com
Bobcat	www.bobcat.com
Bosch Rexroth Corp	www.boschrexroth-us.com
Case New Holland, CNH America, LLC	www.cnh.com
Caterpillar Inc.	www.cat.com
Concentric AB	www.concentricab.com
Deere & Company	www.johndeere.com
Delta Computer Systems	www.deltamotion.com
Deltrol Fluid Products	www.deltrolfluid.com
Donaldson Company Inc.	www.donaldson.com
Eaton Corporation - Hydraulics Operations	www.eaton.com
Enfield Technologies	www.enfieldtech.com
Evonik RohMax USA, Inc.	www.evonik.com
ExxonMobil	www.exxonmobil.com/corporate
Freudenberg-NOK	www.freudenberg-nok.com
G.W. Lisk Co., Inc.	www.gwlisk.com
Gates Corporation	www.gates.com
HECO Gear, Inc.	www.hecogear.com
Hedland Flow Meters (Racine Federated)	www.hedland.com
High Country Tek, Inc	www.highcountrytek.com
Hoowaki, LLC	www.hoowaki.com
HUSCO International, Inc.	www.huscointl.com
HYDAC Corporation	www.hydacusa.com
Hydraquip Corporation	www.hydraquip.com
Hydraulic Innovations LLC	
Kepner Products Co	www.kepner.com

Linde Hydraulics Corp.	www.lindeamerica.com
Master Pneumatic-Detroit, Inc	www.masterpneumatic.com
MICO, Incorporated	www.mico.com
Moog Inc.	www.moog.com
MTS Systems Corporation	www.mts.com
National Fluid Power Association	www.nfpa.com
National Tube Supply Company	www.nationaltubesupply.com
Netshape Technologies, Inc.	www.netshapetech.com
Nexen Group, Inc.	www.nexengroup.com
Parker Hannifin Corp.	www.parker.com
PHD, Inc	www.phdinc.com
PIAB Vacuum Products	www.piab.com
Poclain Hydraulics	www.poclain-hydraulics.com
Quality Control Corporation	www.qualitycontrolcorp.com
ROSS Controls	www.rosscontrols.com
Sauer-Danfoss	www.sauer-danfoss.com
Shell Global Solutions	www.shell.com
Simerics	www.simerics.com
Sun Hydraulics Corp	www.sunhydraulics.com
Takako Industries	www.takako-inc.com
Tennant	www.tennantco.com
The Lubrizol Corporation	www.lubrizol.com
The Toro Company	www.toro.com
Trelleborg Sealing Solutions U.S. Inc.	www.trelleborg.com
Veljan Hydrair Private Limited	www.veljan.com
Woodward	www.woodward.com

Appendix 3 – CoE Planning

Center for Compact and Efficient Fluid Power
CoE Planning Template

CENTER FOR COMPACT AND EFFICIENT
FLUID POWER

Introduction

The purpose of this document is to provide guidelines for proposals for Centers of Excellence (CoE) to be part of the Center for Compact and Efficient Fluid Power (CCEFP). The CCEFP is expected to be funded under the NSF ERC after successful completion of the site review in May 2012. If funded, the CCEFP will receive $4,000,000 per year for the academic years beginning in 2012 & 2013 and will operate similar to the way it has for the last several years. In June of 2014 funding will be reduced by on third for 2014 and again by another third in 2015 with final funds expiring in May 2016. During the last two years the CCEFP will put a priority on funding the Centers of Excellence that that have been selected to be part of the CCEFP.

Description of CoE - *This is to introduce to the reader to the CoE and understand what it will attempt to achieve.*

What is the name of the CoE?

What is the focus of the CoE and how does this support the CCEFP Mission?

Goals of this CoE – *This discussion is to define the proposed Center of Excellence. It is envisions to be 1-2 pages. Some of the content that might be included in this section include:*

- What are the high level goals for the CoE?
    - Mission
    - Vision
    - What are the research activities that the CoE will pursue?
- How will you judge whether the CoE is successful?
- How are the CoEs goals aligned with the Strategic Goals of your organization?
    - Department
    - College
    - University
- Is this an opportunity to create needed change in your institutions' goals?

University Commitment – *This is a discussion about how engaged and committed your institution is with regard to supporting you CoE. It is envisioned that this section is about one page. Some things to consider may include:*

- How has your institution signaled that they will support the CoE?
    - Some Possible Signals
        - Committed lab space
        - Commitments to reduce teaching load to allow more research.
        - Agreement to provide capital equipment
        - Allocated research funding for student support
        - Provide administrative support
        - Technical support staff

        - Marketing of your center
        - Indirect recovery
        - Reduced indirect for Industry funding or Matching funds
        - E&O commitment
- Do you have a sponsor in your University's Administration that is an advocate for the CoE?
- How well is the plan for the CoE aligned with the Strategic Plans of you home University? … This is seen as an indicator of sustainability.

Organization - This is a high level discussion about how the CoE will be managed. It also includes a discussion about resources needed to make the CoE a success.

- Describe how the CoE will be guided /managed? Consider leadership, skills, strengths and opportunities for the proposed CoE.
- Who are the researchers committed to this CoE? Do you need additional resources?
- What value and or services to you expect form to CCEFP as a Member of the organization? Some possible service are identified below:
    - Recruit investment to fund the center and researchers. This may be in several forms:
        - Develop strategic relationships with Industry
        - Recruit industry members
        - Development of relationships with government agencies
    - Coordinate industry member involvement.
    - Provide support for the preparation of proposals to gain funding.
    - Manage the mix of pre-competitive and sponsored research.
    - Work with outside partners to develop relationships with researchers.
    - Identify opportunities for research collaboration between CoEs.
    - Help attract high quality students.
    - Help to develop licensing opportunities for CCEFP inventions as well as market CCEFP developed IP to industry members.
    - Publicize the CCEFP and its members.
    - Manage industry communications.
    - Manage education opportunities across the center.
    - Coordinate internships to place our students in industry.
    - As CoEs need capital, the CCEFP will work with the development offices to create plans for raising necessary funds.
    - Provide financial administration

Financial Model

- Can you achieve the financial targets of $750K pre-competitive Research and $750K of Industry Sponsored research? What support will you need to achieve this?
- Do you need to recruit new resources to achieve the goals set for the CoE?
- How many students will be supported by the CoE?

Summary

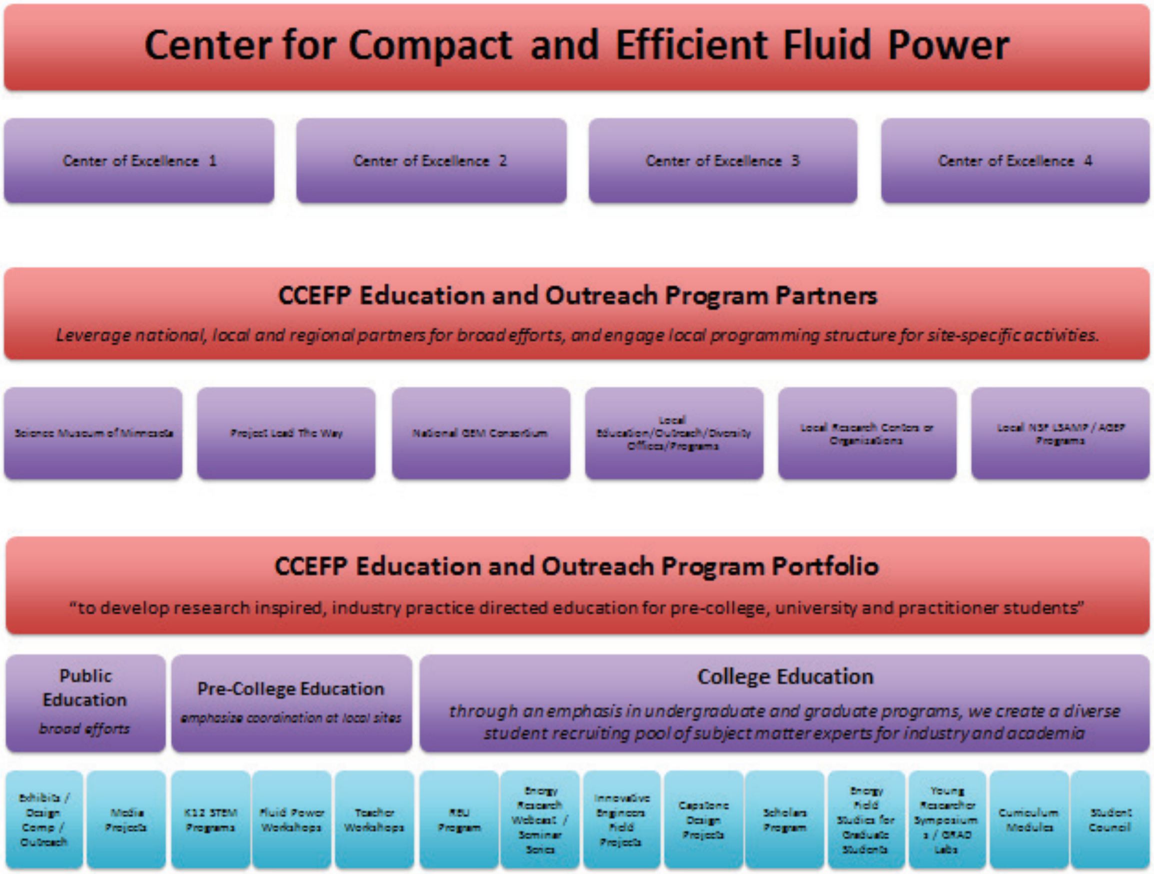
This is meant to be a section that draws together the previous thoughts and really sell the concept.

Appendix 4 PI Skills inventory

CCEFP PI Expertise Based on Current Researchers

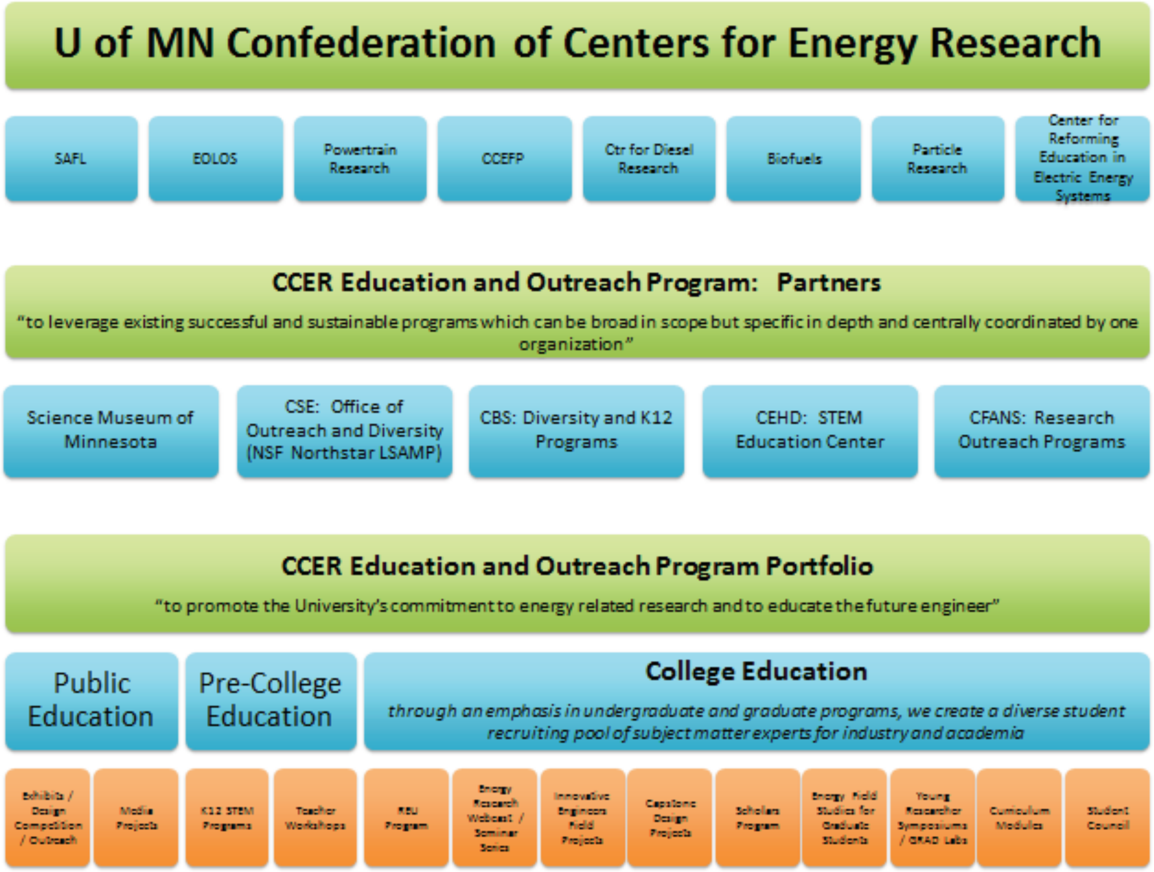
University	Specialty
GT	Acoustics and Seal modeling
GT	Fluid and Structure borne vibration and acoustics, Acoustic management
GT	Systems Engineering, Modeling & Simulation
GT	Robotics, Motion control, Robust control, Tactile sensing, Human-machine interface, Biomechanics, Human modeling, Biologically-inspired actuator design, rehabilitation robots
MN	Advanced Manufacturing, Controls
MN	Heat Transfer
MN	Machine Design, Computer Aided Design, Mechanisms, CAD Database Design
MN	Dynamic systems and control, automotive propulsion applications
Purdue	Automatic controls, robotics, systems modeling and simulation, and electrohydraulic
Purdue	Hydraulic Pumps & Motors
UIUC	Nano-manufacturing, micro & nano Structures
UIUC	Musculoskeletal biomechanics, dynamics, bio controls, biostatistics
UIUC	Vehicle Dynamics, Controls, System modeling and Control
UIUC	System / Hydraulic System modeling, Hydraulic Fluid Modeling
Vanderbilt	Medical Devices, Robotics, Haptic feedback

Appendix 5- E&O Model




CCER Education and Outreach Program
Sources of Funding
National Science Foundation
Department of Education
State of Minnesota Department of Education
Industry Foundations
Private Foundations
Industry Sponsorship (Xcel, 3M, Target Corp)
Endowments
Other


CCEFP Education and Outreach Program
Sources of Funding
National Science Foundation
Department of Education
State of Minnesota Department of Education
Industry Foundations
Private Foundations
Industry Sponsorship (Xcel, 3M, Target Corp)
Endowments
Other
Regional Sponsors
Existing Site Specific Funding



U of MN Confederation of Centers for Energy Research

- SAFL
- EOLOS
- Powertrain Research
- CCEFP
- Ctr for Diesel Research
- Biofuels
- Particle Research
- Center for Reforming Education in Electric Energy Systems

CCER Education and Outreach Program: Partners

"to leverage existing successful and sustainable programs which can be broad in scope but specific in depth and centrally coordinated by one organization"

- Science Museum of Minnesota
- CSE: Office of Outreach and Diversity (NSF Northstar LSAMP)
- CBS: Diversity and K12 Programs
- CEHD: STEM Education Center
- CFANS: Research Outreach Programs

CCER Education and Outreach Program Portfolio

"to promote the University's commitment to energy related research and to educate the future engineer"

Public Education
- Exhibits / Design Competition / Outreach
- Media Projects

Pre-College Education
- K12 STEM Programs
- Teacher Workshops

College Education

through an emphasis in undergraduate and graduate programs, we create a diverse student recruiting pool of subject matter experts for industry and academia

- REU Program
- Energy Research Webcast / Seminar Series
- Innovative Engineers Field Projects
- Capstone Design Projects
- Scholars Program
- Energy Field Studies for Graduate Students
- Young Researcher Symposiums / GRAD Labs
- Curriculum Modules
- Student Council

Appendix 6 Financial models

Y7 Budget	Desirable		Feasible - Used for scenario testing - Fully burdened		With 10% Foundation OH instead of 52% U F&A
I. Travel & Hotel; Professional Development & conferences	**Amount**	**Comments**	**Amount**		**Amount**
ILO	$15,000	10 U.S. ($750 + $250/day expenses); $250 daily is reasonable for meals, car, hotel, parking, etc. 3 day average trip	$10,500	30% Reduction	$15,000
AD	$4,500	3- 3 day trips each at (750 + $250/day);	$3,150	30% Reduction	$4,500
Communication	$1,500	1 - 3 day trip	$1,050	30% Reduction	$1,500
Director	$32,000	1 Japan ($6000), 1 Europe ($3500 ea.), 8 U.S. ($750 + $250/day); Calculated as: =6000+3500+ 8*750+(7+7+8*3)*250:	$22,400	30% Reduction	$32,000
Sustainability Dir	$12,000	8 domestic trips ($750 + $250/day);3 day trips	$8,400	30% Reduction	$12,000
E&O Travel	$12,000	8 domestic trips ($750 + $250/day); 3 day trips	$0	Alternate Funding	$12,000
SAB	$0		$0		$0
Subtotal =	$77,000		$45,500		$77,000
II. Industry					
Non-sponsored activities (alcohol, gifts)	$2,000	estimate	$2,000		$2,000
Misc travel by people like Sunny, Perry, Will, etc.	$12,000	This is calculated as =8*750+8*3*250	$12,000		$12,000
Dinners and lunches (hospitality)	$3,500	estimate	$3,500		$3,500
Sustainability Activities (recruitment/retention)	$5,000	estimate	$5,000		$5,000
External Relations/Public Relations					
Patent filing fees	$0	In FY 5, UMN paid $12,116 in filing fee from	$0		$0
	$22,500		$22,500		$22,500
III. Communication					
AAI Website Hosting Fees	$0	Required for continued operation of website	$0		$0
Survey Monkey Annual Fee	$0	Required for continued survey capabilities	$0		$0
Annual Report printing & overnite shipping--SITE VISIT	$0	Based on actual previous year expenditures (Does NOT include cost of copies for Industry)	$0		$0
Annual Report printing & mailing--INDUSTRY	$0	Based on actual previous year expenditures (Includes postage for mailing all copies)	$0		$0
Genesys Teleconferences	$2,500	Based on actual previous year expenditures (Includes all teleconferences billed for IAB,	$2,500		$2,500
PRINTING: Business cards, letterhead, envelopes	$0	Based on actual previous year expenditures	$0		$0
Website upgrades	$5,000		$0		$5,000
Data Collection System (Drupal/database)	$0		$0		$0
COPY WRITING: High Point Creative	$0		$0		$0
Subtotal =	$7,500		$2,500		$7,500
IV. Salaries including Fringe and Indirect					
Director	$44,444	2 months buy out	$22,222	50% funded	$44,444
ILO	$120,000		$60,000	50% funded	$120,000
SusDir	$90,000		$45,000	50% funded	$90,000
AD	$70,000		$35,000	50% Funded	$70,000
ExternComm	$50,000	$50K Base	$25,000	Eliminate or reduce to PT	$50,000
Comm Coordinator	$50,000		$25,000	50% funded	$50,000
E&O Director	$65,000		$32,500	50%funded	$65,000
Admin Assistant	$40,000		$0		$40,000
SAB Chair	$5,000		$5,000		$5,000
Gary, Accounting, Payroll	$10,000	*ME Services Salaries*	$10,000		$10,000
Fringe	$196,000	Fringe 36%	$93,500		$196,000
Indirect	$385,031	F&A 52%	$166,775		$74,044
Total:	$1,125,476		$519,997		$814,489
V. Supplies					
Gopher Teleconference & NTS charges (NOT Genesys)	$5,000		$5,000		$5,000
Postage	$1,000		$1,000		$1,000
Food, beverages and supplies for socials	$500		$500		$500
Computer hardware and or software	$2,500		$2,500		$2,500
General Office supplies	$5,000		$5,000		$5,000
Subtotal =	$14,000		$14,000		$14,000
V. CCEFP meetings					
Meetings budget	$50,000		$25,000		$50,000
Food	$0		$0		$0
SAB Travel	$18,000	3 from overseas, ($3500 ea.) and 5 from U.S.	$9,000	Cut in Half	$18,000
Meetings Subtotal =	*$68,000*		*$34,000*		*$68,000*
Overhead/Indirect	$98,280	non salary 52%	$61,620		$18,900
Sub Total					
Overall Budget =	**$1,412,756**		**$700,117**		**$1,022,389**
Target Budget =	**$1,000,000**		**$1,000,000**		**$1,000,000**
Difference =	**$412,756**		**-$299,883**		**$22,389**

		Quantity	Assumptions	Unit Value
	Best Case			
	# Platinum Members	5	2 Size 4 & 3 size 3	$390,000
	Additional CoE memberships	10	$46,000	$460,000
	# Gold Members	25	10 - S3, 10 - S2, 5 - S1	$575,000
	Additional CoE memberships	50	11500	$575,000
	# of Silver Member	35	Assume an aveage Size 2	$210,000
	Membership Income			$2,210,000
	Worst Case			
	# Platinum Members	0		
	Additional CoE memberships			
	# Gold Members	10	Assum 5 -S 3 & 5- S4	$450,000
	Additional CoE memberships	0		
	# of Silver Member	20	Half S1 & Half S2	$70,000
	Membership Income			$520,000
	Most Likely			
	# Platinum Members	2	Assume 1-S3 & 1 - S4	$160,000
	Additional CoE memberships	2	1 each	$45,000
	# Gold Members	20	5 of each Size	$550,000
	Additional CoE memberships	10	5 - S3 & 5 S4	$225,000
	# of Silver Member	30	Assume Average Size 2	$180,000
	Membership Income			$1,160,000
Reference				
	Proposed Membership Matrix			
	Base Annual Membership at Gold or Platinum Levels includes 1 CoE			
	Company Size		**Membership Level**	
	10% of Global Sales or Global Hydraulic Power Sales - whichever is greater	Silver	Gold	Platinum
Size 1 - S1	Less than $25 million	$1,000	$5,000	$10,000
Size 2 - S2	$25 - $100 million	$6,000	$15,000	$25,000
Size 3 - S3	$100 - $500 million	$12,000	$40,000	$70,000
Size 4 - S4	Over $500 million	$15,000	$50,000	$90,000
	Addition CoE Memberships			
Size 1 - S1	Less than $25 million		$2,500	$5,000
Size 2 - S2	$25 - $100 million		$7,500	$15,000
Size 3 - S3	$100 - $500 million		$20,000	$40,000
Size 4 - S4	Over $500 million		$25,000	$50,000

Membership Dues	$1,160,000	
4 CoE's each wins 4 - $150K Grants	$2,400,000	
15% University Match	$360,000	
Industry Sponsored Research - Each COE has 4 - $100K projects	$1,600,000	
Additional income (State,Local, Foundations, other)	$1,000,000	Used to evaluate
Total Income	$6,520,000	
Pre-competitive research : Membership ratio	3.24	

Summary

Total Income	$5,375,000	
Operating Expenses	$944,556	
$ Available for research	$4,430,444	Fully Burde
Pre-competitive research : Membership ratio	2.28	
Total / 1.52 = Cost Unburdened	$2,914,766	
indirect at 52%	$1,515,678	

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