CENTER FOR COMPACT & EFFICIENT FLUID POWER

An Engineering Research Center

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Georgia Institute of Technology
Milwaukee School of Engineering (MSOE)
North Carolina Agricultural and Technical State University (NCAT)
Purdue University
University of Illinois at Urbana-Champaign (UIUC)
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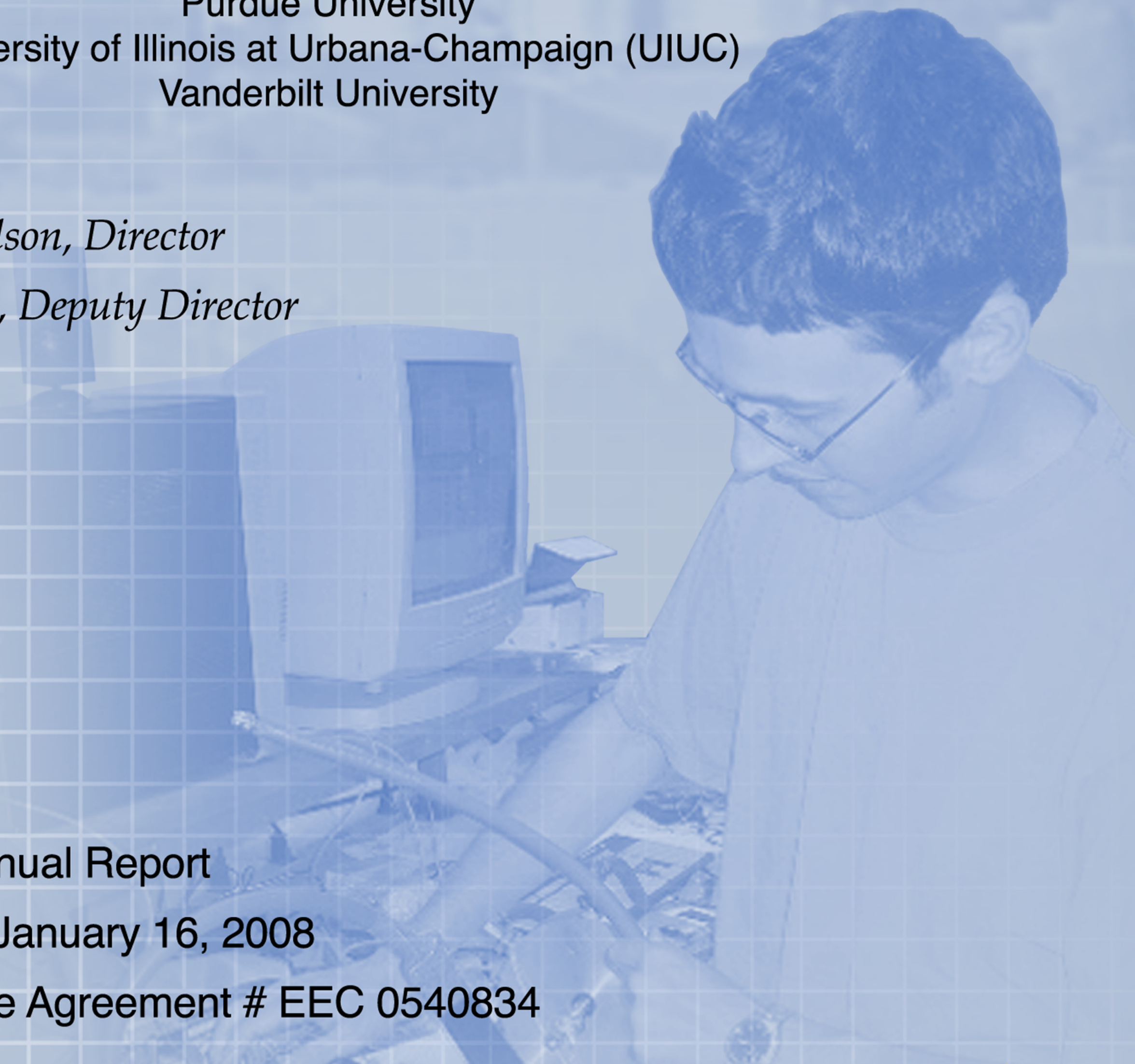

Second Annual Report

Due Date: January 16, 2008

Cooperative Agreement # EEC 0540834

www.ccefp.org

A NATIONAL SCIENCE FOUNDATION ENGINEERING RESEARCH CENTER

CENTER FOR COMPACT & EFFICIENT

FLUID POWER

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VOLUME
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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. Center research is creating hydraulic and pneumatic technology that is compact, efficient, and effective. 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: 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. A team of 35 faculty—each with distinguished academic records, unique and cross-disciplinary interests, and representing seven leading universities—is engaged in work on 22 research projects and five test beds. These projects are organized in three thrusts that achieve the following societal benefits: creation of a new fluid power technology that, with improved efficiency, will significantly reduce petroleum consumption, energy use and pollution; creation of a new fluid power technology that, with improved effectiveness, will make fluid power clean, quiet and safe for its millions of users; and creation of a new fluid power technology that, with improved compactness, will exploit its attributes in a new generation of devices and equipment—orthoses that increase mobility for an aging population, autonomous rescue and service robots needed in our complex world, and enabling fluid-powered portable hand tools.

Broader Impact: The Center's Education and Outreach program fills a long-recognized need. Despite fluid power's ubiquitous presence as an industry enabler, hydraulics and pneumatics instruction is typically scant. But the CCEFP is now transferring knowledge about fluid power and the work of the Center to diverse audiences—students of all ages, users of fluid power and the general public. Some of these programs are focused on STEM education with examples drawn from fluid power when appropriate, while others are specific to fluid power and its application. All are designed as multipliers—leveraging the benefits of working with established partners and/or with the potential to be duplicated by others.

Data on the size and reach of the current fluid power industry speak to the potential for the Center's impact. The National Fluid Power Association (NFPA) estimates that direct fluid power component sales exceed $33 billion. End application sales were easily an order of magnitude greater since fluid power technology is utilized in a wide range of industries: construction, manufacturing, transportation, agriculture, packaging, and many more. The use of fluid power is so prevalent that improvements in its use, driven by the Center's research, will have a profound societal impact.

Industry has supported the CCEFP since its proposal stage. Today, 57 companies support the Center with funding and in-kind donations. Through its committees and conferences, project mentoring, internships, and a host of other projects and individual contacts, the CCEFP is a forum that not only facilitates knowledge transfer between academia and industry but also a growing appreciation of each other's culture. These emerging partnerships will be among the Center's key legacies.

Informed by the CCEFP's research, the Center's Education and Outreach programs enrich understandings of fluid power technology. But its 23 projects share in a broader goal: to heighten interests in technology and engineering among an increasingly diverse student population.

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PARTICIPANTS TABLE

LEADERSHIP TEAM			
Name	**ERC Title**	**Institution**	**Department**
Kim Stelson	Director	University of Minnesota	Mechanical Engineering
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Terry Simon	Thrust 2	University of Minnesota	Mechanical Engineering
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Ken Cunafare	Thrust 3	Georgia Tech	Mechanical Engineering
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Luc Mongeau	Thrust 3	McGill Univerisity	Mechanical Engineering
Daniel Mountjoy	Thrust 3	North Carolina A & T	Industrial and Systems Engineering
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Barbara Pioro	Thrust 3	North Carolina A & T	Industrial and Systems Engineering
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Liz Hsaio-Wecksler	Test Bed 6	UIUC	Mechanical Science and Engineering

EDUCATION AND OUTREACH FACULTY

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INDUSTRIAL MEMBERSHIPS

Name (*IAB Member)	Title	Organization	Type of Industry	Membership Level
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Gary Dostal	Hydraulic Tech. Grp. Ldr.	Deere & Company	OEM	Supporter
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Richard Angell	V. P / Gen. Mgr.	INA USA Corporation	Distributor	Supporter
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Robert Burnett	President & CEO	Mead Fluid Dynamics	Manufacturer	Supporter
Dan McGrath	V.P.	MICO, Incorporated	Manufacturer	Supporter
Martin Berardi	V. P / Gen. Mgr.	Moog Inc.	Manufacturer	Supporter
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Erik Lamke *	Exec. Dir.	National Fluid Power Assoc.	Trade Association	Principal
Gary Chess	President	National Tube Supply Company	Supplier	Supporter
David Hein	VP of Engineering	Nexen Group, Inc.	Supplier	Supporter
Craig Maxwell *	Cor. VP Tech. & Innovation	Parker Hannifin Corp.	Manufacturer	Principal
Joseph Oberlin	President	PHD, Inc	Manufacturer	Supporter
Donald Spradlin	CEO	PIAB Vacuum Products	Manufacturer	Supporter
Alain LePrince *	Dir. Bus. Dev.	Poclain Hydraulics	Manufacturer	Principal
Gregory Williard	President & CEO	Quality Control Corporation	Manufacturer	Supporter
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Ralph Rivera	Individual	Ralph Rivera	Individual	Supporter
James Neumann	President	RB Royal Industries, Inc	Manufacturer/Distributor	Supporter
Steven Herzog *	Global Product Mgr.	RohMax USA, LP	Supplier	Principal
Steven Demster	President & CEO	Ross Controls	Manufacturer	Supporter
David Anderson *	President & CEO	Sauer-Danfoss	Manufacturer	Principal
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Cliff Henderson		Shell Global Solutions	Supplier	Supporter
Allen Carlson *	President & CEO	Sun Hydraulics Corp	Manufacturer	Principal
Justin Jacobi	President & CEO	Sun Source (STS Operating, Inc.)	Distributor	Supporter
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John Heckel	Dir., Ctr. for Adv. Turf Tech.	The Toro Company	OEM	Supporter
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P.S. Reddy *	Mktg. Mgr.	Veljan Hydrair Private Ltd.	Manufacturer	Principal

* On Industrial Advisory Board

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1. Systems Vision, Value Added of the Center

The vision of the Engineering Research Center for Compact and Efficient Fluid Power (CCEFP) is to create new fluid power systems that are compact and efficient. This will lead to significant fuel savings as the new systems technologies are implemented in existing and new applications. The new technologies will enable new products and systems requiring portable high-power, un-tethered operations over long time periods. As the vision of the CCEFP is realized, both short and long term advantages will accrue. Improved efficiency will greatly reduce petroleum consumption and pollution in our economy, recovering the Center's cost many times over. Improved compactness will enable fluid power to perform tasks that are not presently possible, spawning whole new industries to commercialize these systems.

CCEFP has created a highly qualified multi-disciplinary team to realize this vision. The center is becoming recognized as a world leader in fluid power. In the November 2007 issue of *Hydraulics and Pneumatics,* the leading trade magazine in fluid power, Paul Heney, Senior Editor writes: "I've said it before, and I'll say it again. I think the newly formed Center for Compact and Efficient Fluid Power is key to moving fluid power in the U.S. forward. The center is something that both industry and manufacturers should pay attention to and support. Take a look at their website, www.ccefp.org. Their dedication, research and education may be the linchpin that we need to figure out how to keep fluid power strong, competitive, and on the minds of the youngest, brightest students mulling over career choices."

1.1 Systems Vision

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.

The CCEFP has four goals. The first goal is to dramatically improve the energy efficiency of fluid power in current applications; the second goal is to improve the efficiency of the transportation sector using fluid power by developing fuel efficient hydraulic hybrid technologies suitable for small passenger vehicles; the third goal is to develop un-tethered portable human-scale fluid power devices; and the fourth goal is to make fluid power more acceptable and ubiquitous.

Goal 1: Fluid power in the agriculture, mining and construction sector consumes \$56 billion in energy annually, and fluid power in the machine drives sector of manufacturing consumes \$42 billion annually. A ten percent improvement in the energy efficiency of these sectors would save \$9.8 billion annually. Such an annual savings is a realistic expectation as an outcome of CCEFP research that is intentionally structured to achieve these goals.

Goal 2: The transportation sector consumes \$480 billion in energy annually of which \$200 billion is consumed by passenger cars. Hydraulic hybrid vehicles are just coming on the market. Prototype or near market vehicles include refuse trucks, city busses, SUVs and delivery vans. Energy savings in these sectors are expected to be a few hundred million dollars a year for each sector. A ten percent improvement in the energy efficiency of passenger vehicles would save $20 billion annually, a much larger amount. Although current hydraulic hybrid technology can be used for heavier vehicles, it is too large and heavy for competitive use in passenger vehicles. The realization of the goal of the hydraulic hybrid passenger vehicle requires new compact approaches that will be developed by the CCEFP.

Goal 3: Personal service robots are just one example of un-tethered portable human-scale fluid power devices. The market for service robots is estimated to be worth $10 billion in a decade (Japan Government Report, March 2005). These robots must be energetically autonomous to be truly effective, but there currently exists no power supply or actuation system capable of powering a human-scale robot for extended periods of time. Because electric motors and batteries are heavy, this approach cannot provide the required energy, and typical running times for these systems are limited to about twenty minutes. Because of the intrinsic power density advantage of fluid power, it is the natural technology for human-scale, un-tethered applications. The CCEFP will develop novel fluid power based compact power and actuation systems that will provide an order of magnitude greater energy and power density than state-of-the-art batteries and motor drives, thus overcoming one of the major barriers to the development of portable human-scale fluid power devices.

Goal 4: Fluid power has been plagued by a number of troublesome factors that have prevented its wider acceptance. No one will use fluid power unless it is clean, quiet, safe and easy to use. It is critical to overcome the barriers of poor human interface, noise and leakage. The goal is to have operator control that is fast, precise and intuitive, to have equipment that is quiet enough to not be obtrusive to the operator, and to have leaks be so rare that they would have a negligible aesthetic and environmental impact. Overcoming these barriers will dramatically improve the acceptability of fluid power and lead to its more widespread use.

When these goals are achieved, society will benefit from much lower energy consumption and pollution in existing fluid power applications and in transportation. Whole new industries will be created for the new human-scale applications that will improve quality of life in many ways. Fluid power hand tools will be light, maneuverable, un-tethered and capable of operating for long periods of time. These fluid power hand tools will replace noisy, polluting, inefficient two-cycle engine powered equipment in industrial and residential applications. Portable jaws-of-life and autonomous rescue robots will aid in emergencies, and free-roving service robots as well as a new generation of protheses and orthoses will aid those who are mobility impaired or suffering from other afflictions. These and many other applications will greatly benefit humanity.

The SWOT identified three major categories of weakness or threat. The first category of concern was the effectiveness of overall strategy, a major focus of CCEFP improvement during the past year. Although the SVT recognized that the high-level vision for CCEFP was compelling, it also identified the lack of detail in the strategic implementation plan. In the updated strategic plan submitted to NSF in January 2007, detailed descriptions with milestones and time phasing for each project were provided. CCEFP now recognizes that a weakness of the updated plan was in mid-level connections needed to show how projects and test beds support the high level vision. Strategy Action Maps are now being used to clearly articulate mid-level connections.

The second category concern is lack of market understanding and competitive analysis, creating the potential to miss opportunities because of the narrow focus of the research projects. CCEFP knowledge of the current state-of-the-art for fluid power is extensive residing in university researchers, industry partners and the scientific advisory board. Knowledge of competing technologies is not as extensive, and CCEFP recognizes the need to invest effort in benchmarking competing technologies. This will be done by funding several scoping studies in Year 3, providing opportunities for multi-disciplinary collaboration.

The third major category concerns inadequate funding. These include the difficulty of funding seven institutions with a limited budget and the need to target unrealistic projects for elimination. To refocus resources, strategic planning allowed CCEFP to identify one test bed and three poorly aligned projects for elimination, making funding of high pressure and engineered fluids research possible. Two or three additional projects will be eliminated in spring 2008. The resources made available by these cancellations will fund a few crucial projects that are currently being identified.

1.2 VALUE ADDED AND BROADER IMPACTS

Research

The overall research plan is described in detail in section 2. The CCEFP systems level test beds are the focus of technology integration activity. Through integration of research from the three thrusts (efficiency, compactness and effectiveness), they provide concrete demonstrations of achieving the four CCEFP goals: improvement in efficiency in current applications, migration of fluid power to passenger vehicles, development of the next generation of compact tether-less human scaled fluid power equipment, and making fluid power ubiquitous by making it safe, easy to use, quiet, reliable and clean. Test bed demonstrations not only create excitement for faculty and students but also credibility in industry's eyes. Because of the integrative nature of the research challenges, research activities are directed in ways not possible in single investigator projects.

Each of the currently active test beds has made significant progress toward its goals.

Test bed 1: The excavator demonstrates improved efficiency in current applications by using more efficient components, including fluid, and more efficient control strategies. It is also being used to demonstrate progress toward the goals of the Center's effectiveness thrust: easier, quieter and leak-proof operation. An excavator, donated by a CCEFP partner, was instrumented and a real-world energy consumption baseline was established. Detailed dynamics models have been created, predicting a 30% reduction in energy consumption with the implementation of CCEFP developed technologies. Modifications to incorporate these technologies, such as pump controlled linear actuation and engine management, are underway.

Test bed 3: The small Urban Vehicle (sUV) is nearly operational. This vehicle has a novel power train system (a hydro-mechanical transmission with energy regeneration) which is expected to be significantly more efficient than existing approaches. A patent has been applied for. The most significant systems goals of the sUV are to demonstrate more efficient control strategies, more efficient pumps and motors and more compact energy storage. The suV also provides a test bed for demonstrating improved drivability and noise reduction.

Test bed 4: The rescue robot provides an example of a small-scale fluid power application where tether-less operation is required for long periods of time. The rescue robot is being used to demonstrate a compact fluid power energy source. The first version, which is nearly operational, uses existing chemo-fluidic propulsion. Later versions will test two new compact power sources being developed by CCEFP: the chemofluidic hot gas vane motor and the free-piston engine compressor. Test bed 4 is a cooperative project between Georgia Tech and Vanderbilt, providing the researchers on this project with a collaborative research opportunity that does not exist in single investigator projects. Development of the control approach is now shared between the two universities, but eventually will be integrated into a seamless whole.

Test bed 6: Orthosis stretches the capabilities of engineering a compact fluid power application to the limits. As a result of CCEFP strategic planning, this test bed is being redirected. The first orthosis prototype was passive, using energy harvesting from walking for power. Now nearing completion, the first prototype has proven to provide important clinical results for patients with walking problems. Efforts are now being focused on a powered orthosis, a prototype closely aligned with CCEFP goals. This device will use a compact chemo-fluidic power source. It is a challenging project. The new device must be housed in a small, light package despite conflicting demands for power, mechanical strength, heat transfer, and minimal noise.

Test bed 5: Funding for Fluid Power Hand Tools started in Year 2; the test bed is in its initial phase of development.

Test bed 2: Injection molding machine, identified in the Center's proposal, was discontinued in order to focus effort on the other test beds.

Some of the major research accomplishments of the CCEFP projects are listed below.

Project 1B	developed fully coupled fluid-structural-thermal multi-body dynamic model of gaps in hydraulic pumps and motors (see nuggets)
Project 1D	determined that a combination of micro and nano scale texturing achieves highest drag reduction
Project 1E	experimentally demonstrated self-spinning rotary PWM valve modulated 40 lpm flow at 90 Hz. with 0.1 s full off to full on transition time (see nuggets).
Project 1G.1	designed, built and commissioned a 200 horsepower hydraulic dynamometer with electrical regeneration for testing engineered hydraulic fluids under low-speed high-torque conditions (see nuggets)
Project 2A	designed, constructed and tested a chemofluidic hot gas vane motor prototype with a power density of 650 W/kg, greatly exceeding electric motor power density of 160 W/kg.
Project 2B	free-piston engine compressor designed, constructed and tested with successful combustion at 10 Hz. (see nuggets)
Project 2C	created novel open accumulator architecture capable in increasing fluid power energy density by an order of magnitude
Project 2D	developed technology for controlled casting of ferrous and super nickel alloy and new structural optimization techniques that lead to a 33% reduction in weight for a pump casting
Project 2E	developed a knowledge structure for multi-aspect component models to capture and store analysis models for fluid power systems
Project 3A.1	multi-modal human interface with haptic feedback and augmented reality is simulated with hardware-in-the-loop test setup
Project 3A.2	developed and tested passive control of pneumatic human power amplifier
Project 3A.3	human factors oriented models developed for excavator and rescue robot
Project 3B.1	developed fluid power noise transmission test rig (see nuggets)
Project 3C	developed and experimentally verified large-eddy simulation computational model of cavitation (see nuggets)
Project 3D	developed seal model that can predict leakage under realistic conditions of transient mixed lubrication with thermal effects (see nuggets)

This section details the most significant impacts of CCEFP in research, education and outreach, industrial collaboration and technology transfer, and the CCEFP team and its diversity. Data is taken from Table 1: Quantifiable Outputs and Table 1a: Average Metrics Benchmarked Against All Active ERCs

Research funding and publication numbers can be used as metrics of research productivity. Table 1a shows a comparison of these numbers with other ERCs. A comparison shows that CCEFP is less dependent on NSF funding than the average for the class of 2006 (68% versus 74%). But, CCEFP is more dependent on NSF funding than the average of all ERCs (61%). This underscores the need to continue to vigorously seek out additional funding from sources other than NSF. One opportunity for expanded support would be in associated research projects. CCEFP will undertake a major initiative to promote industry support of associated projects in spring 2008.

In comparing ERC publication data, Table 1a shows that CCEFP had no publications in peer reviewed technical journals and 19 publications in peer reviewed conference proceedings. This compares to an average for all ERCs of 24 publications in peer reviewed technical journals and 32 publications in peer reviewed conference proceedings. Because of the normal delays in research and reviewing, publications lag research activity in young research centers. Publication productivity is expected to increase greatly in the next few years. Associated research produced 6 articles in peer reviewed technical journals and 18 articles in peer reviewed conference proceedings, an indication of the potential of CCEFP researchers to publish high-quality research.

Education and Outreach

Education and pre-college outreach are described in detail in section 3. The ERC has had a significant influence on the curriculum of CCEFP universities. Referring to Table 1, CCEFP faculty have introduced one new course, modified 19 courses, and created two degree minors in fluid power. This is far above the average of all ERCs of seven courses added or modified and no new degree programs. Further, the CCEFP plans that all mechanical engineering students in the United States will have significant exposure to fluid power. A Center faculty, in consultation with colleagues, is initiating this effort in Year 2 by writing and distributing a textbook chapter on fluid power to be included in undergraduate system dynamics and controls courses throughout the CCEFP. With information gleaned from these introductions, this material will be made available to all schools of mechanical engineering in the fall of 2009. Table 1 documents the significant outreach activity to industry, including five short courses, 24 seminars, and one web-enabled course.

The CCEFP also has significant involvement among pre-college students and teachers. Table 1a shows that 281 teachers and students participated in CCEFP programs, near the average for all ERCs (298). However, these figures significantly understate the CCEFP's impact on pre-college students and teachers because the Center has significantly leveraged its activities with other organizations. With CCEFP collaboration, Project Lead The Way (PLTW) is integrating fluid power concepts into engineering courses that are taught at thousands of middle and high schools. The CCEFP is introducing FIRST robot competition teams to fluid power. Tens of thousands of high school students participate in FIRST. A workshop introducing high school students to pneumatics was developed and tested in fall 2007, and will be more broadly circulated in advance of the 2009 competition. The Science Museum of Minnesota (SMM) is developing an exhibit that exposes the K-14 students and the general public to fluid power. This exhibit, already showcased on the museum floor, can tour the nation and/or be replicated, thereby having a significant impact beyond the SMM. Lastly, the videos developed by Twin Cities Public Television (TPT) can be rebroadcast across the country and distributed in DVD form (see nugget).

Industrial Collaboration and Technology Transfer Interactions

Strong industry participation has always been a hallmark of the CCEFP. More industry representatives are engaged in this Center than in most other ERCs. As examples, 22 CCEFP member companies are represented on the Industrial Advisory Board (IAB), they have donated $250,000 worth of fluid power equipment to the Center and are active on research projects as project champions. Referring to Table 1a, the CCEFP has 54 member firms, significantly more than the ERC average of 16 firms. Most (57%) of CCEFP firms are small, compared with an ERC average of 30%. The total of CCEFP annual industrial membership fees are $650,000, significantly above the ERC average of $274,266 and somewhat above the class of 2006 average of $512,996.

The CCEFP is young, consequently no licenses for technology, no commercialized products, no spin off firms, and no product lines have result as yet from CCEFP research. Nevertheless, the high level of creative applied research bodes well for future technology transfer. Referring to Table 1a, CCEFP researchers have filed seven invention disclosures and five patent applications, with one patent awarded and one license. These totals compare favorably with the average for all ERCs of five invention disclosures, four patent applications, two patents awarded and two licenses.

Team and Its Diversity

The disciplinary diversity of the CCEFP team is shown in Tables 2, 2a, 2b and Figure 2c, which are discussed in detail in section 2.1. As can be seen, the CCEFP has the broad disciplinary distribution needed to achieve its goals.

The CCEFP has representation of women and underrepresented minorities on its leadership team. It also actively seeks diversity in faculty recruitment. CCEFP recruited one woman, Dr. Ashlie Martini, to its faculty in Year 2. Comparisons of data on underrepresented groups are found in Table 1a. From this table it can be seen that CCEFP is 14% women, 15% underrepresented minorities and 4% Hispanics. This compares to an average for all ERCs of 36% women, 10% minorities and 7% Hispanics. Thus, CCEFP has somewhat more underrepresented minorities and somewhat fewer Hispanics than the average ERC. CCEFP also has significantly fewer women than the average ERC. All of these figures are expected to increase as the CCEFP matures and CCEFP diversity initiatives have some time to have an effect. The recruitment of women is a particular challenge to CCEFP, since a lower percentage of women enter mechanical engineering than other types of engineering, and a lower percentage of women enter fluid power than other types of mechanical engineering.

Seven CCEFP students entered the workforce in Year 2. Four of these students were employed at CCEFP member companies. One was a women and one was Hispanic.

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Table 1: Quantifiable Outputs

Outputs	Early Cumulative Total*	Reporting Year - 4	Reporting Year - 3	Reporting Year - 2	Reporting Year - 1	Jun 01, 2006 - Aug 15, 2007	All Years
Publications That Result from Center Support							
In Peer-Reviewed Technical Journals	0	0	0	0	0	0	**0**
In Peer-Reviewed Conference Proceedings	0	0	0	0	0	19	**19**
In Trade Journals	0	0	0	0	0	1	**1**
With Multiple Authors:	0	0	0	0	0	12	**12**
Co-authored with ERC Students	0	0	0	0	0	12	**12**
Co-authored with Industry	0	0	0	0	0	0	**0**
With Authors from Multiple Engineering Disciplines	0	0	0	0	0	0	**0**
With Authors from Both Engineering and non-Engineering Fields	0	0	0	0	0	2	**2**
with authors from multiple institutions	0	0	0	0	0	0	**0**
Publications That Result from Associated Projects in the Strategic Plan							
In Peer-Reviewed Technical Journals	0	0	0	0	0	6	**6**
In Peer-Reviewed Conference Proceedings	0	0	0	0	0	18	**18**
Participating Industrial and Practitioner Organizations							
Members	0	0	0	0	57	57	**114** **
Affiliates	0	0	0	0	0	0	**0** **
Contributing Organizations	0	0	0	0	0	0	**0** **
ERC Technology Transfer							
Inventions Disclosed (submitted to agencies by researchers or	0	0	0	0	0	7	**7**
Patent Applications Filed	0	0	0	0	0	5	**5**
Patents Awarded	0	0	0	0	0	1	**1**
Licenses Issued	0	0	0	0	0	0	**0**
Spin-off Companies Started	0	0	0	0	0	0	**0**
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	0	0	0	0	1	**1**
New Surgical and other Medical Procedures Adopted	0	0	0	0	0	0	**0**
Degrees to ERC Students							
Bachelor's Degrees Granted	0	0	0	0	0	6	**6**
Master's Degrees Granted	0	0	0	0	0	9	**9**
Doctoral Degrees Granted	0	0	0	0	0	2	**2**
ERC Graduates Hired by							
Industry:	0	0	0	0	0	7	**7**
ERC Member Firms	0	0	0	0	0	4	**4**
Other U.S. Firms	0	0	0	0	0	3	**3**
Other Foreign Firms	0	0	0	0	0	0	**0**
Government	0	0	0	0	0	0	**0**
Academic Institutions	0	0	0	0	0	0	**0**
Other	0	0	0	0	0	0	**0**
Undecided/Still Looking/Unknown	0	0	0	0	0	0	**0**
ERC Influence on Curriculum							
New Courses Based on ERC Research In Use	0	0	0	0	0	1	**1**
Courses Modified to Include ERC Research	0	0	0	0	0	14	**14**
New Textbooks Based on ERC Research	0	0	0	0	0	0	**0**
New Textbook Chapter Based on ERC Research	0	0	0	0	0	0	**0**
Free-Standing Course Modules or Instructional CDs	0	0	0	0	0	0	**0**
New Full Degree Programs	0	0	0	0	0	0	**0**
New Degree Minors or Minor Emphases	0	0	0	0	0	2	**2**
New Certificate	0	0	0	0	0	0	**0**
Active Information Dissemination/Educational Outreach							
Workshops, Short Courses to Industry	0	0	0	0	0	5	**5**
Workshops, Short Courses to Others	0	0	0	0	0	3	**3**
Seminars, Colloquia, etc.	0	0	0	0	0	24	**24**
World Wide Web courses	0	0	0	0	0	1	**1**
Personnel Exchanges							
Student Internships in Industry	0	0	0	0	0	12	**12**
Faculty Working at Member Firm	0	0	0	0	0	0	**0**
Member Firm Personnel Working at ERC	0	0	0	0	0	2	**2**
***For Centers in operation for more than five years.**							

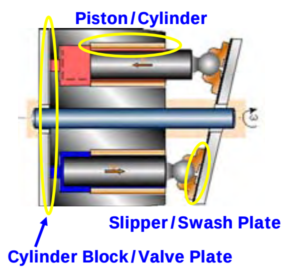
** - Cummulative count of Individual Firms/Organizations may not equal the sum across all years.

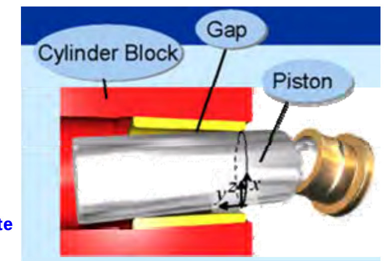
Table 1a: Average Metrics Benchmarked Against All Active ERC's					
Metric	Average All Active ERC's FY2006	Average Manufacturing and Processing Sector FY2005	Average Manufacturing and Processing Sector FY2006	Average for Class of 2006 - FY 2006	Engineering Research Center for Compact and Efficient Fluid Power Total
	(21 ERC's)	(7 ERC's)	(6 ERC's)	(5 ERC's)	FY2007
Industrial Member Firms	16	11	21	18	54
Small	30%	25%	30%	50%	57%
Medium	13%	11%	15%	13%	19%
Large	57%	64%	55%	37%	24%
Non-Industrial Member Firms	1	1	1	2	3
Affiliate Organizations	3	3	4	0	0
Contributing Organizations	5	3	2	0	0
Industrial Membership Fees Received	$274,266.00	$138,442.00	$493,946.00	$512,996.00	$650,000.00
Sources of Support 1	$4,703,913.00	$2,800,401.00	$4,533,142.00	$2,979,400.00	$4,870,128.00
NSF	61%	66%	61%	74%	68%
Industry	13%	18%	26%	16%	14%
Other Federal	4%	3%	1%	0%	0%
Academic	18%	7%	8%	10%	18%
State	4%	6%	4%	0%	0%
Other	0%	0%	0%	0%	0%
Associated Project Support	$1,408,243.00	$793,600.00	$1,600,418.00	$883,256.00	$790,235.00
ERC Personnel & Educational Participants 2 (Average)	689	401	301	0	553
Leadership Team 9	9	9	8	0	10
Faculty 3	34	29	27	0	35
Graduate Students	134	59	60	0	102
Undergraduate Students	174	55	39	0	84
REU Students	11	27	10	0	27
K-14 Teachers and Students, and Community College Faculty	298	216	145	0	282
% Women 7	36%	25%	30%	0%	14%
% Underrepresented Racial Minorities 4 7	10%	9%	17%	0%	15%
% Hispanic 5 7	7%	24%	6%	0%	4%
Publications	**Average**	**Average**	**Average**	**Total**	**Total**
In Peer Reviewed Technical Journals	24	24	23	0	0
In Peer Reviewed Conference Proceedings	32	8	12	0	19
Multiple Authors: Co-Authored With ERC Student	46	20	30	0	12
Multiple Authors: Co-Authored With Industry	4	5	7	0	0
Intellectual Property	**Average**	**Average**	**Average**	**Total**	**Total**
Invention Disclosures	5	2	2	0	7
Patent Applications	4	2	1	0	5
Patents Awarded	2	1	0	0	1
Licenses (patents, software)	2	1	0	0	0
Education and Outreach Outputs	**Average**	**Average**	**Average**	**Total**	**Total**
Courses Developed or Modified	7	1	2	0	15
New Degree Programs	0	0	0	0	2
Publications in Refereed Journals 6	56	34	35	0	20

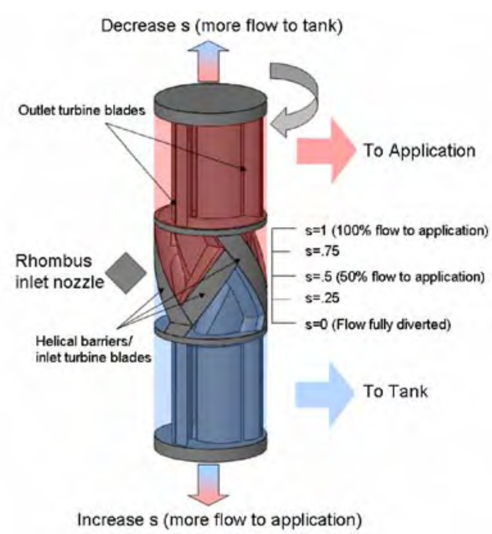
1.3 Nuggets of Significant Achievement and Impact

Discovery Nuggets

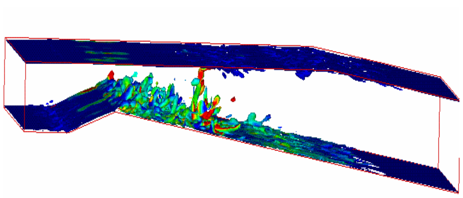
Multi-Mode Pump Model - One way to reduce energy consumption is by the development of hydraulic hybrid vehicles. For hydraulic hybrid technology to become a viable option, the efficiency of today's pumps and motors needs to be increased. Improving pump and hydraulic motor efficiency requires an understanding of the most miniscule of design elements. These design elements, called lubricating gaps, typically have dimensions on the order of tens of microns and are formed between the moving components of the pump. Even small changes in the design of these gaps can have a major impact on the efficiency of the machine. If the gaps are too large the internal leakage will become excessive and the volumetric efficiency will suffer. If the gaps are too small and mechanical efficiency falters or fails, catastrophic seizure may occur. With an appropriate gap design energy loss can be minimized. The challenge is to develop sophisticated models and algorithms allowing a fully coupled simulation of fluid-structure-thermal and multi-body dynamic interactions allowing direct calculation of surface deformation. CCEFP researchers have created and are currently validating a coupled fluid-structure interaction and multi-body dynamics model for the cylinder block-valve plate and piston-cylinder interfaces of a swash plate axial piston machine.





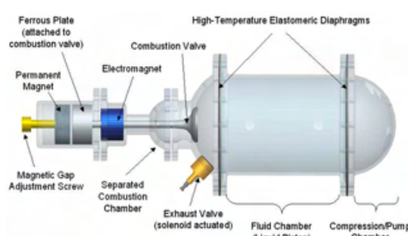


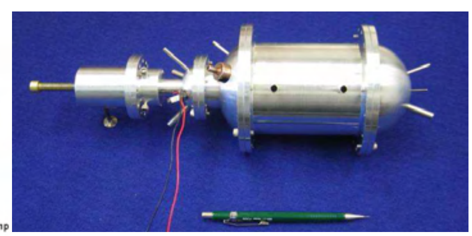
Self-Spinning Rotary PWM Valve – A major source of energy loss in current fluid power systems is the use of metering control valves that achieve control function by dissipating energy through partially opened valve orifices. Replacing them with throttle-less methods will increase energy efficiency significantly. Pulse width modulation (PWM) of on/off valves that are either fully open or fully closed is a potential approach for throttle-less control. This approach is analogous to switched mode converters in power electronics. A primary challenge to realizing PWM control of fluid power system is the lack of high speed on/off valves. These on/off valves must have large orifices (to allow large flow to pass through at low pressure drops), have fast transitions (to reduce the time when the valve is partially open), and must operate at high PWM frequencies (to reduce ripples and to achieve high control bandwidth). Typically, a control valve consists of a linear translating element such as a spool or poppet that opens and shuts an orifice. Actuating such valves at high frequency requires rapidly accelerating and decelerating the element, which in turn requires large actuators and power input proportional to the third power of the frequency. To overcome this challenge, a self-spinning rotary on/off valve is being developed at the CCEFP. The valve is turned on and off as the spool rotates and the PWM duty ratio is adjusted by translating the spool axially. Since the spool is continuously rotating, rapid acceleration and deceleration are not required, and the power input is proportional to the second power of frequency allowing much faster operation. The CCEFP rotary valve uses fluid momentum to achieve rotary motion so that no external rotary actuator is needed. To date, a 3-way version of the rotary on/off valve that is integrated with a (40 lpm) fixed displacement pump to achieve variable displacement function has been prototyped and demonstrated. PWM frequency up to 90Hz, closed loop duty ratio modulation with 0-100% modulation time of less than 0.1sec have been achieved. Further development will consider improved performance and configurations for regenerative applications.



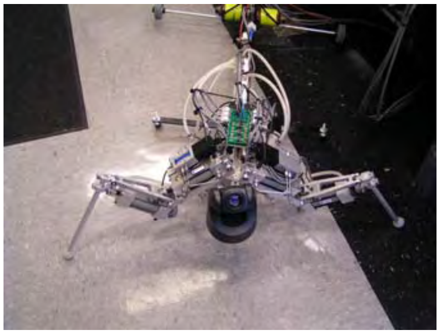
Cavitation Modeling - Whenever pressures within fluid power systems become too low, cavitation occurs. A common location for this problem is the pump inlet where the fluid is being drawn into the system. The problem is exacerbated by high flow rates, highly viscous fluids such as encountered during cold weather start up, operation at high altitudes and abrupt changes in geometry. There presently is no truly accurate means of modeling cavitation. The Center is taking a unique approach by employing high-fidelity large eddy simulation (LES) as the computational method and laser-based diagnostics, specifically particle imaging velocimetry (PIV), along with fiber-optic probes and piezo-electric pressure transducers, to make detailed flow, void fraction, and dynamic pressure measurements in venturi-type flow passages. Significant progress has been made on both the computational and experimental fronts including capturing, for the first time, the inherently complex 3D vortical structure associated with cavitating internal flows as shown in the accompanying figure. Center researchers hope to exploit the control of these vertical structures in future studies as a means of minimizing cavitation, either passively through geometric changes or actively through flow modification.

Free Piston Engine Pneumatic Compressor - The CCEFP free-piston engine compressor program will provide a compact source of power for new fluid power applications. The free-piston engine compressor prototype shown below is a compact and efficient source of compressed air derived from propane, which possesses an energy density 200 times that of batteries. The device has successfully demonstrated 10Hz combustion during testing. Novel design innovations include a "liquid slug" trapped between two high-temperature elastomeric diaphragms acting as its piston in order to exploit dynamics in achieving an efficient and powerful engine within a small package. The free piston engine compressor is the power source for the rescue robot test bed, demonstrating the possibility of greatly increasing the force and duration achieved for untethered robots.



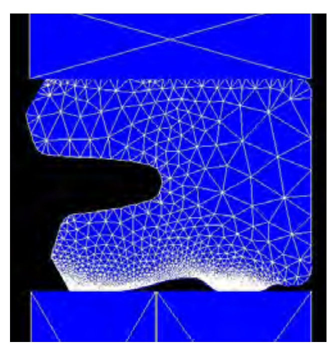


Rescue Robot - The difficulty with which a conventional electric vehicle traverses a disaster site, such as a collapsed building, results partly from the relatively low power available and partly from the lack of adaptability that wheels or tracks provide. The Rescue Robot will



overcome these obstacles through fluid power actuation and effective human-machine interface. In the process, a better understanding of the challenges of more common applications of fluid power to mobile equipment will also be gained. Excavators, backhoes, telehandlers, forest harvesters and other multi-axis devices with fluid actuation currently rely on simple-to-implement operator joysticks. These joysticks are far from simple to operate and require substantial training and impose a high cognitive workload on the operator that could be better employed in completing higher level tasks. The eighteen degree of freedom rescue crawler provides an opportunity for researchers to explore new multimodal interfaces, employing haptics and augmented reality displays. Head trackers point the crawler's cameras to provide the operator a "bug's eye" view of the operation underway. The haptic manual control of the front legs allows the user to test potentially unstable footholds while intelligent autonomous operation of the remaining degrees of freedom reduces the operator workload. The first prototype, based on a current chemofluidic approach, has been completed. The front legs of the prototype have been fabricated and are currently being tested. Custom valves and associated control electronics are also being fabricated so that the legs can be thoroughly tested, prior to full fabrication. Operator interfaces incorporating head tracking camera and helmet mounted display with audio and voice control, and haptically controlled front legs have been implemented.

Seal Modeling - Feedback from industry partners indicates that the number one nuisance and environmental issue facing the fluid power industry is that of seal leakage. Previous models assumed full film lubrication in the sealing interface, greatly simplifying the problem but giving unrealistic results. In Center research, realistic mixed lubrication is being considered. For reciprocating seals, a basic model including analyses of the quasi steady state fluid mechanics, contact mechanics and deformation mechanics must first be developed. The model will be validated by comparison with experimental results in the literature and obtained from industrial collaborators which will lead to the creation of an enhanced model that also takes into account transient and thermal effects which must also be experimentally validated. So far the development of the basic model, including a thermal analysis, has been completed. It has been used to analyze several types of U-cup rod seals and compared with those from an industrial injection molding application.

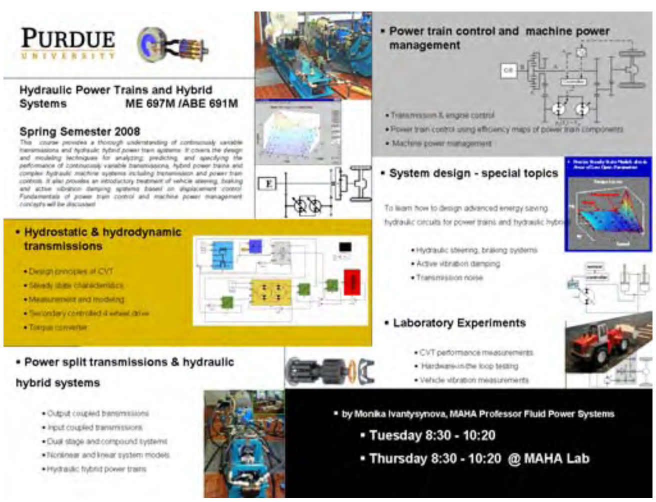


LEARNING NUGGETS

Fluid Power Videos

tpt MN channel

The CCEFP has partnered with the National Fluid Power Association (NFPA) to create two half-hour videos, one to educate the general public on fluid power and the other to inform engineering graduates of the career opportunities in fluid power. The videos feature CCEFP faculty, students and industry members. The main themes of the video for the general public are that fluid power is all around us even though we may not realize it, that fluid power has intrinsic capabilities that are unmatched by any other technology, and that fluid power has the potential for solving many of society’s pressing problems. The career opportunity video features graduate students and engineers in fluid power communicating the excitement and importance of their work. Additional financial support for the careers video was provided by fluid power organizations from other countries. The video was produced by Twin Cities Public Television for broadcast in April 2008. It will be made available to all public television stations in the United States by satellite. CCEFP and NFPA hold the copyright on the video and are free to distribute it in DVD form for educational purposes. The Center and its partners in this project are developing a plan to widely distribute the video for high impact.



New Fluid Power Courses and Area of Specialization at Purdue

In response to the lack of advanced graduate courses in fluid power at American universities, CCEFP faculty have developed several new courses and created a new Area of Specialization in fluid power within the Agricultural and Biological Engineering Department at Purdue. Students are required to choose three courses from a group of existing and newly developed courses. The new courses are *Design and Modeling of Fluid Power Systems* (ABE 591/ME 597) and *Hydraulic Power Trains and Hybrid Systems* (ABE 691/ME 697). These courses complement the existing courses covering hydraulic control systems, sensors and data acquisition, and control systems theory. Further information is available at Purdue’s MAHA Fluid Power Research Center website (http://cobweb.ecn.purdue.edu/~mahalab/).

Hydraulic Hybrid Vehicle Exhibit

The CCEFP has developed an interactive hydraulic hybrid vehicle exhibit that allows the operator to witness how energy regeneration is possible for a hydraulic hybrid passenger vehicle. The simulator is currently on display at the Science Museum of Minnesota (SMM) and will ultimately become part of a permanent exhibit on fluid power. The hydraulic hybrid vehicle exhibit was built in spring 2007 by senior mechanical engineering students at the University of Minnesota as a capstone design project. Advisors for the project were CCEFP faculty and staff of the SMM. The exhibit won first prize in the senior design show as the best capstone design project in mechanical engineering. The concept of energy regeneration holds great promise for future hybrid vehicles to greatly improve fuel economy, and is being demonstrated in the small urban vehicle research test bed being built at the University of Minnesota. The CCEFP displayed the exhibit at the 2007 Minnesota State Fair. The photo shows a CCEFP graduate student explaining the exhibit to a young State Fair visitor. The exhibit will be shown in the CCEFP booth at the International Fluid Power Exhibition (IFPE) Trade Show in March 2008. IFPE is part of the largest trade show in North America.

INFRASTRUCTURE NUGGETS

High Tech Treadmill Helps Researchers Develop Fluid-Powered Orthotic Braces

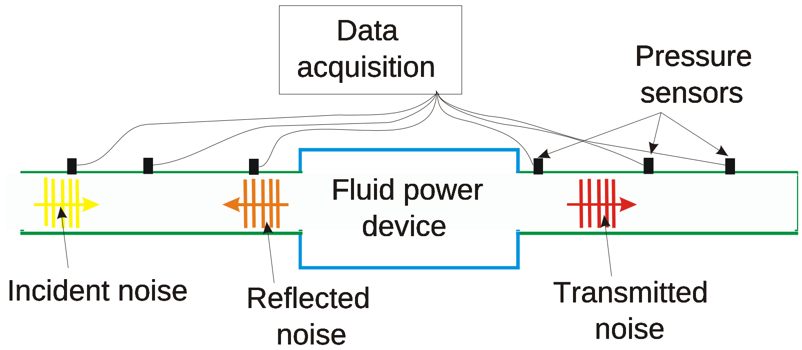
CCEFP researchers require state- of- the- art movement analysis equipment to assess the efficacy of new fluid-powered orthotic braces. These orthoses are being developed in a CCEFP test bed that focuses on developing challenging, human-scale, un-tethered, fluid-powered orthotic devices. CCEFP funds were used to purchase a special instrumented treadmill (recently released by Bertec Corporation, Columbus, Ohio) to meet this need. This cutting edge treadmill has many special features enabling researchers to look at contact force measurements under each foot in three directions (vertical, fore-aft, and sideways) for multiple steps and over many minutes. By combining force measurements with motion-capture data of joint and body segment movements, researchers are also able to examine the torques and reaction forces generated by the joints of each leg. From these data, detailed observations about gait behaviors are possible. Most gait analysis labs use one or more force platforms embedded into the floor to record these forces. However, that method only allows the examination of a couple of steps at a time and requires precise placement of only one foot on a platform at a time. Thus, test subjects need to make many passes across the platforms to get enough good data. This new treadmill allows researchers to collect good gait data with every step and also allows users to walk in the orthoses for longer assessment periods.

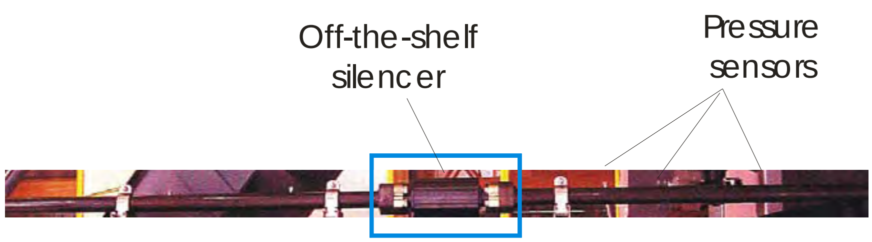
CCEFP Industry-University Partnership Builds Hydraulic Dynamometer with Electrical Regeneration Capabilities

Milwaukee School of Engineering, in partnership with the fluid power industry and CCEFP, recently completed the design, development, construction and commissioning of a 200 HP hydraulic dynamometer. This test stand will be used to develop energy efficient hydraulic fluids for use in a prototype hybrid car and mini-excavator that are being constructed by the CCEFP. The system uses a constant-torque AC motor to provide the load required to evaluate fluid-related torque and leakage losses within a hydraulic circuit. Using twin Rockwell variable frequency drives, the AC power that is generated by the load motor is converted to DC power and then synchronized with the electric pump drive in a regenerative loop. This reduces electrical energy usage and cooling water consumption while providing precise low-speed high-torque (LSHT) hydraulic motor control. This new facility, the first LSHT regeneration system in the academic world, serves both research and educational missions. In research, it makes possible the testing and development of energy-efficient hydraulic fluid chemistries for fluid power propelled vehicles. Since passenger car motor oils are formulated for energy conservation, extension of this technology to hydraulic fluids seems plausible. In education, this research has helped students to gain hands-on fluid power engineering experience in the areas of circuit design, component procurement, assembly, instrumentation and control.

Experimental Setup for Fluid Power Noise Evaluation

CCEFP researchers at Georgia Tech have developed an advanced test rig for fluid power noise measurement. Fluid power components naturally produce fluid-borne noise in their normal operation. This noise can be a major source of vibration as well as having an adverse human impact, not only as an annoyance but as a risk to hearing. While modeling methods are under development for the prediction and optimization of fluid-borne noise, it is essentially to be able to measure the actual noise production and noise control performance of fluid power devices. When noise propagating in fluid lines encounters a fluid power device, such as a silencer, a portion of the noise is reflected, some is absorbed, and some is transmitted. Researchers have developed a technique that permits the accurate measurement of each of these noise components, using a spectral-based method and multiple sensors. In a fluid power system, pressure sensors take the place of the more familiar microphone for the measurement of noise. Spectral decomposition and application of appropriate transfer function relationships to the pressure signals recorded upstream and downstream of a fluid power device permit the accurate resolution of the noise components. The method also permits the measurement of the input acoustic impedance of fluid power devices. Knowledge of a device’s impedance is valuable for the modeling of fluid power systems. (Continued on next page.)





When applied to devices such as fluid power silencers, the method yields the frequency-dependent transmission loss of the silencer. For silencers, this characteristic is a measure of how much incident energy actually transmits past the silencer. The test rig developed for this purpose provides the means to assess existing commercial devices as well the prototype components that are being developed by CCEFP.

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2. STRATEGIC RESEARCH PLAN AND OVERALL RESEARCH PROGRAM

The mission of the CCEFP is to utilize system driven, cross functional research to transform fluid power so that it becomes more compact, efficient, and effective to use. By doing so, societal benefits in the areas of energy conservation, productivity and improved quality of life are expected. Direct energy savings will be realized on existing fluid power applications by improving the efficiency of fluid power components and systems. By combining these efficiency gains with advancements in compactness, the possibility of a viable fluid power enabled, fuel efficient passenger automobile becomes a reality. When these gains in compactness are coupled with new ways of generating fluid power that is both energy dense and mobile, then entirely new systems and applications are attainable. Unfortunately none of these perceived benefits will be realized unless fluid power becomes more effective, that is, easier and safe to use, quiet and leak free. Therefore, the Center has chosen its strategic research thrusts to be that of Compactness, Efficiency and Effectiveness, and selected projects that address critical barriers. By cascading its breakthrough, system level vision into enabling technologies and fundamental research requirements, the CCEFP was able to prioritize where to focus its efforts. An explanation of this thought process, as well as a description of improvements we have recently incorporated, follow.

During strategic preparation for the initial supplemental proposal, CCEFP researchers discovered that key sub-elements of the envisioned fluid power systems were not being adequately investigated. Specifically, the maximum operating pressures of these systems needed to be increased in order to drive additional reduction in size. In addition, focus was needed on fluid, one of the most critical elements of a fluid power system. Therefore additional research projects were developed to address these areas.

CCEFP organization is driven by its mission, vision and strategy. However, feedback from the Center's last site visit indicated that greater clarity in alignment was required in describing the relationships from the top level vision to the research projects underway. In response, the Center is in the process of implementing a refinement to its strategic planning process called *strategic action mapping* (SAM) where the anticipated benefits realized by society from the Center's combined research are translated directly downward into system capabilities requirements, key enablers necessary to achieve these requirements, fundamental knowledge that must be gained and finally resources necessary to attain the vision.

Figure 1 below represents a completed action map for the goal of mass adoption of hydraulic hybrid vehicles. Similar action maps are now being prepared for the other CCEFP goals and will be completed in time for the February 2008 site visit review.

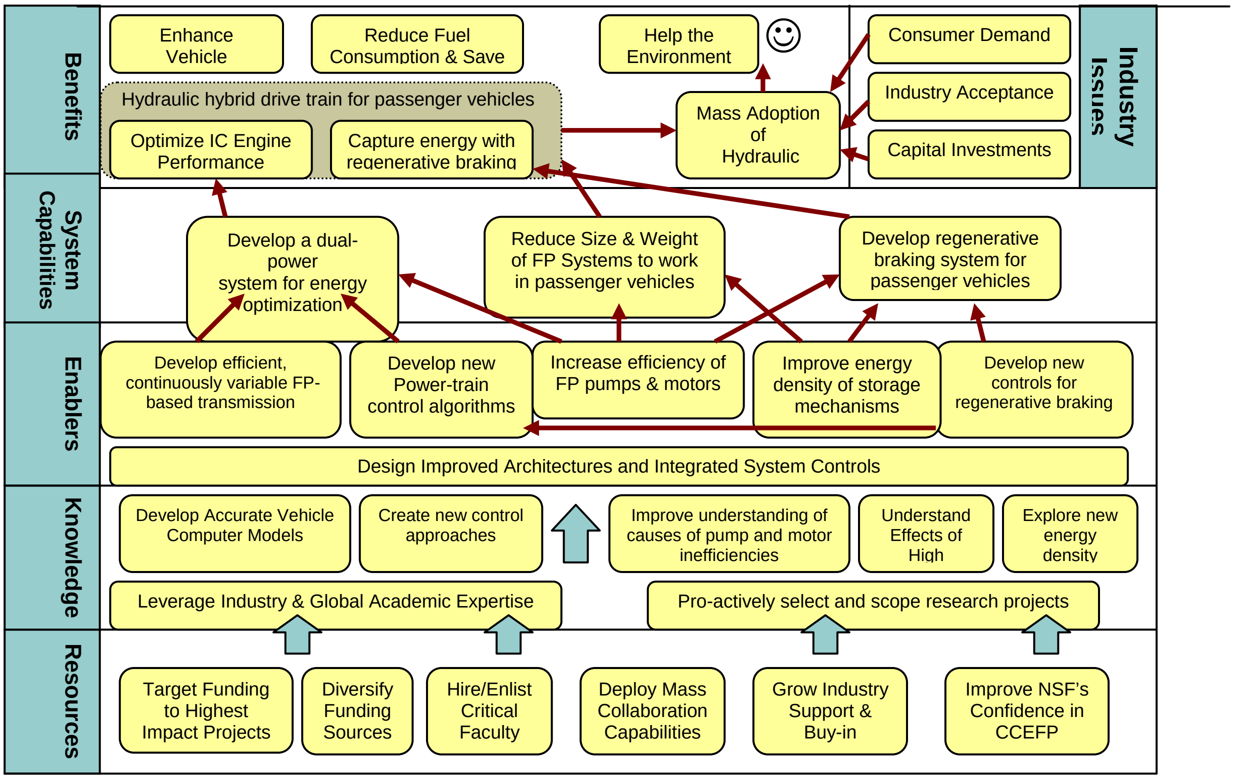


Figure 1: sUV Strategic Action Map

Following preparation of the SAM, the level of uncertainty or risk that each of these barriers pose to achieving the goals for the sUV test bed were scrutinized (see figure 1a.) In doing so, two main obstacles to this test bed's future success were clearly evident: 1) realization of a compact fluid power energy device and 2) dramatic improvement of existing pump and motor efficiencies. These are illustrated in figures 1b and 1c. Both areas call for focused research beyond the work currently being done in the CCEFP. Consequently, during the upcoming call for strategic future projects and subsequent funding, CCEFP principle investigators as well as other research contacts with relevant expertise will be asked to submit project proposals related to these two areas. This approach also provides the Center with additional avenues to increase its cross disciplinary exposure and diversity.

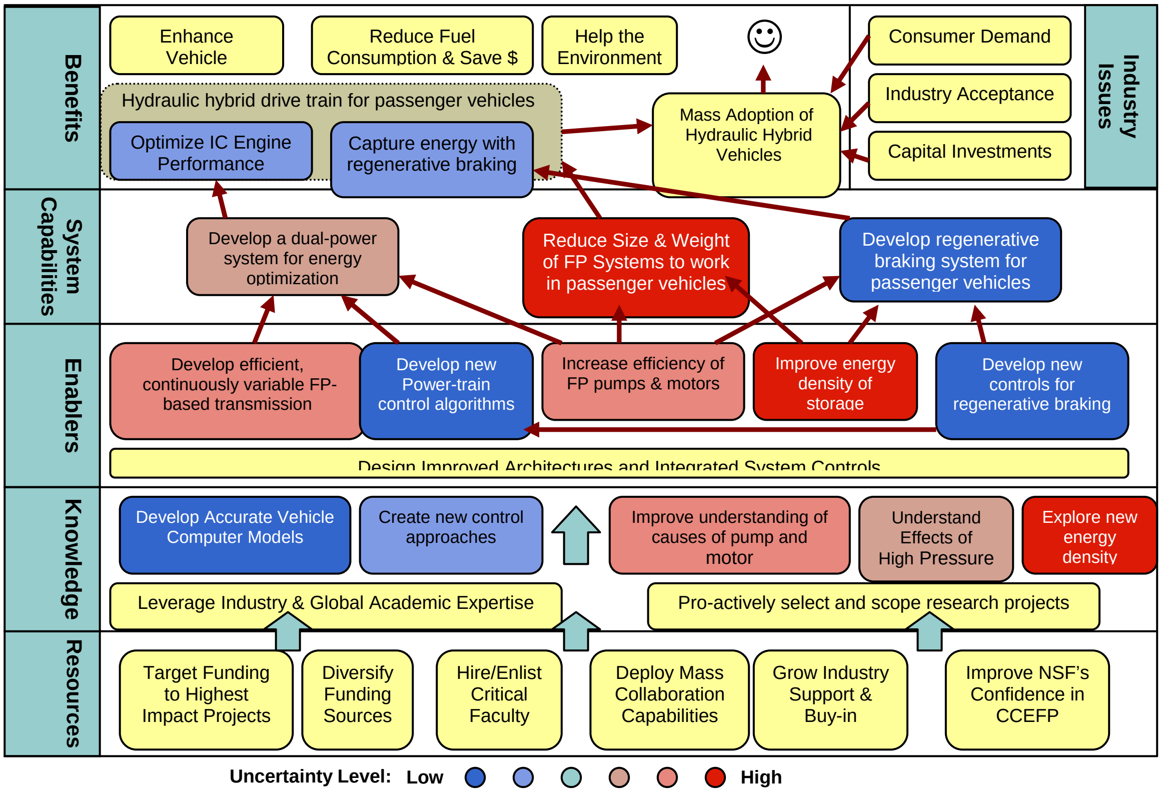


Figure 1a: sUV Strategic Action Map with Risk Levels

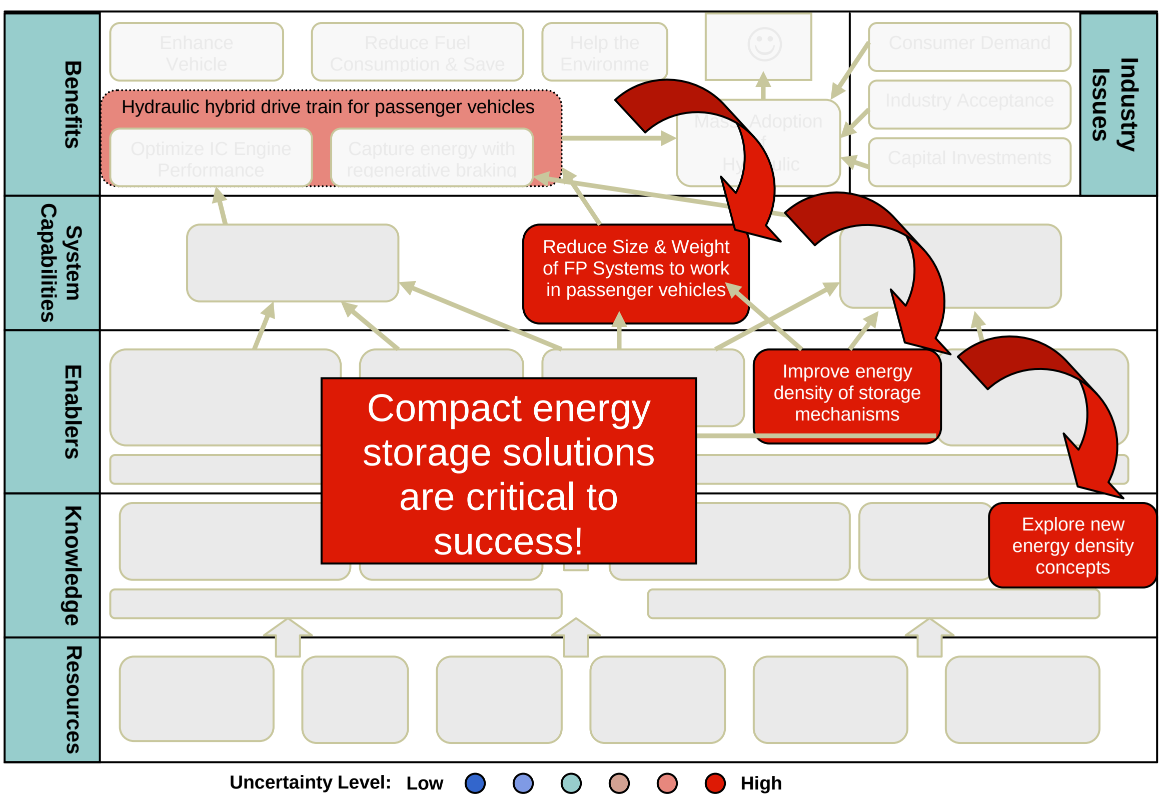


Figure 1b: Compact Energy Storage as a Critical Research Goal

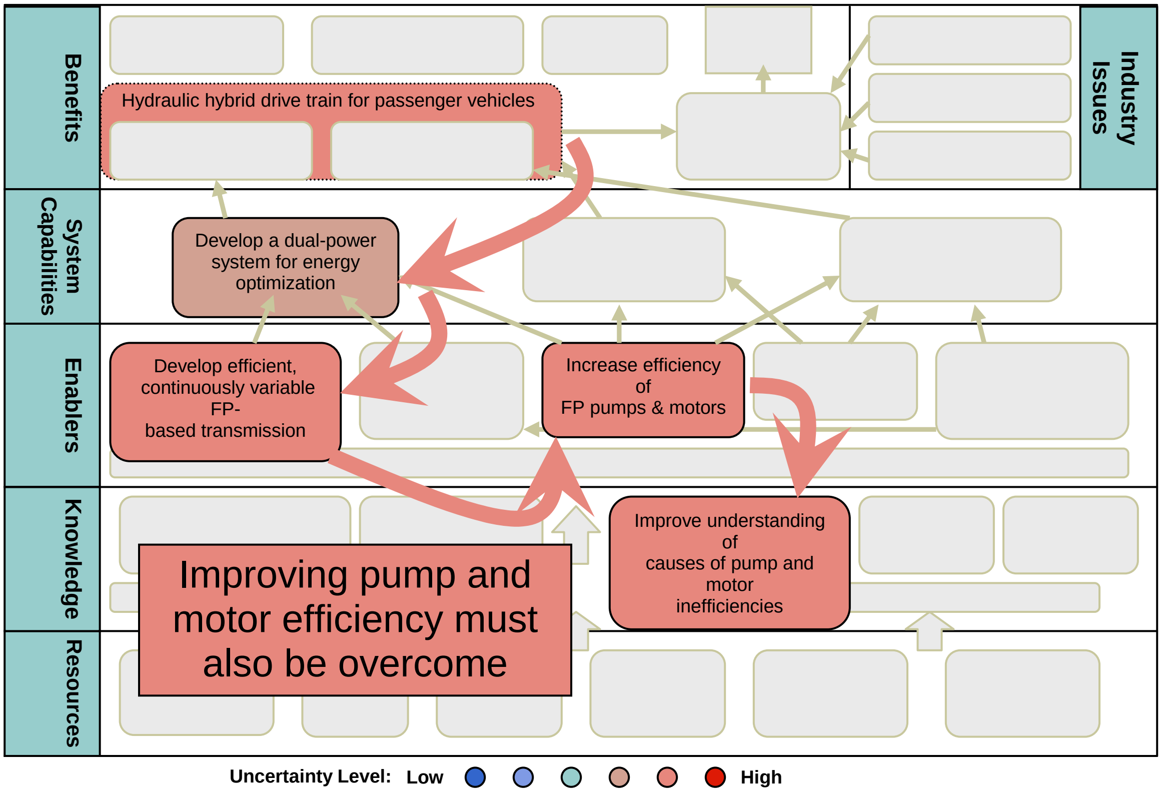


Figure 1c: Improving Pump and Motor Efficiency as a Critical Research Goal

2.1 ERC'S STRATEGIC RESEARCH PLAN

CCEFP research is targeted at developing enabling technologies and fundamental knowledge that will integrate into one of five test beds that were selectively chosen to address the barriers to CCEFP research goals.

Center Goals and Barriers

Goal 1: Efficiency of existing applications. Fluid power in the agriculture, mining and construction sector consumes $56 billion in energy annually, and fluid power in the machine drives sector of manufacturing consumes $42 billion annually. A ten percent improvement in the energy efficiency of these sectors would save $9.8 billion annually. Our goal is to significantly reduce energy consumption in existing applications of fluid power through development of efficient system configuration, control methodologies, and efficient components.

The excavator (TB1) and the injection molding machine (TB2), representing the mobile construction and stationary manufacturing sectors respectively, were initially chosen when CCEFP started in June 2006 as the intended test beds for demonstrating efficiency improvement in existing fluid power applications. TB2 was later eliminated. This is because electric injection molding machines are displacing hydraulic injection molding machines especially at smaller capacities. Electric injection molding machines are more energy efficient than hydraulic injection molding machines.

State-of-the-art excavators make use of a load sensing pump and throttling valves for control. Although the pump is controlled to match the load of the circuit with the highest pressure, a third of the energy is still lost via throttling valves in the other circuits, another third of the energy is lost through inefficient components, leaving only a third of the energy for useful work.

Control configurations that do not involve throttling, systems that allow energy regeneration and appropriate energy and engine management schemes are needed to dramatically increase system efficiency. Improvement in pump and motor efficiency, especially at partial load conditions will also be needed. In the case of human operated systems like the excavator, effective and intuitive human/machine interfaces are needed to greatly improve operation efficiency which leads to reduced energy use.

Goal 2: Hydraulic hybrid passenger vehicles. The transportation sector consumes $480 billion in energy annually of which $200 billion is consumed by passenger cars. Hydraulic hybrid vehicles are just coming on the market. Prototype or near market vehicles include refuse trucks, city busses, SUVs and delivery vans. Energy savings in these sectors are expected to be a few hundred million dollars a year for each sector. A ten percent improvement in the energy efficiency of passenger vehicles would save $20 billion annually, a much larger amount. Accompanying this saving is a corresponding reduction in harmful emissions. Our goal is to develop hydraulic hybrid drive-trains suitable for passenger vehicles.

Current hydraulic hybrid technology (e.g. by the U.S. EPA and various industry partners) can be used for heavier vehicles, but it is too large and heavy for competitive use in passenger vehicles. Electric hybrids, while already on the market after decades of research and development, rely on electric motor/generators whose power densities are an order of magnitude lower than that of hydraulic pump/motors of the same size or weight. This means that hydraulic hybrids can be more powerful for the same size can accelerate faster and are able to re-capture more braking energy during hard braking. Hydraulic hybrids are also potentially more reliable and cost-effective.

TB3, small Urban Vehicle (sUV), is the test bed to demonstrate the technologies needed for hydraulic hybrid passenger vehicles. The unique challenge for small hydraulic hybrid vehicles lies in the weight and size requirements. State-of-the-art hydraulic accumulators, used for storing energy, have energy storage densities that are two orders of magnitude lower than electric batteries. Energy storage for fluid power systems that are five to ten times more compact than presently possible will be sufficient for hydraulic regenerative hybrid passenger vehicles. Other components, such as pumps and motors, must also be made more efficient over a broad operating range, quieter and more compact. Appropriate system architecture, operational strategy including engine and energy management, and precise control are all needed to realize the energy savings.

Goal 3: Portable, un-tethered, human-scale applications. Personal service robots are just one example of un-tethered portable human-scale fluid power devices. The market for service robots is estimated to be worth $10 billion in a decade (Japan Government Report, March 2005). These robots must be energetically autonomous to be truly effective, but there currently exists no power supply or actuation system capable of powering a human-scale robot for extended periods of time. Because electric motors and batteries are heavy, this approach cannot provide the required energy, and typical running times for these systems are limited to about twenty minutes. Because of the intrinsic power density advantage of fluid power, it is the natural technology for human-scale, un-tethered applications. The CCEFP will develop novel fluid power based compact power and actuation systems that will provide an order of magnitude greater energy and power density than state-of-the-art batteries and motor drives, thus overcoming one of the major barriers to the development of portable human-scale fluid power devices.

Three CCEFP test beds, TB4: compact rescue crawling robot; TB3, fluid power assisted tools; and TB6, fluid powered orthosis, are designed to capture the vision for a host of human-scale applications made possible by new fluid power technologies that will be tetherless, portable and self-powered. The key functional barriers to these systems lie in the need for compactness. Specifically, compact and portable power supplies suitable for long periods of operation, compact power generation and actuation (pumps, motors and actuators), and compact energy storage for regenerative modes of operation must be developed. Safe and intuitive human machine interfaces are key to the functional success of these test beds and applications.

Goal 4: Ubiquity. Key barriers to making fluid power widely accepted and having greater societal impact are: 1) unfriendliness to human operators, 2) noise and vibrations, 3) leakage of hydraulic fluids. The image that fluid power is an outdated technology must be overcome. The five active test beds were selected to demonstrate societal impact as well as to engender the interest and excitement in CCEFP, industry and the general public. New technologies that mitigate noise and vibration, leakage, cavitation are being demonstrated in all five test beds. Development of these technologies is especially critical for the success of several test beds: intuitive and safe human machine interfaces for TB1 excavator, TB4 compact rescue crawler, TB5 fluid power assisted tools, and TB6 fluid powered orthosis; quiet and leak free operation for TB3 small Urban Vehicle, TB4 the compact rescue crawler, TB5 FP assisted tools, and for TB6 fluid powered orthosis. These shared priorities foster significant opportunities for CCEFP researchers to communicate and integrate their research findings.

In summary, the technical barriers, as motivated by the engineered systems test beds, to accomplishing the four goals of CCEFP are:

1. Inefficient throttling control approach
2. Lack of energy management
3. Inefficient components
4. Lack of compact power supplies
5. Lack of compact energy storages
6. Lack of compact integration and distribution
7. Inability to achieve high pressure operation
8. Lack of effective human/machine interfaces
9. Noise and vibration
10. Leakage

Of these, barrier #7: “Inability to achieve high pressure operation,” was identified during the Center’s first year as being important for achieving compact components and systems. Since power is the product of flow and pressure, if pressure can be increased without changing geometry, the power density of the component will proportionately increase. Similarly, the energy stored in an accumulator increases with the peak allowed pressure. New projects on sealing, drag reduction, and high speed valves under high pressure were added as a result.

The barriers above can be naturally placed into groups related to: efficiency (1-3), compactness (4-7), and effectiveness (8-10). These form our thrust structure so that projects that mainly tackled these barriers belong to the particular thrust. One exception is that projects related to barriers “Inability to achieve high pressure operation” are extensions of existing efficiency (on/off valves and fluid) and effectiveness (sealing) projects. They are distributed in those thrusts instead.

Multiple project teams from multiple universities and disciplines collaborate closely in tackling the key barriers list above. For example, the barrier of “Inefficient components” is tackled from the perspective of tribological gaps (Project 1B, Purdue), surface texturing (Project 1D, Illinois), and fluid additives (Project 1G, MSOE). The importance of fluid properties to overall system efficiency under specific operating conditions was identified through interaction with CCEFP’s industry members. The addition of Project 1G is a consequence of this recognition. Similarly, the barrier of “Lack of effective human machine interface” is tackled by multiple projects: Multimodal Human Machine Interface (Project 3A.1), Passive control of chemofluidic actuators (Project 3A.2), and Human performance modeling (Project 3A.3). The three projects emphasize information display, controller safety, and human factors, respectively.

The major barriers to each of the four goals and the test beds (TB) that drive the research to remove these barriers are summarized below.

Center Test Bed	Thrust: Efficiency	Compactness	Effectiveness
Excavator	Meterless systems, more efficient pumps and motors, power management, energy regeneration	High pressure operation	Leak-free and quiet systems, productivity enhancing and intuitive user interfaces
sUV	Powertrain management, energy regeneration, more efficient pumps and motors	New compact energy storage concepts	Leak-free and quiet systems
Compact Rescue Robot		Compact power source	Remote user interfaces with haptic feedback
Human Orthosis		Compact fluid power components	Safe and passive user interface
Powerful Hand Tools		Compact power source	Safe and passive user interface

Major research barriers

The fundamental research program currently underway to overcome these major barriers is listed below.

Major barrier	Fundamental knowledge
Meterless systems	On/off control strategies
More efficient pumps and motors	Multi-mode model development of an axial piston pump
Power management	
Energy regeneration	
New compact energy storage concepts	Heat transfer in air motor/compressor
Compact power source	Optimized energy conversion from fuel to fluid power
Compact fluid power components	Fluid properties at high pressures
Leak-free and quiet systems	Cavitation model development, seal model development
Productivity enhancing and intuitive user interfaces	
Remote user interfaces with haptic feedback	
Safe and passive user interface	Passive control algorithms for compressible fluids -w- heat transfer

From Table 2, it is seen that research funding is roughly evenly distributed among the three thrusts and test beds. Table 2a, 2b and Figure 2c depicts the disciplinary distribution of the Center's faculty. Although a large proportion are housed in mechanical engineering departments, they represent a diverse number of disciplines. Many projects within the center involve multiple disciplines. For example, the development of rotary on/off valve in Project 1E.1 involves collaboration between faculty with system dynamics and control, fluid power and machine design expertise. Students working on this project consult regularly with fluid mechanics and electro-magnetics faculty. Similarly, Project 2C (Open accumulator approach to compact energy storage) involve faculty with expertise in fluid power, control, heat transfer and fluid mechanics.

Table 2: Research Program Organization and Effort

Cluster/Thrust: Compactness	Cluster/Thrust Leader: Andrew Alleyne					
Personnel: 8 Faculty Members, 9 Undergraduates, 11 Graduate Students, 1 Post Doc, 0 Other Personnel						
Project	**Leader**	**Investigators (name, department, university)**	**Disciplines Involved**	**Number of Students and Post Docs**	**Current-Year Budget**	**Proposed Budget**
Center-controlled Projects						
2A: Chemofluidic Hydraulic Actuators	Michael Goldfarb	Michael Goldfarb Mechanical Engineering Vanderbilt University	Mechanical engineering	U=1 G=2 P=0	$76,843	$84,047
2B: Free-Piston Engine Compressor	Eric Barth	Eric Barth Mechanical Engineering Vanderbilt University	Mechanical engineering	U=2 G=3 P=0	$86,129	$94,203
2C: Compact Energy Storage	Perry Li	Jane Davidson Mechanical Engineering University of Minnesota Kim Stelson Mechanical Engineering University of Minnesota Perry Li Mechanical Engineering University of Minnesota Terry Simon Mechanical Engineering University of Minnesota	Mechanical engineering	U=0 G=2 P=1	$99,738	$109,089
2D: High Pressure, Light Weight Components Using Engineered Materials	Vito Gervasi	Doug Cook Applied Technology Center Milwaukee School of Engineering Vito Gervasi Applied Technology Center Milwaukee School of Engineering	Mechanical engineering	U=5 G=4 P=0	$72,965	$79,805
2E: Component Integration for Compact Fluid Power Systems	Chris Paredis	Andrew Alleyne Mechanical Engineering University of Illinois at Urbana-Champaign Chris Paredis Mechanical Engineering Georgia Institute of Technology	Mechanical engineering	U=4 G=1 P=0	$58,185	$63,641

2F: Dynamically Scalable Fluid Power Systems	Andrew Alleyne	Andrew Alleyne Mechanical Engineering University of Illinois at Urbana-Champaign Chris Paredis Mechanical Engineering Georgia Institute of Technology	Mechanical engineering	U=0 G=1 P=0	$46,302	$50,643
				Subtotal	**$440,162**	**$481,428**
Sponsored Projects - None						
Associated Projects						
Anthropomorphic Transhumeral Prosthesis for Revolutionizing Prosthetics	Michael Goldfarb	Michael Goldfarb Mechanical Engineering Vanderbilt University	Mechanical engineering	U=0 G=2 P=0	$150,000	$0
Architectural Models for Fluid Power Systems	Chris Paredis	Chris Paredis Mechanical Engineering Georgia Institute of Technology	Mechanical engineering	U=0 G=1 P=0	$66,487	$33,984
				Subtotal	**$216,487**	**$33,984**
Grand Total for Compactness					**$656,649**	**$515,412**
Cluster/Thrust: Effectiveness		**Cluster/Thrust Leader: Wayne Book**				
Personnel: 13 Faculty Members, 9 Undergraduates, 13 Graduate Students, 1 Post Doc, 0 Other Personnel						
Project	**Leader**	**Investigators (name, department, university)**	**Disciplines Involved**	**Number of Students and Post Docs**	**Current-Year Budget**	**Proposed Budget**
Center-controlled Projects						
3A1: Multimodal Human Machine Interfaces	Wayne Book	Daniel Mountjoy Industrial and Systems Engineering North Carolina Agricultural and Technical State University Eui Park Industrial and Systems Engineering North Carolina Agricultural and Technical State University Perry Li Mechanical Engineering University of Minnesota Silvanus Udoka Industrial and Systems Engineering North Carolina Agricultural and Technical State University Wayne Book Mechanical Engineering Georgia Institute of Technology Xiaochun Jiang Industrial and Systems Engineering North Carolina Agricultural and Technical State Univers	Industrial engineering, Mechanical engineering	U=3 G=3 P=0	$168,754	$184,575
3A2: Human/Machine Interfaces - Passified Chemofluidic Control	Perry Li	Perry Li Mechanical Engineering University of Minnesota	Mechanical engineering	U=0 G=1 P=0	$40,802	$44,627

3A3: Human Performance Modeling and User Centered Design	Xiaochun Jiang	Daniel Mountjoy Industrial and Systems Engineering North Carolina Agricultural and Technical State University Eui Park Industrial and Systems Engineering North Carolina Agricultural and Technical State University Silvanus Udoka Industrial and Systems Engineering North Carolina Agricultural and Technical State University Xiaochun Jiang Industrial and Systems Engineering North Carolina Agricultural and Technical State Univers	Industrial engineering	U=3 G=3 P=0	$93,607	$102,384
3B1: Noise and Vibration Reduction in Fluid Power Systems	Ken Cunafare	Ken Cunafare Mechanical Engineering Georgia Institute of Technology	Mechanical engineering	U=1 G=1 P=0	$80,549	$88,100
3B2: Active Control of Hydraulic Pump	Luc Mongeau	Luc Mongeau Mechanical Engineering McGill University Monika Ivantysnova Agricultural and Biological Engineering Purdue	Agricultural engineering, Mechanical engineering	U=0 G=1 P=0	$54,759	$59,893
3C: CFD Simulations of Cavitation Flows	Steven Frankel	Monika Ivantysnova Agricultural and Biological Engineering Purdue Steven Frankel Mechanical Engieering Purdue University Steven Werely Mechanical Engineering Purdue University	Agricultural engineering, Mechanical engineering	U=0 G=3 P=0	$74,820	$81,834
3D: Leakage Reduction in Fluid Power Systems	Richard Salant	Richard Salant Mechanical Engineering Georgia Institute of Technology	Mechanical engineering	U=0 G=1 P=0	$40,194	$43,752
3D1: Sealing and Liquid Property Investigations Applied to Hydraulics at High Pressure	Richard Salant	Richard Salant Mechanical Engineering Georgia Institute of Technology Scott Bair Mechanical Engineering Georgia Institute of Technology	Mechanical engineering	U=0 G=1 P=0	$40,002	$43,752
				Subtotal	**$593,487**	**$648,917**
Sponsored Projects - None						
Associated Projects						

Control Models for the INCOVA System	Wayne Book	Wayne Book Mechanical Engineering Georgia Institute of Technology	Mechanical engineering	U=0 G=1 P=0	$49,050	$0
Hardware in the Loop Simulation for Hydraulic System Development	Wayne Book	Wayne Book Mechanical Engineering Georgia Institute of Technology	Mechanical engineering	U=0 G=2 P=0	$30,000	$30,000
Hydraulic Motor Wear Particle Analysis	Paul Michael	Paul Michael Fluid Power Institute Milwaukee School of Engineering	Mechanical engineering	U=1 G=2 P=0	$20,000	$0
Integrated Position Sensors for Fluid Actuators	Wayne Book	Wayne Book Mechanical Engineering Georgia Institute of Technology	Mechanical engineering	U=0 G=0 P=1	$5,000	$5,000
The Haptic Backhoe	Wayne Book	Wayne Book Mechanical Engineering Georgia Institute of Technology	Mechanical engineering	U=0 G=2 P=0	$30,000	$30,000
				Subtotal	**$134,050**	**$65,000**
Grand Total for Effectiveness					**$727,537**	**$713,917**

Cluster/Thrust: Efficiency		**Cluster/Thrust Leader: Monika Ivantysnova**				
Personnel: 12 Faculty Members, 14 Undergraduates, 14 Graduate Students, 1 Post Doc, 0 Other Personnel						
Project	**Leader**	**Investigators (name, department, university)**	**Disciplines Involved**	**Number of Students and Post Docs**	**Current-Year Budget**	**Proposed Budget**
Center-controlled Projects						
1A1: Throttle-less Control and Regeneration for Fluid Power Systems	Kim Stelson	Andrew Alleyne Mechanical Engineering University of Illinois at Urbana-Champaign Kim Stelson Mechanical Engineering University of Minnesota	Mechanical engineering	U=0 G=2 P=0	$95,906	$104,897
1A2: Integrated Algorithms for Optimal Energy Use in Mobile Fluid Power Systems	Monika Ivantysnova	Monika Ivantysnova Agricultural and Biological Engineering Purdue	Agricultural engineering	U=1 G=2 P=0	$49,368	$53,996
1B: Study of EHD Effects for Adaptive Surface Desgn for Pumps and Motors	Monika Ivantysnova	Ashlie Martini Mechanical Engineering Purdue University Monika Ivantysnova Agricultural and Biological Engineering Purdue	Agricultural engineering, Mechanical engineering	U=0 G=4 P=0	$54,232	$59,316
1D: Drag Reduction via Biomimetic Nano-Surface Features	Eric Loth	Eric Loth Aerospace Engineering University of Illinois at Urbana-Champaign	Aerospace, aeronautical, astronautical engineering	U=0 G=1 P=0	$68,749	$75,194
1E: On/Off Valve Concepts for Throttle-Less Energy Tranformation and Control	Perry Li	Perry Li Mechanical Engineering University of Minnesota Thomas Chase Mechancial Engineering University of Minnesota	Mechanical engineering	U=1 G=3 P=1	$90,138	$98,588

1E1: High Pressure supplement	John Lumkes	John Lumkes Agricultural and Biological Engineering Purdue University	Agricultural engineering	U=0 G=1 P=0	$51,395	$56,213
1G: Optimized Engineered Fluid	Paul Michael	Matey Kalchev Physics and Chemistry Milwaukee School of Engineering Paul Michael Fluid Power Institute Milwaukee School of Engineering	Mechanical engineering, Physics	U=12 G=4 P=0	$72,621	$79,429
1G2: Carbon Nano-Tube Additives to Reduce Volumetric and Pressure Losses	Eric Loth	Eric Loth Aerospace Engineering University of Illinois at Urbana-Champaign	Aerospace, aeronautical, astronautical engineering	U=0 G=1 P=0	$41,175	$45,036
				Subtotal	**$523,584**	**$572,669**
Sponsored Projects - None						
Associated Projects						
Efficiency of Pumps and Motors	Monika Ivantysnova	Monika Ivantysnova Agricultural and Biological Engineering Purdue	Agricultural engineering	U=0 G=2 P=0	$276,124	$0
Improvements of Pumps and Motors	Monika Ivantysnova	Monika Ivantysnova Agricultural and Biological Engineering Purdue	Agricultural engineering	U=0 G=2 P=0	$163,574	$0
Software Enabled Variable Diplacement Hydraulic Pumps	Perry Li	Perry Li Mechanical Engineering University of Minnesota	Mechanical engineering	U=0 G=2 P=0	$28,831	$0
				Subtotal	**$468,529**	**$0**
Grand Total for Efficiency					**$992,113**	**$572,669**

Cluster/Thrust: Test Beds	**Cluster/Thrust Leader: N/A**					
Personnel: 11 Faculty Members, 7 Undergraduates, 9 Graduate Students, 1 Post Doc, 0 Other Personnel						
Project	**Leader**	**Investigators (name, department, university)**	**Disciplines Involved**	**Number of Students and Post Docs**	**Current-Year Budget**	**Proposed Budget**
Center-controlled Projects						
Test Bed 1: Excavator	Monika Ivantysnova	Monika Ivantysnova Agricultural and Biological Engineering Purdue	Agricultural engineering	U=1 G=1 P=0	$50,989	$55,769
Test Bed 3: Small Urban Vehicle	Perry Li	David Kittleson Mechanical Engineering University of Minnesota Kim Stelson Mechanical Engineering University of Minnesota Perry Li Mechanical Engineering University of Minnesota Zongxuan Sun Mechanical Engineering University of Minnesota	Mechanical engineering	U=1 G=2 P=1	$96,805	$105,880

Test Bed 4: Rescue Robot	Wayne Book	Michael Goldfarb Mechanical Engineering Vanderbilt University Wayne Book Mechanical Engineering Georgia Institute of Technology	Mechanical engineering	U=1 G=2 P=0	$143,430	$156,877
Test Bed 5: Hand Tools	William Durfee	William Durfee Mechanical Engineering University of Minnesota	Mechanical engineering	U=0 G=1 P=0	$53,869	$58,920
Test Bed 6: Orthosis	Elizabeth Hsaio-Wecksler	Andrew Alleyne Mechanical Engineering University of Illinois at Urbana-Champaign Elizabeth Hsaio-Wecksler Mechanical Science and Engineering University of Illinois at Urbana-Champaign Eric Loth Aerospace Engineering University of Illinois at Urbana-Champaign	Aerospace, aeronautical, astronautical engineering, Mechanical engineering	U=1 G=4 P=0	$102,076	$111,645
				Subtotal	**$447,169**	**$489,091**
Sponsored Projects - None						
Associated Projects - None						
Grand Total for Test Beds					**$447,169**	**$489,091**

Table 2: Research Program Organization and Effort Totals	**Current-Year Budget**	**Proposed Budget**
Total, Center-controlled Projects	**$2,004,402**	**$2,192,105**
Total, Sponsored Projects	**$0**	**$0**
Total, Associated Projects	**$819,066**	**$98,984**
Grand Total, All Projects	**$2,823,468**	**$2,291,089**

LEGEND:
U - Number of Undergraduate Students
G - Number of Graduate Students
P - Number of Postdoctoral Fellows

Table 2a: Disciplines Involved in Research Projects

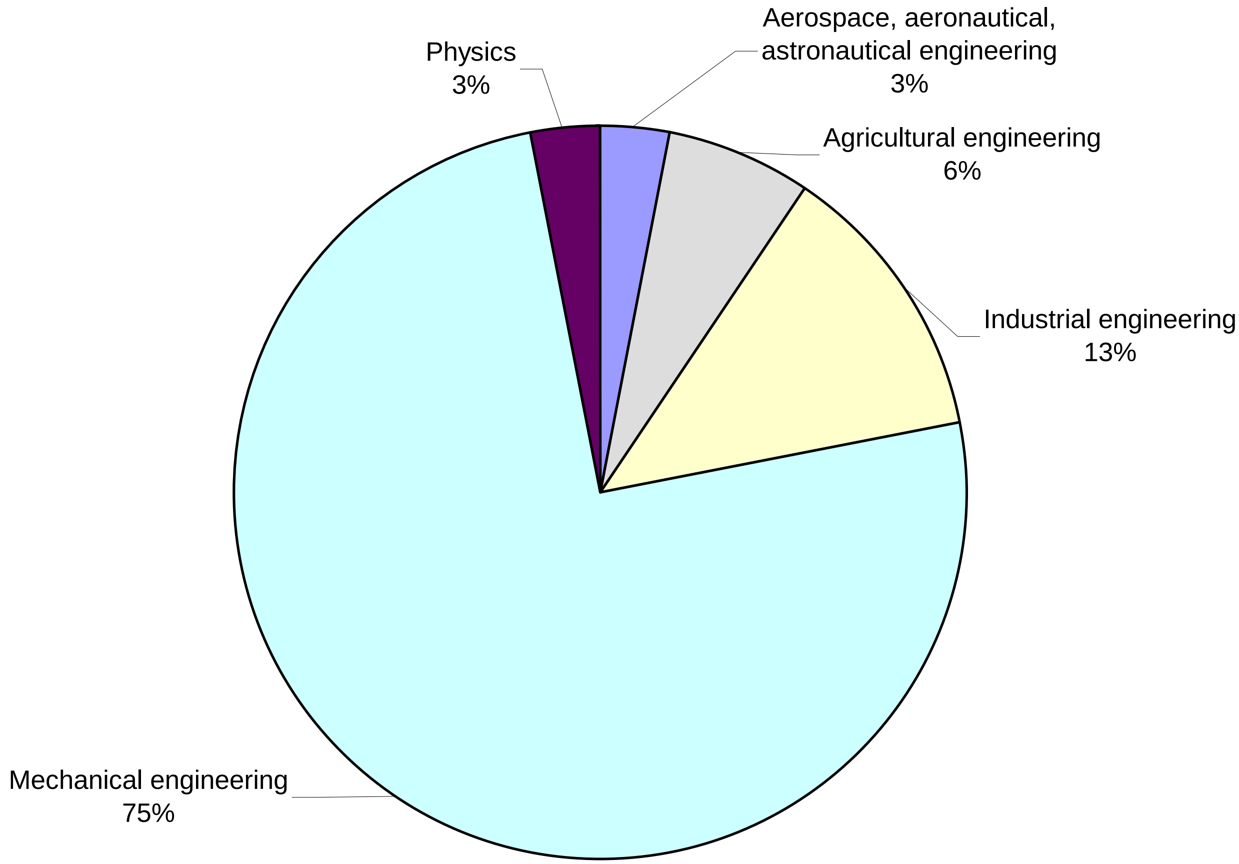
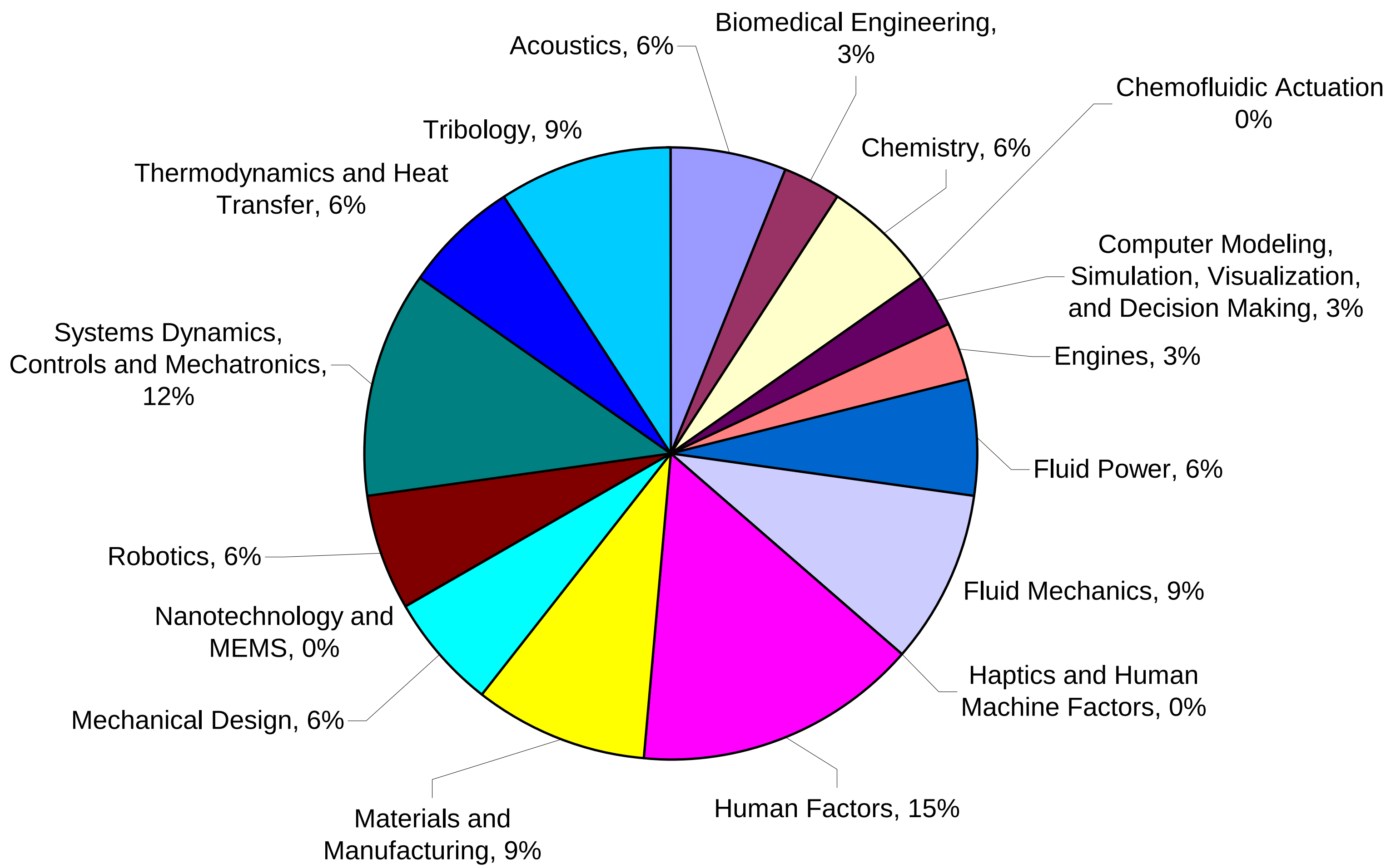


Table 2b: Facuty Breakdown of Disiplines

Disciplines of Key Faculty	Acoustics	Biomedical Engineering	Chemistry	Chemofluidic Actuation	Computer Modeling, Simulation, Visualization and Decision Making	Engines	Fluid Power	Fluid Mechanics	Haptics and Human Machine Interface	Human Factors	Materials and Manufacturing	Mechanical Design	Nanotechnology and MEMS	Robotics	Systems Dynamics, Controls and Mechatronics	Thermodynamics and Heat Transfer	Tribology
Alleyne, Andrew							S								P		
Bair, Scott							S										P
Barth, Eric				S		S	S								P		
Book, Wayne							S		S					P	S		
Chase, Tom					S		S					P					
Cook, Doug							S				P						
Cunefare, Ken	P						S										
Davidson, Jane							S	S								P	
Durfee, William		S					S		S	S		P			S		
Frankel, Steven					S		S	P									
Gervasi, Vito							S				P						
Goldfarb, Michael		S		S			S		S			S	S	P	S		
Hsiao-Wecksler, Liz		P					S					S					
Ivantysynova, Monika					S		P					S					S
Jiang, Xiaochun							S		S	P							
Khalil, Medhat							P								S		
Kittleson, David						P	S	S					S			S	
Li, Perry							S		S					S	P		
Loth, Eric							S	P					S				
Lumkes, John							P					S			S		
Maltchev, Matey			P				S						S				
Mantell, Susan							S				P	S	S				
Martini, Ashley							S										P
Michael, Paul			P				S						S				S
Mongeau, Luc	P	S			S		S	S								S	
Mountjoy, Daniel							S		S	P							
Paredis, Chris					P		S										
Park, Eui							S		S	P							
Pioro, Barbara							S		S	P							
Salant, Richard					S		S	S									P
Simon, Terry						S	S	S								P	
Stelson, Kim	S						S				S				P		
Sun, Zongxuan						S	S					S			P		
Udoka, Silvanus							S		S	P				S			
Werely, Steven							S	P					S				

P = Primary S = Secondary

Figure 2c: Primary Disciplines of CCEFP Faculty



For some barriers, multiple approaches are used to ensure success. For example, “inefficient throttling control” barrier is being attacked by developing displacement control approaches that use either conventional swash plate pumps (Project 2A.2) or new technologies using on/off valves (Project 1E). Projects 2A and 2B both address the barrier of “lack of compact power source”. Whereas Project 2A adopts the chemo-fluidic approach that achieves compactness via the simplicity of the catalytic chemical decomposition of monopropellants, project 2B adopts the approach of designing a novel free-piston engine using hydrocarbon fuel. As another example, Projects 3B.1 and 3B.2 both address the “noise and vibration” barrier. Project 3B.1 uses micro-voided materials for passive damping, and project 3B.2 reduces noise by actively controlling the structural vibration.

The project deliverables are directly targeted for integration in the test beds. For example, research in multi-modal human/machine interface (Project 3A.1, 3A.2) is focused specifically on TB1 and TB4. The passive control laws to be developed in Project 3A.2 will be integrated into TB4 and TB5 after successful bench top testing. Integration for projects in which the states of knowledge are less mature will require more time. For example, fundamental research in nano-surface texturing (1D) and nano-particle additives (1G.2) is needed to determine where and how best to apply this research. The open accumulator project (2C) requires significant fundamental research and development, and intermediate prototypes, before a prototype can be produced to be integrated into TB3. In some cases, projects are integrated to form useful subsystems to be eventually integrated into test beds. An example is that a quiet, light weight, efficient pump can be designed using the lubricating gap design software (1B), the micro-voided noise dampening silencers (3B.1), the structurally optimized housing (2D). The pump can also be integrated with the rotary on/off valve (1E) to achieve variable displacement functionality that can be integrated into the sUV test bed (TB3). Some other projects will be integrated into test beds in a supporting role. For example, hybrid fabrication technique (2D) can assist in the manufacturing of the rotary on/off valve which may be difficult to make using standard manufacturing practices.

The updated three plane CCEFP research diagram for year 2 is depicted in figure 2d. Several notable improvements to our strategy are reflected in the figure. The biggest change was the elimination of TB2 – Injection Molding Machine. This was a result of direct feedback from our industry partners that the majority of this application had migrated over to an electrical architecture and was not a good strategic fit anymore. Other proposed research projects that were eliminated due to poor strategic alignment include actively controlled surfaces, biomimetric concepts and contamination characterization. These were replaced by more strategically important projects: energy management concepts, surface texturing, optimized fluids and high pressure operation.

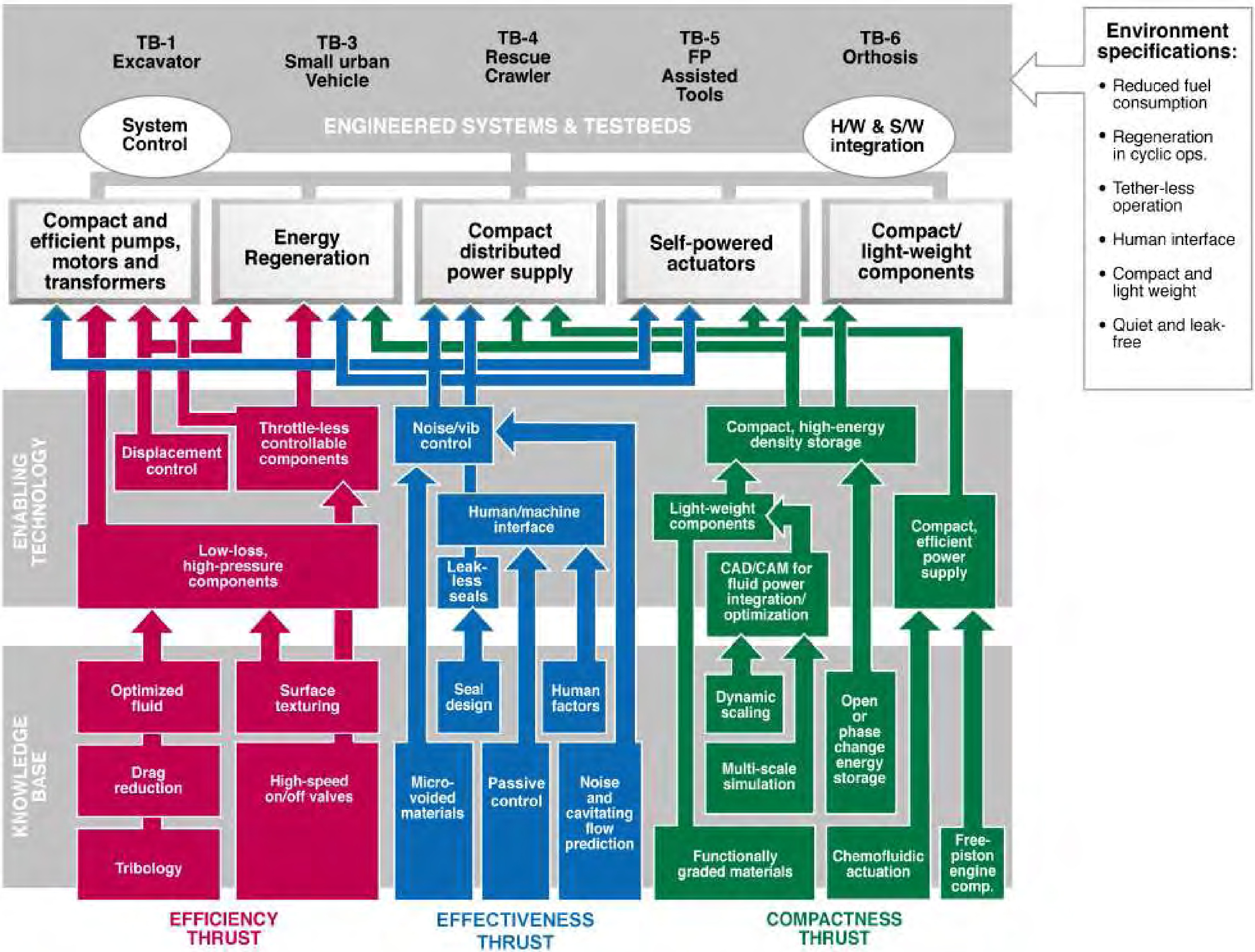
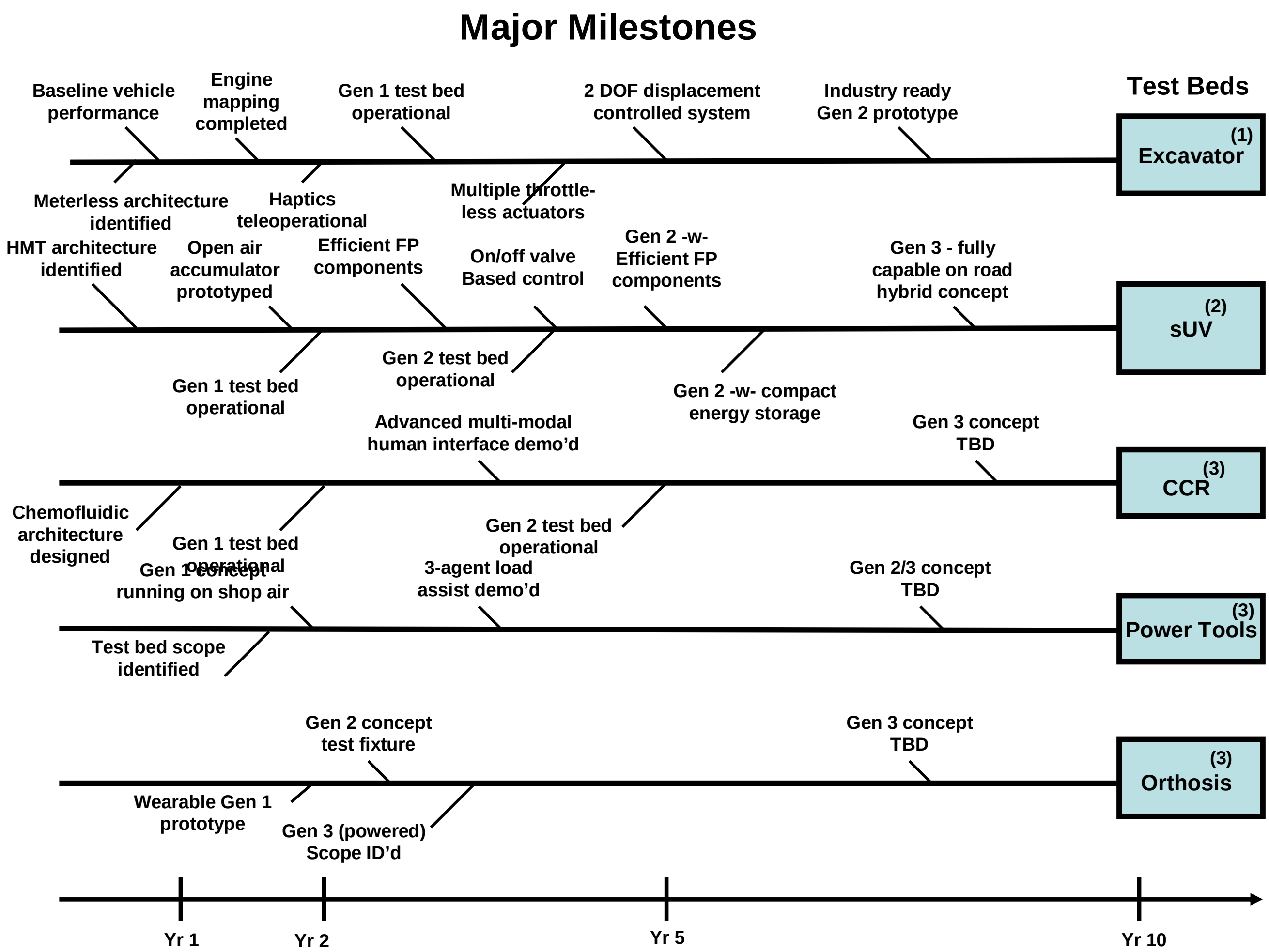


Figure 2d: Three-Plane Chart

Milestone Chart

The major milestones by test bed for the CCEFP are depicted in the figure below with more detailed descriptions in the accompanying table. As one might expect there is less clarity in years 5 to 10 but a final generation of each test bed will be developed during this timeframe that not only incorporates aspects from previous research projects throughout the Center but is much more market ready than previous versions. For example, the sUV will not be street legal in its first version but will be street legal in later versions. This logical progression allows for rapid evaluation of various fundamental concepts early in the program with the best solutions identified being integrated in the final versions. The outer year major deliverables for TB5 and TB6 are notably less defined than the other test beds because TB5 was started in year 2 and TB6 underwent a major modification to include active 'fluid power generation' instead of passive generation from the wearer's motion. This change will allow TB6 to achieve additional industry attention because of the increased market potential.



(1) Aligns with goal of improving the efficiency of existing FP systems
(2) Aligns with the goal of a passenger car FP hybrid
(3) Aligns with the goal of nontethered automous FP applications
(4) Note: All test beds align with making FP safe, quiet and leak free

Figure 2e: Milestone Chart

Excavator (TB1)	Year 2: - Modification of machine control, test and demonstration of haptic teleoperation - Implementation of displacement controlled actuator for one machine function Year 3: - Test of machine with minimum one displacement controlled actuator completed. -Fuel and performance measurement for modified machine Year 4: - Design modifications to install multiple throttle-less actuator systems completed - Sensor installation and test for power management and automatic machine control - Test of machine using engineered fluids and nano-textured hoses Year 5: - Displacement control of minimum two DOF - Displacement control using on/off valve control - Demonstration of advanced multi-modal human interface for teleoperation - Fuel and performance measurements using defined operating cycle
sUV (TB3)	Year 2: - Generation 1 vehicle drivable with power management Year 3: - Generation 1 vehicle modified with more efficient components Year 4: - On/off valve based controlled pump/motors demonstrated on Gen 1 vehicle. - Generation 2 vehicle design complete. Year 5: - Generation 2 vehicle with CCEFP developed efficient pump/motors Year 6: - Compact energy storage concepts implemented.
Compact Rescue Crawler (TB4)	Year 2: - Generation 1 prototype operational, demonstration with rudimentary controller, and user interface formulated and multiple functions operational over the Internet. - Limited sensory modalities and feedback functional with simple shared autonomy. - Evaluation and critique of initial operator interface fielded on two-legged plus wheel Prototype. Year 5: - Demonstration of advanced multi-modal human interface on generation 1 prototype. - Generation 2 prototype completed, powered by centralized hot gas vane motor (2A) and/or free piston engine (2B).
Fluid Power Hand Tools (TB5)	Year 2: - Prototype, shop powered, haptic yard tool demonstration and evaluation report. - Technical report on optimized structures that carry loads and pressure. - Single degree-of-freedom haptic pneumatic device demonstrated and technical report created. Year 3: - Planar, two-agent load assist system demonstrated. - Hardware for prototype three-agent system completed.
Fluid Power Orthosis (TB6)	Year 2: - Integrate components onto Gen 1 to achieve wearable prototype. - Determine capability of new Gen 2 design. Identify functional design components. Year 3: - Examine initial Gen 3 hardware design and enhance interaction with TB 5 (hand tools), other center projects and investigators, and industry contacts. - Identify new and existing center projects to integrate with test bed (areas include miniaturization, materials, seals, compact power sources). - Bring on post-doc to facilitate center and industrial liaisons, and design Gen 3 prototype.

Table 2f: Test Bed Milestones

Strategic Research Management

The Center's leadership team has incorporated well established business practices to facilitate the efficient and effective management and coordination of CCEFP research. (An overview of these practices is shown in figure 2g below.) The process starts with an annual review of the Center's strategic plan in order to identify successes and major obstacles in attaining the Center's research goals. From here a request for proposals for research projects that are focused on any shortcomings is sent out to the organization. In response, a standardized project template must be completed by the interested PI and returned to the center administration. To ensure that funding is being administered properly, Center staff has also created standardized budget templates along with appropriate guidelines for expenditures that all project leaders must complete. A funnel is thus developed from which the Executive Council selects which projects—new and continuing—will be funded based upon their strategic alignment and expected impact. As shown in the figure, input from industry, including the Center's Industrial Advisory Board (IAB) is included in the decision making process. After the projects have been selected, their progress is monitored through reviews held three times a year during fall, spring and summer terms. Once again, a standardized process and template is employed to maximize efficiency and ensure uniformity between projects. The projects are judged to be either on track, in need of some adjustment or in need of major adjustment. The results summary is shared with each researcher, thrust leader and industry. Whenever adjustments or corrections are needed, an appropriate action plan is developed and implemented. These management processes are described in more detail in section 5.3: Management Effort.

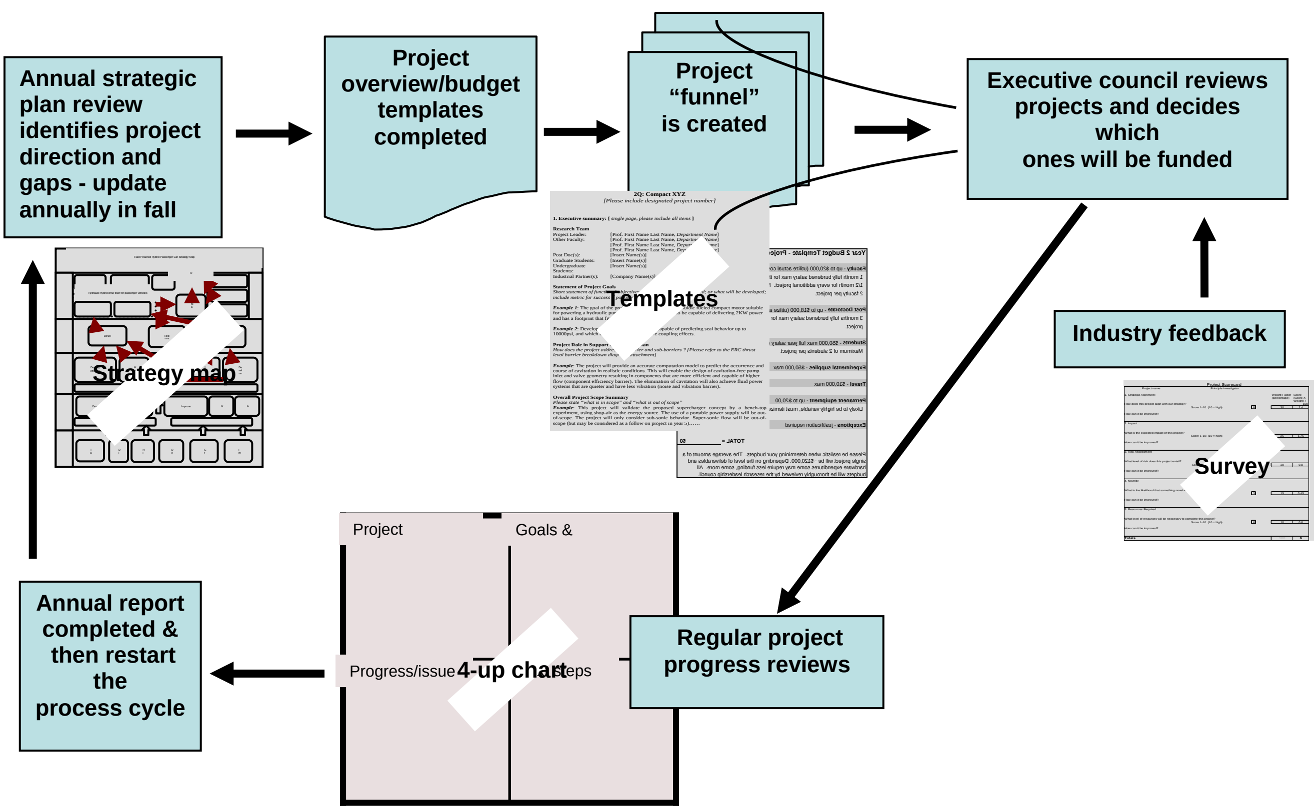


Figure 2g: Management of CCEFP Research

SWOT Analysis and Response

During the Center's initial site visit in October 2006, the Site Visit Team prepared a SWOT analysis of the Center. Now, fourteen months later, this tool continues to be a useful tool for Center leadership and its Management Committee.

The Center's responses to the identified strengths, weaknesses, opportunities and threats are summarized below.

Strengths

- *Interesting topic area that is amenable to advancing education, systems engineering, and contributing to economic competitiveness.*
- *Outstanding and enthusiastic industrial support, including financial, technical, intellectual, and moral support.*
- *Cadre of active and interested students who understand the need to communicate and collaborate.*
- *Diversity of the leadership team and commitment of partner universities to use new faculty hires to improve diversity;*
- *Commitment of NCA&T to connect the LSAMP they lead to the proposed ERC;*
- *Commitment of industrial members to provide at least 50 student internships per year;*
- *Outreach collaboration with the Science Museum of Minnesota to provide hands-on experiences;*
- *Collaboration with Project Lead The Way;*
- *Commitment of the National Fluid Power Association (NFPA) to employ their network to bring ERC innovations to market;*
- *Commitment of NFPA to fluid power education (NFPA invests one third of profits from tri-annual exposition to fluid power education)*
- *Agreement of all 53 industrial members and 7 universities on a patent/licensing policy for the proposed ERC.*

CCEFP response: We concur with the Site Visit Team's assessment of our Center's strengths and are committed to improving upon them.

Weaknesses

- ***7 institutions, each with a limited budget. This may make it difficult to establish a critical mass of activity at each institution and coordinate among them, if more funding is not raised.***

  CCEFP response: We are applying a two-fold approach in overcoming this challenge. First, each project is subject to ongoing review for its strategic alignment and impact to determine if funding should be continued. Second, the Center will seek out additional funds through new grants from other agencies and sources, and through adjacent research made possible by industry support. .

- ***Lack of design and systems engineering expertise at the subsystems and systems levels to pull research results together into devices and products.***

  CCEFP response: Many of the faculty in the Center come with an extensive design background and a strong systems focus. Supplemental product and systems design experience is being provided by our industry project champions. (In a recent example of this collaboration, a CCEFP member company not only provided recommendations for the sUV test bed's fluid power circuitry, but also installed the accumulators while completing the vehicle's plumbing at its design headquarters.)

- ***Inadequate understanding of the market to assess the likely impacts of the technologies being developed*.**

  CCEFP response: Most of our industry partners employ extensive marketing departments whose primary goal is to understand current and future market drivers. We are reaching out to leverage this expertise through both our Industrial Advisory Board and related industry surveys. As examples, a survey conducted by the National Fluid Power Association of industry's research interests was influential in developing the original CCEFP proposal to NSF. Center staff will conduct a follow-up study in late winter 2008.

- ***Failure to address safety issues*.**

  CCEFP response: Center staff assumes that this issue relates to the use of chemofluidics as the primary source of power generation for the compact rescue crawler and portable hand tools. Use of heat shielding, noise abatement, and passive control methodologies will adequately address these safety concerns. (Note that every effort is made to conduct all research within the Center according to best practices for safety.)

- ***Failure to address societal impacts, such as the impact of nanotubes in the hydraulic oil.***

  CCEFP response: Center research is conducted with a careful eye toward the societal impact of any given project. Familiarity with the Material Safety Data Sheet for the multiwalled carbon nanotubes is a case in point. According to this source, the primary hazards of CNT are eye and respiratory irritation. Prior to introduction into hydraulic fluid, the nanotubes are handled in a fume hood that incorporates a high-efficiency HEPA filter. Once the CNT are incorporated a dispersant-polymer and synthetic oil blend, the risk of exposure is mitigated.

- ***Cost, manufacturability and reliability should be considered, even in the early stages of research.***

  CCEFP response: The leading expertise within the Center for cost, manufacturability and reliability resides within our industrial membership. Regular feedback is provided from project champions and during project reviews.

- ***Some of the projects may be unrealistic and should be considered for elimination.***

  CCEFP response: Three projects and one test bed were eliminated. These were the biomimetic pump project, contaminant characterization project, active surface modification project and the injection molding test bed. Two newly implemented analysis tools, the project progress tracking review process and the SAM, are already proving to be helpful in weeding out impractical, low performing or non-strategic projects. Two or three projects will be eliminated in spring 2008 to provide sufficient funding for new initiatives.

Opportunities

- ***Involvement of aerospace and automotive industries.***

  CCEFP response: This is indeed an exceptional opportunity that must be leveraged. In the past year the Center has actively reached out to 10 major companies within these market segments. Although membership progress has been slow to realize, interest has been demonstrated by several and discussions are ongoing.

- ***Development of hybrid fluid/electric devices.***

  CCEFP response: Hybrid fluid/mechanical devices with electronic sensing and controls are being developed within the Center.

- ***Advances in systems engineering applied to the research could easily migrate into the classroom, since fluid systems are particularly well suited to systems analysis.***

  CCEFP response: Center faculty is currently writing a comprehensive textbook chapter on fluid power system dynamics, intended to replace the fluids chapter in introductory courses on system dynamics. This chapter will first be used in system dynamics course at the University of Minnesota in spring 2008 and at other CCEFP universities in fall 2008. Upon classroom validation, it will be distributed nationally.

- ***Commercialization of educational kits***

  CCEFP response: An *ad hoc* committee made up of representatives from Center universities, industry, Project Lead The Way, the Science Museum of Minnesota, NFPA and the Fluid Power Educational Foundation, studied existing and potential fluid power educational kits through a series of conference calls during the fall of 2007. After reviewing all currently available fluid power kits it was determined that "one size does not fit all needs." Therefore, the Center will continue to work with FIRST, PLTW and SMM in maximizing the usefulness of the kits, while development is underway at Purdue for a low-cost, hands-on kit that illustrates the principles of pneumatics.

Threats

- ***Lack of detail in the Strategic Implementation Plan***

  CCEFP response: Effectively addressing this critique has been a major focus of CCEFP leadership since it was received. The revised Strategic Implementation Plan provided extensive project details, but failed to clearly connect these projects to high level goals. To clearly define the connections between the projects and the high level goals, the CCEFP is using Strategic Action Mapping (SAM), discussed in section 2.

- ***Lack of awareness of competitive threats to fluid power***

  CCEFP response: This is an admittedly challenging area. There is sufficient understanding within the CCEFP of the current state of the art regarding competitive threats to fluid power (e.g., power electronics, fuel cells, etc.) Every effort is made throughout the Center, with help from industry partners, to understand the potential impact of competing technologies. However, it is admittedly difficult, perhaps impossible, to be aware of undisclosed research and/or proprietary product development that is underway. Our plan is to leverage our relationship with our partner ERC, the Center for Power Electronic Systems (CPES), to remain abreast of future innovations. Additional relationships of this sort will also be sought out.

- ***Narrow focus across many activities could miss opportunities***

  CCEFP response: There is widespread awareness throughout the Center of the potential to miss opportunities. The thrusts, with their projects and test beds, as well as the education and outreach projects, were initially selected at the outset of the Center for their potential in reaching CCEFP goals. Now, as the Center is mid-way into its second year, the project monitoring tools described in other sections of this report are proving useful in assuring that these projects are fulfilling the promise identified earlier. New projects, perhaps with different subjects, approaches and mechanisms, will be added as current projects are completed or culled out. Creation of associated research projects will expand the Center's research. And, ongoing brainstorming to identify concepts that may have been overlooked to date as well as the use of scoping studies to further delineate where the Center should apply additional focus will also mitigate this concern. This will also increase our awareness of competitive technologies.

- ***Pressures from the extensive industry support could redirect emphasis toward development and away from fundamental research***

  CCEFP response: This concern was shared throughout the Center early on. To everyone's delight the opposite has been true. In general industry has been pushing the Center to take greater risk and pursue more fundamental research.

2.2 ERC's Strategic Research Plan by Thrust

1. Efficiency thrust:

- **Inefficient throttling control approach** (Project 1A.2, 1E, 1E.1)
- **Lack of energy regeneration** (Project 1A.1, Project 1A.2)

Current fluid power systems are controlled by the use of metering valves or variable displacement pumps and motors. With metering valves, a large pressure drop across the valve reduces pressure sensitivities and increases control accuracies. This pressure drop also causes large energy losses. Variable displacement pumps and motors are used in hydrostatic transmissions where the control performance is limited by the responsiveness of the variable displacement pump or motor. Metering valves and variable displacement pumps can be combined in the load sensing strategy where the variable displacement pump is controlled so that its outlet pressure is slightly above the desired load pressure of the highest pressure circuit. Load sensing systems are more efficient than metering approaches, but with multiple circuits, significant throttling losses will still occur in the circuits with lower pressures.

Two approaches will be considered for eliminating throttling losses:
a) displacement controlled actuators;
b) on/off valve based control.

a) *Displacement controlled actuators* (Project 1A.2)
This approach utilizes one variable displacement pump (i.e., swash plate pump) to control each hydraulic actuator or motor. The pumps will be driven in tandem by the prime mover. This configuration is being developed on the excavator test bed (TB1). The configuration allows energy to be recuperated by operating the pump in a motoring mode whenever an actuator is operating under a regenerative condition. This recuperated energy reduces the load on the engine resulting in major efficiency gains. Progress realized to date includes development of a detailed simulation model for an existing excavator LS system to serve as a baseline for comparison to future systems, detailed performance mapping of the engine, instrumentation of TB1 and the validation of our vehicle model utilizing industry provided typical operating duty cycles. Previous work using this concept on a wheel-loader has demonstrated a 15% fuel savings and adequate control performance. Predicted energy savings for the excavator is 30%.

b) *On/off valve based control* (Projects 1E.1, 1E.2)
In this approach, on/off valves are used to control the fluid power systems. By varying the duty ratio of the on/off shunt valve, a fixed displacement pump or motor can achieve variable displacement. Fixed displacement pumps are cheaper and smaller than the same capacity variable displacement pump. On/off valve control is inherently more efficient than metering valve control because there are almost no losses when the valve is fully open or closed. On/off control is the basis of switched mode converters that have transformed power electronics. On/off control for fluid power is not new but requires a high speed, low loss on/off valve. The significant challenge lies in the fact for a linear valve, the power required to operate the valve increases as the third power of the PWM frequency. Currently two in-house

valve concepts are being pursued. One approach is to use a rotary valve (Project 1E.1). Since the rotary valve avoids the accelerations and decelerations needed to reverse motion direction, power is only needed to overcome friction which increases as the second power of frequency. Our latest prototype rotary valve incorporates a self spinning feature where energy from the flow is used to rotate the valve. This prototype is coupled with a 40 lpm fixed displacement pump, operates at 270 Hz PWM frequency. The duty ratio under closed loop control has a 0-100% modulation time of less than 0.1sec. An alternate concept (1E.2) uses optimized solenoids, flow force balancing, and large flow gain to achieve high speed (linear) poppet valve operation. Poppet valves have superior sealing under high pressure conditions and are insensitive to contamination. System configurations and control theory for on/off systems are also being created.

Both the displacement controlled actuator configuration and the on/off valve based configuration will have the possibility of energy regeneration, either from one actuator to another directly, or stored temporarily in accumulators. This provides the redundancy that allows for energy savings, through trajectory optimization and proper engine management. These aspects are tackled in Project 1A.1, where the focus is on engine control and management of the energy storage in hydraulic hybrid drive train (TB3); and in Project 1A.2 where the focus is on mobile multi-axis machines such as the excavator (TB1).

- **Inefficient components**. (Projects 1B, 1D, 1G.1, 1G.2)

  Current pumps and motors have a maximum efficiency of around 90%, and the theoretical overall maximum efficiency for a pump and motor combination is 81%. Such a pump-motor combination is needed in a hydraulic hybrid vehicle (such as the small Urban Vehicle test bed [TB3]). Moreover, the efficiency of pumps and motors at partial load is much less than the maximum. The drop-off in efficiency is larger for motors than for pumps since the range of motor speeds is usually wider. Because the starting efficiency of hydraulic motors is low, there is a need to over-size the motor and other components resulting in unnecessary weight and cost. It is therefore necessary to develop pumps and motors with high efficiency throughout their operating range. Losses in pumps and motors are attributable to either friction between their sliding surfaces or internal leakage. Since this involves the gaps, the surface textures and the fluid, a three prong research strategy has been adopted:

  a) *Minimize total gap losses throughout the operating range* (Project 1B). CCEFP's approach is to develop a fully coupled fluid-structure-thermal and multi-body dynamics simulation code for advanced design of new piston machines. Once verified, the model will be used to investigate novel surface design methods for the sealing and bearing gaps of axial piston machines to minimize energy dissipation and to increase the load carrying ability of lubricating gaps. This will lead to a new generation of variable piston pumps and motors that are more efficient, more compact and quieter. Initially, surface shapes and local stiffness will be considered as means for affecting the gaps. To date, the model is capable of analyzing the cylinder block-valve plate and piston-cylinder interfaces of a swash plate design axial piston pump. The model has been validated by friction force measurements of the piston-cylinder interface using a specially designed tribological test rig and for two standard industry pumps with measured effective pump flow rates and case flows for a large range of operating parameters.

b) *Determine properties of fluid additives that minimize losses in gaps* (Project 1G.1, 1G.2). Polymer additives that reduce the temperature dependence of viscosity can increase pump efficiency significantly by reducing the internal leakage flow. The role of additives on motor efficiency, especially at low speed and during starting conditions, is unknown. Project 1G.1 focuses on measuring and improving motor efficiencies using engineered fluids. Dispersant and non-dispersant polymers of varying molecular weight and shear stability will be compared for their effects on the efficiency of various motor designs. To do so a new state of the art motor test stand has been built (see nuggets). The effect of carbon nanotubes on static friction and startup efficiency, and how carbon nanotube suspensions can be stabilized is under evaluation in Project 1G.2. Tests show that a 10 ppm concentration should be effective, which ensures lowcost (important for industrial use). Several oils are being evaluated to determine high pressure (up to 20,000 psi) characteristics.

c) *Develop nano-texturing to reduce system drag losses, internal leakage and increase the load carrying ability of sealing and bearing surfaces* (Project 1D). As systems become smaller, losses in conduits become more important since friction loss is inversely proportional to the fourth power of the hose diameter. This project investigates the use of nano-texturing to reduce drag loss in hoses. Surface texturing is known to reduce drag drastically for water at atmospheric pressure (50% for flow over a surface, and 99% for single droplet). The use of texturing for fluid power applications has, however, not been attempted. Project challenges include creating cost and performance effective surfaces, high pressure, flexible hoses, and application to hydraulic fluids. It was observed that surface geometries with a mixture of micro-scale texturing and nano-scale texturing achieved the best performance. Another nano-scale aspect being tackled in Project 1D is that of surface texturing as a means for improving tribological properties of lubricated mechanical components. The benefits of surface texturing are well known. Both positive and negative micro asperities have been found to improve load bearing performance via the micro hydrodynamic bearing effect. However, negative micro asperities (dimples) have more drastically reduced leakage than positive micro asperities. For this reason, the goal is to develop nano-dimpling for improved lubricating gap performance such as in pumps and motors. As gap clearances are reduced for high pressure operation, nanoscale texturing rather than microscale is needed. The main challenge will be to create nano-surfaces that are simultaneously cost effective and performance effective and can be selectively located within fluid power systems. Another challenge will be to develop methods to predict the surface structure to optimize load carrying ability and energy dissipation in the gaps and seals. To meet these challenges, innovative nano-surface textured components such as pump pistons are being developed and investigated.

Efficiency thrust projects and personnel (Thrust leader: Monika Ivantysnova)

Throttle-less control	1A.1	Integrated algorithms for optimal energy use mobile fluid power systems	Kim Stelson, Andrew Alleyne
	1A.2	Displacement controlled actuators and Optimal Power Management	Monika Ivantysnova
	1E	On/off valve based control	Perry Li
	1E.1	Design of high pressure on/off valves	John Lumkes
Efficient components	1B	Advanced sliding surface design	Monika Ivantysnova
	1D	Nano-texturing for fluid power applications	Eric Loth
	1G	Optimized engineered fluid	Paul Michael

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2. Compactness Thrust:

- **Lack of compact power supply**. (Projects 2A, 2B) Fluid power actuators are compact, but existing power supplies are large and bulky. Portable power supplies that can operate for long periods are needed for new mobile and un-tethered human-scale applications. The actuation potential, a measure of overall compactness of a system that delivers useful work from fuel, is determined by three factors: a) the energy density of the fuel, b) the compactness and efficiency of the energy transformation process, and c) the compactness and efficiency of the actuation method. The best state-of-the-art power supply for human scale use in the 1KW range is the electric-battery/motor combination. Although efficient, the batteries suffer from low energy density and motors suffer from low power density. In mobile hydraulic machines, energy dense hydrocarbon fuel is burned in an IC engine to drive a hydraulic pump. This is an efficient and well-accepted approach for the 10’sKW to 100’s KW range. However, current 1KW range meso-scale IC engines have poor efficiency making the approach infeasible. To overcome this barrier the CCEFP is pursuing two approaches: chemo-fluidic actuation (Project 2A) and a free-piston engine-compressor (Project 2B). Development of a free-piston engine-hydraulic pump is also being considered as a follow on project. This approach is expected to be even more efficient as the heat loss associated with the air compression can be avoided.

  Chemo-fluidic actuation (Project 2A): In this approach, a monopropellant (hydrogen peroxide) fuel is oxidized using a platinum catalyst pack to deliver pressurized hot gas products. While the energy density of the monopropellant is 1 to 2 orders of magnitude lower than that of the hydrocarbon fuel, the energy transformation based on surface catalyst is remarkably compact and efficient. This gives an overall actuation potential that is an order of magnitude higher than a battery/electric motor or IC engine based system. Since chemo-fluidic actuation currently operates at 100-200psi, it will be targeted for test beds that do not require high pressures: TB5 Fluid power assisted tools, TB6 Orthosis, and the early generation of TB4 Compact rescue crawler. To enable higher pressure operation (35MPa) and in the 1KW power range, Project 2A focuses on developing a chemofluidically actuated Hot Gas Vane Motor (HGVM) that will power a hydraulic pump that will be used to power later versions of TB4. Two chemo-fluidic hot gas vane motor prototypes have been designed, fabricated, and tested. The first prototype, V1, ran on 70% peroxide and provided180 W/kg of power. For comparison, a good, brushless electric motor will provide about 160 W/kg. The second prototype, V2, was designed to be lighter, have a greater expansion ratio, have a greater torque output, and to have adjustable geometry. The V2 prototype provides 650 W/kg, and is expected to provide more power with subsequent improvements. The goal for next year is to provide 1000 W/kg.

Free-piston engine-compressor (Project 2B): Project 2B exploits the high energy density of hydrocarbon fuels and overcome the inefficiency of IC engines in the sub KW range. Chemo-fluidic actuation is compact because it is simple, but the energy density of its fuel is still 1-2 orders of magnitude lower than hydrocarbon fuels. The free piston engine compressor burns a hydrocarbon fuel (propane) to compress air into a high-pressure supply tank, providing a portable pneumatic power supply for mobile un-tethered robotic systems. Free-piston engines have fewer moving parts than crankshaft based IC engines, leading to a design that is compact and simple. The inertial load of a free-piston can be used to increase the thermal efficiency. Project 2B is the first time that this feature has been explicitly exploited in free-piston engine design. The fundamental research barrier preventing the development of a free-piston engine compressor is the lack of design tools for "dynamic engines." Dynamic engines (a non-standard term) replace the kinematic linkages with dynamic elements and controlled valves. Such a configuration could greatly increase the efficiency and compactness of small scale IC engines. Efficiency is enhanced by utilizing a combination of dynamic elements, such as inertial and spring/elastic elements, to transform fuel energy with fewer losses. Dynamic elements are typically more compact and physically "simpler" than kinematic arrangements, leading to increased compactness. To develop tools for the design of dynamic engines, a system dynamics and controls perspective has been used. A system dynamics and controls approach is not typically applied to engine design, and this research provides an opportunity to formulate a dynamic analysis and synthesis method for free-piston engines that can be tailored for certain applications, such as pumping hydraulic fluid or compressing air, while also being "shaped" to optimize the combustion cycle for efficiency, power density or other metrics. Achievements to date include the development of detailed model of a free piston engine compressor, subsequent design trade off studies, fabrication of a working prototype and initial test validation to include successful operation at 10Hz.

- **Lack of compact energy storage**. (Project 2C) Compact energy storage is one of the two main impediments to developing the hydraulic hybrid passenger vehicle. Our approach is to focus on an open accumulator design, which has been analytically shown to have a more than tenfold improvement over a conventional accumulator. In our strategic planning, CCEFP has determined that further focus is required in this area and a call for proposals is being issued to the CCEFP for additional research projects. Besides the open accumulator approach, several alternatives are under consideration: 1) Increasing the pressure of the gas accumulator; 2) Reducing the effective volume of the accumulator by designing accumulators that can be embedded in structural elements; 3) Developing phase change or reversible chemical reaction based energy storage devices; 4) hybrid hydraulic-mechanical-electric devices.

Open accumulator (Project 2C): The energy density of a conventional gas charged hydraulic accumulator is limited by the small expansion/compression ratio (about 2), and the requirement that the accumulator must contain both the volume and the weight of the expanded gas and the hydraulic fluid displaced between compression and expansion. In an open accumulator, gas is expanded and compressed between an accumulator and atmosphere, significantly increasing the compression/expansion ratio so that the stored energy increases by a factor of 6.5. Since the accumulator no longer needs to contain the expanded gas volume, its volume can be decreased by a factor of 3.3, giving a potential 20 times increase in energy density. The main challenges involved in the project are: the design of an efficient air compressor/motor capable of generating high power and pressure; and internal leakage, heat transfer, and safety concerns associated with compressing air to 35MPa. A system architecture that allows for constant pressure operation during normal operation and the accommodation for large transient loads has been developed. A unique multi-stage compressor/motor design that utilizes 'liquid pistons' to overcome sealing issues has also been developed. A two-stage prototype has been designed and is currently being assembled for initial test and evaluation. System modeling has indicated that heat transfer during compression and expansion is a key determining factor for efficiency, and that the proposed architecture allows for a gradual tradeoff between energy and power densities. Because of the importance of heat transfer, two heat transfer experts (Professors Terrance W. Simon and Jane H. Davidson) have been added.

- **<u>Lack of compact integration and distribution</u>**. (Projects 2E, 2F) Existing fluid power systems are constructed by connecting discrete components introducing redundant interfaces, hoses and enclosures. Existing systems are inefficient, bulky and heavy. Properly integrated systems can overcome these difficulties. The design of integrated systems must consider multiple objectives and utilities such as performance, cost, efficiency, compactness, safety and noise. To enable the design of compact and efficient fluid-power systems that must satisfy multiple objectives, software tools are needed to formulate and solve complex systems engineering problems where the impact of design decisions on system level trade-offs is explicit.

Component Integration for Compact Fluid Power Systems (Project 2E): The goal of the project is to reduce significantly the time and effort required to formulate and solve systems engineering problems for compact and efficient fluid-power systems. With the advent of electronic control, fluid-power systems have become increasingly integrated and multi-disciplinary and the number of potential system architectures has exploded making it much more difficult for system engineers to explore new system architectures that provide adequate tradeoffs studies. In short the barrier that needs to be overcome is one of complexity: a very large amount and variety of knowledge is necessary to properly synthesize and analyze promising system architectures but unless this knowledge is managed well, the cost of acquiring, validating and applying this knowledge will be tremendous. The research question then is: How should one represent, store, retrieve and use knowledge efficiently and effectively in support of the design of fluid power systems? The goal of project 2E is to do that by developing a knowledge repository and corresponding systems engineering methodology and software framework that reduces significantly the time and effort required to formulate and solve design problems for compact and efficient fluid power by leveraging the formal capture and reuse of knowledge. The knowledge in the repository will include both synthesis and analysis knowledge. The approach is to use the OMG SysML™ language to represent analysis models formally, including the model context and uncertainty. Within the corresponding systems engineering framework, these models can then be used and re-used to predict the performance, cost or reliability of fluid power system architectures. A second important achievement is the development of algorithms for model composition in terms of graph transformations. For example, in a schematic of a fluid-power circuit, components are port-based nodes (symbols in the circuit schematic) and the arcs correspond to the fluid lines connecting the components. By taking advantage of the relationships that have been defined in the MACMs, a graph representation of a composition of components can be transformed into a corresponding graph representation of the system-level behavioral models. This has been demonstrated for a case study for an excavator. For the implementation of the algorithms, we combine SysML models for representing the system structure and the corresponding behavior models with the VIATRA graph transformation engine.

Dynamically Scalable Fluid Power Systems (Project 2F): Properly designed fluid power dynamic systems satisfy undiscovered scaling rules. Identifying dynamic scaling rules for currently available systems of a certain class will enable a compact, non-dimensional description of the entire class to be obtained. The fundamental research barrier being addressed is that it is difficult to establish good design criteria for new components and systems. Once a system's dynamical description is properly reformulated in a dimensionless framework, distinct advantages will emerge and will provide the engineer with constraints or very good initial conditions from which to start their search for a suitable design of their particular system. Over the past year, we have begun to model individual dynamic components and determine parameters sets of the dimensional systems starting with pumps, valves and motors. Preliminary analysis of the data and determined sets of dimensionless parameters seem to indicate good scalable designs. Despite repeated requests our major challenge to date has been to gather sufficient data from our industry partners regarding their best in class valves and pumps. Without their renewed cooperation this project stands to suffer further delays.

- **<u>Lack of compact components</u>**

  In pursuit of this challenge the CCEFP is developing methods for utilizing engineered materials that are both light weight and high strength. In addition, new approaches to designing and manufacturing of individual components are underway.

Design Optimization and Hybrid Fabrication (DOHF) of High Performance Fluid Power Components (Project 2D): This project will develop a unique and complete integration of fabrication and design optimization leading to the creation of structural components that derive their light weight and high stiffness from complex small-scale internal structures. This is a unique approach to the problem of high performance light weight materials: instead of developing new materials, the project develops smarter ways to arrange existing materials to maximize their effectiveness. Rather than a solid cast component, for example, this process leads to a component with a microstructure designed to maximize the stiffness-to-weight ratio. In the past year, significant advancements in the knowledge required to successfully cast both ferrous and super nickel alloys utilizing this methodology were realized. The structural optimization approach has been applied to a commercially available axial piston pump component resulting in 33% reduction in mass.

- **<u>Difficulty in achieving high pressure operation</u>**. High pressure operation can improve both compactness (energy density and power density) and efficiency (via reduced flow). The CCEFP is developing enabling technologies for high pressure systems without sacrificing compactness or efficiency. These technologies are improved load bearing surfaces (Projects 1B, 1D), seals (Project 3D), and light weight and high strength components (Project 2D). In support of the numerous load bearing and wear challenges we expect to encounter during high pressure operation we are actively pursuing the proper project description and enlistment of services for a new PI; Prof Ashlie Martini from Purdue. A high pressure supplement request was submitted in September 2006 to address issues in high pressure operation (20,000 Psi) of a) seals, b) carbon nano-tubes in hydraulic fluids, and c) high speed on/off poppet valves. These new projects have since been integrated into their appropriate thrust.

Compactness thrust projects and personnel (Thrust leader: Andrew Alleyne)

Compact power supplies	2A	Chemo-fluidic actuation	Michael Goldfarb
	2B	Free piston engine-compressor	Eric Barth
Compact energy storage	2C	Compact energy storage – Open accumulator approach	Perry Li
Compact integration	2D	Optimization and Hybrid Fabrication	Vito Gervasi
	2E	Compact integration of FP systems	Chris Paredis
	2F	Dynamically scalable fluid power systems	Andrew Alleyne

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3. Effectiveness Thrust:

- **Lack of effective human machine interfaces** (Projects 3A.1, 3A.2, 3A.3)
  Effective human machine interface is the key to improving operational efficiency of various test beds and fluid power applications. Target test beds are TB1 (excavator) TB4 (compact rescue crawler), TB5 (assistve tools) and TB6 (orthosis). TB1 involves teleoperation with multi-modal feedback (haptics, GPS and other feedback). TB4 involves shared human and computer coordination of gait with a large number of degrees of freedom. TB5 involves direct human operation with amplification of human force. TB6 involves a wearable device that functions in parallel with the existing human functions. Three projects are currently being pursued in this area:

  Multi-modal human machine interfaces (Project 3A.1): This project, which involves close collaboration between GT and NCAT, will develop human machine interfaces for machines powered by the new compact and efficient fluid power, focusing on TB1 and TB4 initially. Multimodal command and sensory feedback to the users is an important theme. Intuitive “feel” will need to be re-engineered for the new throttle-less actuators. Further, the interface for TB4 must enable the human operator to control the high degrees of freedom intuitively. In addition to haptic feedback, a variety of feedback in the form of an augmented reality (AR) provide an immersive experience. Since the human operator plays a key role in many test beds, a human-centered design methodology must be followed.

  The functioning degrees of freedom of a Bobcat Mini Excavator, controllable via a Phantom ® haptic manipulator, have been visually modeled in Open GL. The initial versions of a trench and other surrounding features have also been completed. A Hardware in the Loop (HIL) facility incorporating two 60 hp Siemens electric servo motors under computer control has been constructed. These motors drive variable displacement pumps, one under the command of the operator while the other simulates the load encountered by the excavator. Control of these motors and pumps continues to be refined. Meanwhile at NCAT preliminary Micro Saint and Jack models for the excavator have been developed. Surveys for determine expert operator wants and needs have been developed for soliciting requirements from industry. The Compact Rescue Crawler-Operator Interface (CRC-OI) has incorporated haptic control of the front legs and the initial augmented reality displays have been implemented but the cameras are not yet on the crawler. The computers to be placed on the crawler are on order and we will soon have the operator viewing from a riding position. NCAT has developed a prototype GUI interface for the rescue robot.

Passified chemo-fluidic control for human machine interfaces (Project 3A.2): Passivity is an important property for machines that interact closely with physical environments and humans by providing a guaranteed level of stability and safety when coupled with other systems. Many of the CCEFP test beds fall into this category of machines. Passivity is particularly useful for the design of teleoperated systems (TB1, TB4), and systems that amplify human power (TB5). While passivity based control has been developed for more conventional valve controlled hydraulic (and to some extent, pneumatic) systems, there is a gap in applying this to chemo-fluidic actuated systems, which is the likely source of power for TB4 and TB5. This project will develop passive teleoperation control for TB4 and passive human power amplifier control for TB5. To date, passive control algorithms for pneumatically actuated human power amplifier have been developed and demonstrated on a bench top setup. Extension to pneumatic teleoperation, and controllers for chemofluidic actuated systems will be studied next.

Human performance modeling and user centered design (Project 3A.3): This project is developing a framework for modeling human performance in the context of interaction with the new fluid power systems. These models provide insights to physical and cognitive limits of humans when they operate these machines. This project is also developing and implementing a user-centered design (UCD) methodology for human machine interfaces to ensure that usability by the operator is taken into account from the inception, and is formally evaluated during each design phase. This is in contrast to methodology that focuses on product features only.

- **Noise and vibration** (Projects 3B.1, 3B.2) Noise and vibration represent a significant barrier for the application of fluid power systems. Treatment of this issue within the CCEFP is considered through two general project areas, with one focusing on opportunities within passive noise control while the second concerns opportunities in active noise control. Both seek to exploit novel approaches to achieve significant reductions in noise and vibration of fluid power systems.

  In the passive noise control project (Project 3B.1), opportunities exist through the application of optimally designed components using non-traditional materials, e.g., composites, functionally graded materials, and microvoided polymers. The methodologies for addressing the barriers include an incremental approach of increasing model complexity in order to develop the lowest order model that achieves an acceptable level of prediction fidelity when compared to parallel experimental efforts. A transmission loss model has been developed for an in-line silencer with a linear dissipative material. The model allows the analytical prediction of the acoustic impedance in the silencer section of flow and the corresponding axial wavenumber of the plane wave propagation mode, which are then used to predict acoustic losses due to reflections and material dissipation. Extension of the model to incorporate non-linear materials (dispersive, amplitude-dependent loss factor, etc.) is a major focus of current efforts. A hydraulic test rig was also designed and constructed for the measurement of acoustic transmission loss for two-port devices.

The active noise control project (Project 3B.2) focuses on developing active vibration damping for swash plate pumps. Opportunity exists for noise reduction through control of unbalanced forces on the swash plate itself. A model of an electro-hydraulic displacement control system was developed which accounts for the vibration effects on the swash plate due to the moment about the tilt axis and the flow of the hydraulic fluid through the valve orifice needed for actuation. The dynamics of the system were captured for any operating condition. Active control techniques were tested in simulations. A hydraulic pump test bed was built and instrumented to measure the noise and vibration response of a pump over a range of operating conditions. The effect of active swash plate control actuation on pump vibration was quantified, and the authority of the swash plate actuator on the vibration response was assessed. It was determined that the fundamental frequency noise can be affected by the servo-valve actuated piston, but cancellation of higher order harmonics will require alternate actuation approaches.

- **Cavitation**. Cavitation in pumps and valves reduces their efficiency, and cause material damage and noise. Therefore, it is important to be able to accurately predict cavitation so that it can be avoided in the new compact, efficient and quiet fluid power components and systems that the CCEFP will develop.

  Hydroacostic measurements and simulation of cavitation noise (Project 3C) is developing and applying the large eddy simulation (LES) techniques to hydraulic components, focusing on submodels for cavitation and noise. The currently used Reynolds-Averaged Navier Stokes approach cannot capture the unsteady vortical flow structures. The project also utilizes commercial CFD codes (FLUENT, using RANS initially and LES subsequently) to develop a more complete model of an axial piston pump. This will serve as a technology transfer vehicle for the new in-house developed LES code. In addition, experimental measurements are being performed for validating the simulations in simple geometries, such as the Venturi nozzle and valve plates. Significant progress has been made on both the computational and experimental fronts including capturing for the first time the inherently complex 3D vortical structure associated with cavitating internal flows. Our focus going forward will be to seek out ways to control these vortical structures as a means to control cavitation either passively through geometric changes or actively through flow modification.

- **Leakage** (Project 3D) Leakage in fluid power systems is both a major environmental concern and a source of component inefficiency, particularly as pressures are increased. The CCEFP will attack leakage via advanced modeling resulting in improved seal designs. Project 3D will focus on developing realistic models that take into consideration mixed film lubrication for both rotary and reciprocating seals, including thermal and transient effects, to predict key seal performance characteristics, especially seal leakage and friction. So far the development of the basic model, including a thermal analysis, has been completed. It has been used to analyze several types of U-cup rod seals and compared with those from an industrial injection molding application. Further experimental validation is envisioned at which point the model will be upgraded to include any enhancements identified.

Effectiveness thrust projects and personnel (Thrust leader: Wayne Book)

Human machine interfaces	3A.1	Multi-modal human machine interfaces	Wayne Book
	3A.2	Passified pneumatic and chemo-fluidic actuation	Perry Li
	3A.3	Human performance modeling and Human Centered Design	Steven Jiang
Noise and vibration	3B.1	Passive noise reduction	Ken Cunefare
	3B.2	Active noise cancellation using swash plate actuator	Luc Mongeau
Cavitation	3C	CFD modeling and noise prediction	Steven Frankel
Leakage reduction	3D	Seal modeling and design	Richard Salant

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3. EDUCATION AND PRE-COLLEGE OUTREACH

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 educate the general public; 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 calls for:

- 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;
- an entire population of undergraduates in mechanical engineering programs across the country who learn about fluid power because it is embedded in their curriculum;
- industry that capitalizes on new knowledge to lead the world in fluid power innovation;
- participants in all aspects of fluid power who reflect the gender, racial and ethnic composition of this country.

The strategy

Realizing this vision requires significant change. It also requires that the Center's Education and Outreach Program be broader and more robust than what could be achieved through local programs. Therefore it is the Center's strategy to:

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

The Center's mission, vision and strategy inform each of its Education and Outreach projects. These projects (there are 20, with emphases on minority recruiting and evaluation applying to all) are organized around six thrust areas: Public Outreach, Pre-College Education, College Education, Industry, Filling a Diverse Pipeline, and Evaluation.

Table 3c offers a snapshot of the projects by thrust area, and the target groups who will benefit from each project. Only projects that have been started are included in the table. This table also indicates the primary focus for each thrust. Some projects are specific to fluid power technology and its applications while others support STEM education with examples drawn from fluid power when appropriate. The project summaries in Volume 2 provide detailed information on these education and outreach projects. As shown in Table 3a, there have been 348 direct participants in CCEFP education programs.

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Table 3a: Education Program Participants

Participant Type	Participant Total: Early Cumulative Total	Reporting Year - 4	Reporting Year - 3	Reporting Year - 2	Jun 01, 2006 - May 31, 2007	Jun 01, 2007 - May 31, 20
Enrolled in ERC-developed Modules						
Undergraduates	0	0	0	0	0	0
Masters	0	0	0	0	0	0
Doctoral	0	0	0	0	0	0
Practitioner	0	0	0	0	0	0
Enrolled in ERC-deveoloped Courses						
Undergraduates	0	0	0	0	0	10
Masters	0	0	0	0	0	11
Doctoral	0	0	0	0	0	0
Practitioner	0	0	0	0	0	0
Enrolled in Full ERC Degree Programs*						
Undergraduates	0	0	0	0	0	6
Masters	0	0	0	0	0	15
Doctoral	0	0	0	0	0	14
Enrolled in ERC Degree Minors*						
Undergraduates	0	0	0	0	0	0
Masters	0	0	0	0	0	3
Doctoral	0	0	0	0	0	3
Enrolled in ERC Certificate Programs*						
Undergraduates	0	0	0	0	0	0
Masters	0	0	0	0	0	0
Doctoral	0	0	0	0	0	0
Practitioners Taking Courses/workshops*						
Practitioner	0	0	0	0	0	9
K-14 (Pre-college) Education						
Students	0	0	0	0	0	274
RET and Non-RET Faculty						
RET Community College	0	0	0	0	0	1
RET K-14 Teachers	0	0	0	0	0	2
Non-RET K-14 Teachers	0	0	0	0	0	0
Total	**0**	**0**	**0**	**0**	**0**	**348**

* Optional Activities

Table 3b: Curricular Impact

	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	
	Jun 01, 2006 - Aug 15, 2007	Cumulative	Jun 01, 2006 - Aug 15, 2007	Cumulative	Jun 01, 2006 - Aug 15, 2007	Cumulative	Jun 01, 2006 - Aug 15, 2007	Cumulative	Jun 01, 2006 - Aug 15, 2007	Cumulative	Jun 01, 2006 - Aug 15, 2007	Cumulative
New courses based on ERC research	1	1	0	0	0	0	0	0	1	1	0	0
Courses modified to include ERC research*	10	10	4	4	0	0	9	9	7	7	0	0
Workshops and short courses to industry	3	3	1	1	0	0	0	0	1	1	1	1
New textbooks based on ERC research	0	0	0	0	0	0	0	0	0	0	0	0

* - The cumulative totals for "Courses modified to include ERC research" may count the same course more than once. This is due to to the fact that a single course can be modified in multiple years and therefore will be included in the cumulative total multiple times.

Thrust and Project	General Public	College	Pre-College	Industry
Thrust A - Public Outreach Bringing the message of fluid power to the general public				
A.1 Interactive Exhibits	✓	✓	✓	✓
A.2 Fluid Power Youth Science Team	✓		✓	
A.3 Public Television Video	✓	✓	✓	✓
A.4 Web Site Information Repository	✓	✓	✓	✓
Thrust B – Pre-College Education Bringing fluid power education to K-12 student audiences, with a focus on middle and high school				
B.1 Project Lead The Way			✓	
B.2 FIRST Robotics Teams			✓	
B.3 Fluid Power Demonstration Curriculum			✓	✓
B.4 Research Experiences for Teachers (RET)	✓	✓	✓	
Thrust C – College Education Bringing fluid power education to undergraduate and graduate engineering student audiences.				
C.1 Research Experiences for Undergraduates - (REU)		✓		
C.2 Inserting Fluid Power Curriculum into Existing Undergraduate Engineering Courses		✓		✓
C.5 Advanced Graduate Courses		✓		✓

Thrust D – Industry				
Making connections between the CCEFP and Industry				
D.1 Intern Program		✓		✓
D.2 Resume Bank		✓		✓
D.3 Specialized Short Courses				✓
D.4 Transportable Universal Fluid Power Laboratory for Professional Training Courses		✓		✓
D.5 The Fluid Power Coloring Book		✓		✓
D.6 CCEFP Webcasts		✓		✓
Thrust E - Filling a Diverse Pipeline				
CCEFP's Emphasis on Native American Programs				
E.1 G-Camp			✓	
E.2 LEGO Camp and FIRST Robotics Team			✓	
E.5 AISES Activity Support		✓	✓	✓
E.6 Minority Recruiting: Every research and every education project at every CCEFP institution is committed to actively recruit underrepresented and minority students to participate	✓	✓	✓	✓
Thrust F - Evaluation: Providing comprehensive and rigorous evaluation of the CCEFP education and outreach projects and program.	✓	✓	✓	✓

Table 3c: CCEFP Education and Outreach Projects and Target Groups

Five examples, drawn from CCEFP Education and Outreach projects, illustrate how the Center's strategy is being implemented:

Fluid power content in Project Lead The Way (PLTW) curricula: In partnership with PLTW and the National Fluid Power Association (NFPA), both affiliated outreach institutions of the Center, the CCEFP is working to enhance and expand fluid power content in several PLTW courses that are a part its middle and high school curricula. PLTW programs are now established in all 50 states and the District of Columbia, engaging 7,000 teachers and 5,000 counselors who, in turn, work with 200,000 students. Embedding fluid power basics and applications in a number of PLTW courses leverages our pre-college education impact far beyond the impact if our engagement were restricted to teachers in individual districts. PLTW's fluid power course content is focused and enriched with the help of subject matter experts from industry (through the help of NFPA) and from the Center's faculty and staff. To further take advantage of the PLTW distribution network, the CCEFP 2008 RET program will recruit from high schools with the PLTW curriculum. Faculty from the CCEFP will participate in selected PLTW summer training institutes to bring the message of CCEFP research to PLTW teachers.

Pneumatic training for FIRST Robotics teams: FIRST team students have a natural motivation to learn because they want the robots they design to be effective. They want to find ways to best utilize the components they receive at the outset of the competition. Pneumatic components, donated by manufacturers in the fluid power industry, are included in these kits of parts. Distributing a high-quality, accessible CCEFP pneumatics workshop to FIRST teams and their mentors, designed to help them understand pneumatics and its potential for use in building their robots, has more impact than occasional workshops in local high schools. FIRST's numbers speak for themselves. In 2008 there are 1,500 FIRST Robotics teams involving 37,000 high school students. Since inception, FIRST programs have impacted 156,000 students. In a pilot program for 2008, the Center has developed a pneumatics workshop and field-tested it among several Minnesota- and Georgia-based FIRST teams. Next year, this workshop will be made available to other FIRST teams in other locations. And, in an example of leveraging successes as well as program coordination, the Center is connecting its diversity efforts to FIRST by sponsoring a rookie, all Native American, FIRST Robotics team located in Cloquet, MN.

Delivering fluid power education through the core curriculum of mechanical engineering. Consensus reached at a recent NFPA Education/Industry Summit reaffirmed what has long been widely assumed: new departments and new four-year undergraduate degrees in fluid power are not realistic goals. But, inserting fluid power into core curriculum is. The CCEFP is working to develop curriculum material to insert into controls and fluid mechanics courses, which are part of every mechanical engineering program in the world. This material is being written now, and dissemination will start in the fall of 2008 with the seven CCEFP schools. With this start as a foundation, the Center's goal is to reach all 283 ABET accredited mechanical engineering programs in the United States. Universities in other parts of the world come next.

***Transferring knowledge through industry partnerships*:** Partners from the fluid power industry have been engaged with the CCEFP since its proposal stage. As the above examples attest, industry's work with the CCEFP is central to many of its research and education programs. There are additional examples of how and why these partnerships work. The CCEFP internship program enables undergraduate engineering students to experience the fluid power industry first hand. Bi-monthly CCEFP webcasts, organized by the Center's Student Leadership Council, provide industry with a first look at CCEFP research as well as the undergraduate and graduate students who are conducting it. The industry project champion program, in which more than 90 industry volunteers are sharing their expertise with research faculty and their students, is a powerful avenue for knowledge transfer. All of this, coupled with diversity recruiting efforts for CCEFP programs, provides a pathway for the next generation of fluid power leaders.

Interactive learning models: Through its partnership with the Science Museum of Minnesota (SMM), an affiliated institution of the CCEFP, staff from the museum and Center faculty are developing interactive exhibits on fluid power and on CCEFP research that engage the public. The Hydraulic Hybrid Vehicle Exhibit, the first in the exhibit series, and already on the SMM's floor, made a trip to the Minnesota State Fair where it was seen by thousands of fair goers, and will be featured in the CCEFP's booth at the upcoming International Exposition for Power Transmission and its show partner, CONEXPO – CON/AGG. Together, these shows will host more than 100,000 attendees, primarily from the construction and aggregates markets. With CCEFP member industry financial support, SMM will be able to further disseminate its exhibits through existing science museum networks, thereby increasing the reach of the CCEFP to the general public beyond what we could do locally.

Note: Volume II includes further detail for these and all other projects. Each project's summary includes a statement of goals, the project's role in support of the strategic plan, fundamental challenges and solutions, achievements to date, other relevant work (where applicable), plans for next year, expected milestones and deliverables, member company benefits (where applicable), and project team members.

Priorities for Year Two

In year two, highest priority has been placed on projects that are likely to have the most impact. Listed by elements of the vision statement, these projects are:

- A general public aware of fluid power: interactive exhibits and the video;
- Rigorous pre-college education that is in tune with STEM initiatives: PLTW, RET program, mechanical engineering programs that include fluid power insertion into required curriculum, specialized graduate courses;
- A pipeline for future leaders in the fluid power industry: internships, webcasts, resume bank, short courses;
- Industry, student and faculty populations that reflect the diversity of our country: targeted minority recruiting, Native American outreach.

Education and Outreach review criteria for Centers in Years 1-3:

An interdisciplinary, cross-institutional culture is emerging. Most research and test-bed projects have the targeted ratio of graduate to undergraduate students of 2:1. For example, during Years 1 and 2, the orthosis Test Bed (TB6) has had 4 (Y1) and 6 (Y2) graduate and 1 (Y1 & 2) undergraduate students involved. While the project is centered in mechanical engineering at

UIUC, the project leader's main disciplinary interests are in musculoskeletal biomechanics and rehabilitation engineering. That test bed is collaborating with faculty and students at UMN who are working on an allied project on fluid power gait assist for individuals with spinal cord injury. The rescue robot test bed has a cross-disciplinary, cross-institution team of graduate and undergraduate students. Students at Vanderbilt are taking the lead in developing the mechanical and electrical design, students at Georgia Tech are creating the control structures and students at NCAT are researching human factors strategies for user interaction with the robot.

Students are being exposed to best practices in industry in several ways. In the Center's industry champions program, at least one engineer from member companies is on the advising team for every research project. Undergraduates are provided opportunities to work in industry through the intern program. The test bed projects provide significant opportunities for students to understand systems integration issues. (For example, students on the hand tool test bed are required to understand that electronic control components, including microcontrollers consume energy just like actuators and must be considered when conducting a power, energy, size and weight assessment.)

Research results already have impacted graduate and undergraduate courses within the center. For example, Purdue has started a series of graduate level courses on fluid power for a graduate specialization program with the courses incorporating latest results from CCEFP research (see the Learning Nuggets section of this report). At UMN, the undergraduate systems course now has a unit on fluid power modeling and dynamics that includes examples from CCEFP work. Undergraduate students were engaged in CCEFP related capstone projects at both UMN and Vanderbilt. Georgia Tech modified its Modeling and Control of Motion Systems course to include material on the rescue crawler test bed. As shown in Table 3b, 14 courses have been modified and two new courses started because of the CCEFP.

Increasing diversity through recruiting is in initial stages. Recruiting for the Summer 2007 REU, RET and intern programs occurred without a specific strategy toward reaching this goal. Center staff learned that the key for recruiting among a diverse population is regular, personal contact. The Center now has a defined recruiting strategy with specific recruiting events and organizations targeted and scheduled. This includes recruiting through the new North Star LSAMP headquartered at UMN. Consequently, a more diverse population will be engaged in the Center starting with the summer 2008 programs. The Center has also learned that including the Native American population is particularly challenging and requires genuine connections to the Native American community. In year two the Center hired a part-time coordinator who lives on the reservation in Cloquet, MN and has extensive experience with STEM activities. Another activity new in year two is helping to revive and coordinate the AISES chapters at engineering schools in the upper Midwest.

In 2007 there were 23, non-CCEFP REU students working on CCEFP projects for 10 weeks during the summer. From this experience, Center staff learned the challenges of coordinating an REU program at seven university sites and were not satisfied that the students felt sufficiently connected to either the CCEFP or to their fellow REU students at other sites. In addition, while the REU students were academically talented and contributed significantly to

CCEFP research, there was general dissatisfaction with the diversity of the cohort. Plans are in place to fix both these metrics for the summer 2008 REU program.

Four teachers participated in the CCEFP RET program during summer 2007. Again, it was a learning experience for the Center to determine the most effective way to maximize the teachers' experiences as well as the impact of their pre-college curriculum creation. Plans are being formulated for the summer 2008 program, which will be larger, will target PLTW teachers and will have means for teachers to connect and coordinate with each other both during the summer and during the following school year when they are implementing their curriculum. A second important part of the Center's pre-college education efforts—developing curriculum with PLTW—is on track, following the defined PLTW schedule for introducing module changes.

The Center's education and outreach programs touch all seven CCEFP sites. The Education and Outreach Network, with one member from each site, meets monthly by teleconference to discuss and coordinate education plans. And, the Student Leadership Council, with members from each of the Center's campuses, has taken on significant tasks in recruiting for CCEFP programs and in leading others (bi-monthly webcasts, information repository).

The formal assessment and evaluation of CCEFP education and outreach programs is behind, but a plan is in place to fix this recognized weakness. The team of assessment experts put in place at the start of the Center was not able to participate in significant assessment activities. A new team of assessment and evaluation experts, located in the College of Education and Human Development at the UMN, will be part of the CCEFP and will be developing formative and summative assessment methods for every education project and for the education program as a whole to measure whether the Center is proceeding towards its goal of achieving its education and outreach vision. Assessment and evaluation of these programs has been conducted in other ways, however. As examples, the Center's Education Advisory Board (EAB) provided valuable input in prioritizing possible projects named in the proposal, and has subsequently offered additional guidance on prioritization and implementation. The EAB conducts quarterly conference calls. The Center began conducting internal reviews for each project in December 2007.

The October 2006 site visit team identified weaknesses in the CCEFP education and outreach program. The following is how the Center is addressing these issues.

No integration of research outcomes into educational opportunities and no relation between technology transfer to education.

There is now the expectation that each of the Center's research projects has education milestones. Reporting on the education milestones is part of the tri-annual project reporting process. In addition, the education program now targets specific research projects and provides opportunities for all CCEFP participants to be involved in the education program. (For example, the PWM valve and the hydraulic car were two of the prototype exhibits developed in collaboration with the Science Museum of Minnesota where staff will further polish them for permanent display.)

No implementation plans and timelines, and not clear which location is taking the lead on which project.

Projects within the education and outreach program now follow the same tri-annual reporting process used by the research projects. Part of the reporting process is having specific milestones and plans for future activities. These are listed in the individual education and outreach reports in Volume 2.

Not clear why NCAT is not a core member, and diversity activities should not be a silo at GT and NCAT.

While NCAT is officially one of the Center's two outreach universities as defined by the NSF ERC program, in practice there is no difference between NCAT and the other university members of the CCEFP. Research, test-bed and education projects are conducted by NCAT, as they are at the other universities. Within the CCEFP, NCAT has no special status. Diversity recruiting is being coordinated by the CCEFP central administration, but involves all seven CCEFP sites. For example, the Student Leadership Council, representing all CCEFP universities, is involved in recruiting efforts. Note that for now, the Native American activities are limited to UMN because of the geographic proximities of tribes and several TCUs to UMN. However, successful programs will be shared with other sites through existing and emerging networks.

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4. INDUSTRIAL/PRACTITIONER COLLABORATION AND TECHNOLOGY TRANSFER

The CCEFP strategy for industrial collaboration and technology transfer is aligned with the Center's overall strategy in accomplishing its major goals. Industry enthusiasm has been demonstrated for the major goals. This is shown by the high number of industry members, currently 57, listed in the Table 4 below who have joined the Center. All tiers of the fluid power supply chain are represented by Center members ranging from third tier (o-rings, oil additives, etc.) to second tier (pumps, valves, motors, etc.) to system integrators (excavators, tractors, etc.). The vast majority of Center membership is focused on the industrial, agriculture or construction markets, with little representation from the automotive, aerospace and medical markets. Based on these membership statistics, the Center's focus in year 2 has shifted slightly to the following:

- Maintain existing memberships in the CCEFP by regular communication and engagement;
- Target specific membership gaps such as oil additive, sensors and bearing companies while being vigilant regarding unsolicited opportunities;
- Target automotive and aerospace companies for membership;
- Begin development of a strategy for engaging membership affiliated with medical devices, power tools and autonomous robots.

Communication

- The Center's website (www.ccefp.org) has become the primary vehicle for member-wide communication. Items of keen industry interest, such as the internship program, upcoming Center events, patent disclosures, etc., are regularly posted and maintained at the site, which features both a public and a members-only section. In the fall of 2007, the CCEFP website launched a major new feature—the design and implementation of a secure data base that allows for selected individuals from all industry partners to access confidential materials remotely.
- The Center publishes an electronic newsletter, *FP Monthly*, with articles and links featuring research progress, faculty and student bios, photos of Center projects and events, etc…
- The National Fluid Power Association features an article about the Center in its bi-monthly newsletter, with a circulation of approximately 2000 industry stakeholders, and its website features information about the Center with links to the CCEFP website.
- Monthly Industrial Advisory Board (IAB) meetings are another very active means for communicating between the Center and industry.
- Increasingly, interest in the Center is growing among writers and editors in the trade press.

Recruitment

The Center's industrial liaison office maintains a status log to track progress of strategically targeted companies that have been contacted. During the past year six aerospace companies (Boeing, BAE, Hamilton Sundstrand, Honeywell, HR Textron and Ideal Aerosmith) and three automotive companies (BMW, Ford and GM) have been contacted. There was interest level expressed across the board, with ongoing discussions continuing. Several oil additive companies and a major supplier of bearings were also contacted.

Membership Agreement

All members have signed the Center's standard Membership Agreement listed in Appendix I. The major elements covered include membership level (Supporter, Principal and Sustaining), escalating membership dues based on level and company sales, terms and conditions regarding patent disclosures, publications, and information concerning access to intellectual property. A tiered royalty rate depending on membership level at the time a disclosure is utilized. A secure members-only web site has been implemented to facilitate the disclosure of confidential information.

IP Portfolio

The Center is actively developing its IP portfolio. Some recent additions include:

- Two patent disclosures - Soft switching Approach for On/Off Valve Applications; Hydraulic hybrid engine control during lean NOx trap and filter regeneration.
- Three patent applications filed - Hydro-mechanical hybrid drive train; Open Accumulator Compact Energy Storage for Regenerative Fluid Power Applications; Hydraulic Actuation of a Spool Using an Actuated Pump.

Industry is currently reviewing the above to gauge interest. Going forward the IP portfolio is expected to grow dramatically as existing research projects begin to produce further results. To increase awareness Center staff have conducted center-wide basic training of what constitutes IP and the proper methods for handling it to avoid inadvertent disclosure.

The Industrial Advisory Board (IAB)

The IAB conducts regular monthly meetings to identify and address key issues facing the Center. To lay the groundwork for a permanent and lasting structure, initial focus was placed on identifying the optimum organizational structure, electing and/or choosing key leadership positions (Chairman and Vice Chairman), defining leaders' roles and responsibilities, and outlining major IAB goals for the upcoming year. Continuity is assured by a transition policy that allows for the existing Chairman's role to be assumed by the Vice Chairman, whose vacancy is subsequently filled by a board vote. The exiting chairman assumes one of the two industry representative positions on the CCEFP Executive Committee.   Other positions of leadership include the chairs of the various subcommittees that are formed to tackle major issues facing the center. Of particular note is the project champion subcommittee. Under its direction more than 90 industry employees were identified who, because they have a keen interest in a particular research project, volunteered to act as a mentor or "champion" to assist along the way. Sometimes this means providing data, expertise, or hardware, depending on the project need. Because of its relative infancy, the overall effectiveness of this initiative is unknown, but individual success stories are emerging, and there is widespread optimism that this initiative holds great promise.

The current IAB organizational structure is depicted in figure 4a.

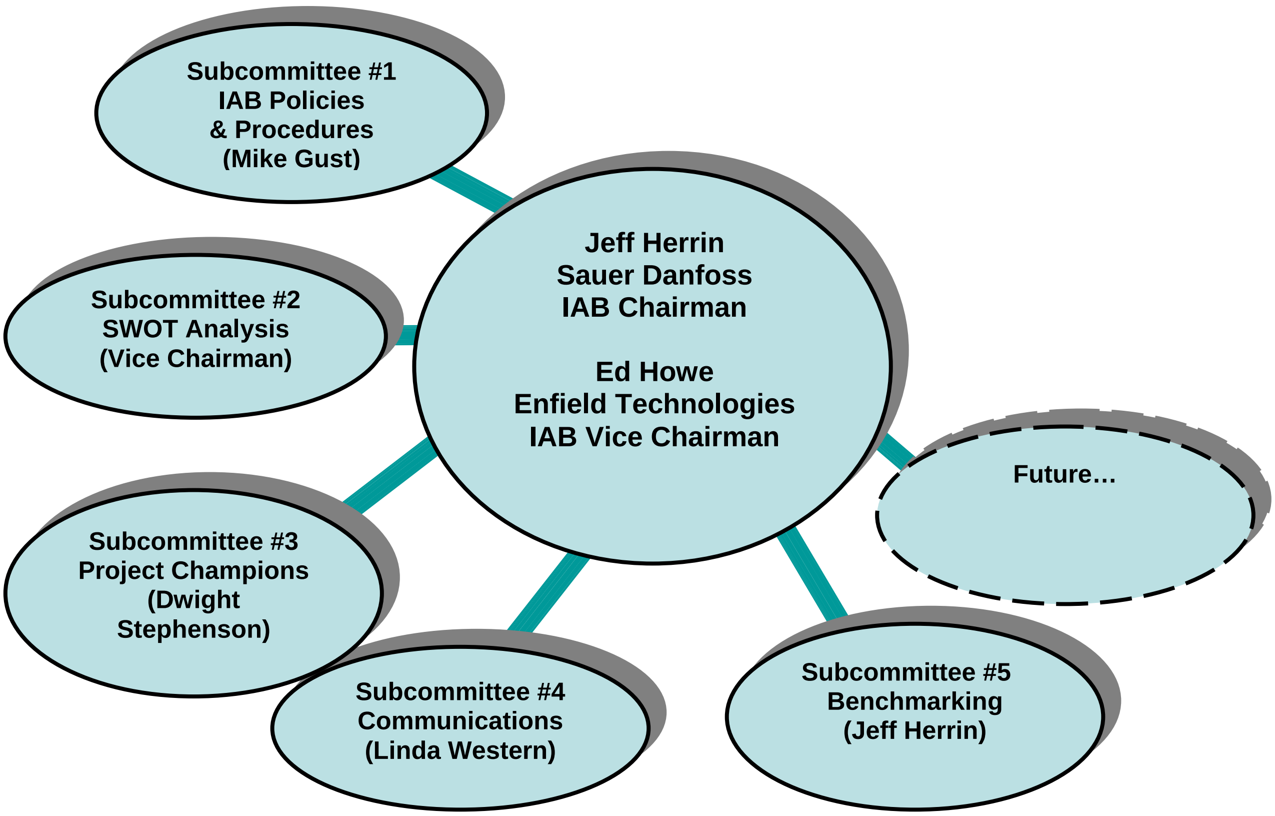


Figure 4a - IAB Organizational Chart

IAB goals for the upcoming year are currently being formulated. Appropriate metrics will be used to drive progress. While these metrics are currently being formulated, they are likely to focus on areas such as interns positions created, level of input to project direction and overall strategy, amount of associated research funded, etc.

Benefits await industry members who take an active role in the Center. Industry feedback indicates that a “pipeline for future talent” is at or near the top of this list. Another major benefit is insight into breakthrough technologies which only the Center is uniquely positioned to provide. CCEFP technologies could be commercialized in several ways. Near term developments are expected to be in the business area of CCEFP member companies, so the companies themselves would provide commercialization. Many of these technologies would be demonstrated on the excavator test bed.

Medium term developments are expected in the hydraulic hybrid vehicle market. It is unlikely that the hydraulic hybrid vehicle would be commercialized by the established automobile industry. Hydraulic hybrid vehicles are disruptive technology, meaning they would undermine established business practice. Further, the early market for these vehicles would be too small to interest automobile manufacturers. The more likely path for hydraulic hybrid vehicle commercialization would be by a vehicle manufacturer other than an auto maker. Examples are manufacturers of ATVs, snowmobiles and street and floor sweeping equipment. These companies are much smaller and do not have competing products, so the hydraulic hybrid vehicle business would be more attractive to them. These companies also use many of the same manufacturing methods of automobile companies. A parallel fluid power hybrid vehicle development path is expected for heavy trucks and buses. Heavy hydraulic hybrid vehicles are viable with off-the-shelf technology, so the market can be expected to develop faster. This growing market will encourage improvements in the technology that could migrate to the hydraulic hybrid passenger market and speed development.

Longer term developments may be in businesses far removed from current fluid power markets. Fluid power companies could move into these markets, but companies from other sectors could also be attracted. Startup companies often result from this type of new technology. Examples of areas that could produce startup companies would be compact fluid power energy sources, compact energy storage devices, service and rescue robots, fluid power hand tools, and biomedical devices. Early examples of the kinds of technologies that have been identified as having a potential to impact industry in which the Center can play a leading role are depicted in Figure 4b. Nearer term opportunities identified for early migration into industry includes new seal design concepts, CFD code for predicting cavitation, free piston engine compressors and fluid power noise silencers. Longer term technologies with high impact potential include compact fluid power based energy storage devices, new high speed/high flow valve concepts, new fluid power system control methodologies, high performance fluids with nano-particle additives, autonomous robots with fluid power based propulsion and work circuits and fluid power based transmissions for automobiles that can regenerate energy.

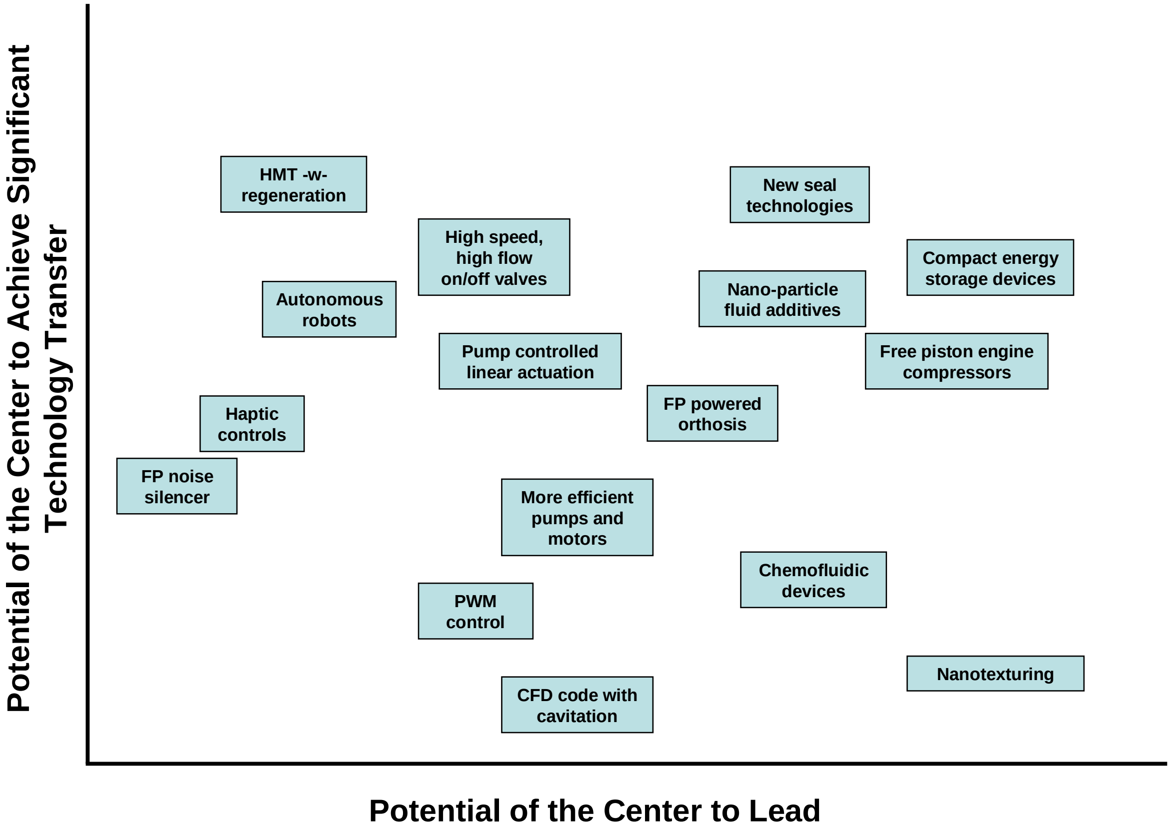


Figure 4b: Opportunities for Emerging Technologies

Figure 4b shows major commercialization opportunities for emerging technologies of the Center as a function of the potential of the Center to lead this technology and the potential of the Center to achieve technology transfer. The most promising opportunities are for those projects in the upper right hand corner of figure 4b.

Table 5 shows Industry Lifetime Full Membership History and figure 5a shows Cumulative Industry Support.

Table 4: Current Member, Affiliate, and Contributing Organizations; Sponsors of Associated Projects

Summary:
57 - Full Members
0 - Affiliate Organizations
0 - Contributing Organizations

Section 1: Full Members - 57 Full Members								
						Current Year Support		
Organization	Sector	Type of Support	Type of Involvement	Domestic/Foreign	Industry Only: Size	Received	New	# of Sponsorships added to Previous Year 1
57 Full Members								
Full Members That Have Already Provided Current Year Support								
AAA Products International	Industry	Membership cash - fees for unrestricted use	None Listed	Domestic	Small (<500 employees)	Yes	No	
Air Logic	Industry	Membership cash - fees for unrestricted use	None Listed	Domestic	Small (<500 employees)	Yes	No	
Bimba Manufacturing Company	Industry	Membership cash - fees for unrestricted use	None Listed	Domestic	Medium (500-1000 employees)	Yes	No	
Bobcat	Industry	Membership cash - fees for unrestricted use	None Listed	Domestic	Large (>1000 employees)	Yes	Yes	
Bosch Rexroth Corporation	Industry	Membership cash - fees for unrestricted use In-kind Equipment, Materials, or Supplies	Member of Center's Industrial Advisory Board Technology Transfer	Domestic	Large (>1000 employees)	Yes	No	
Caterpillar, Inc.	Industry	Membership cash - fees for unrestricted use	Member of Center's Industrial Advisory Board	Domestic	Large (>1000 employees)	Yes	No	

Command Controls Corporation	Industry	Membership cash - fees for unrestricted use	None Listed	Domestic	Small (<500 employees)	Yes	Yes	
Deere & Company	Industry	Membership cash - fees for unrestricted use	Technology Transfer	Domestic	Large (>1000 employees)	Yes	No	
Deltrol Fluid Products	Industry	Membership cash - fees for unrestricted use	Member of Center's Industrial Advisory Board Participation in Education Projects Technology Transfer	Domestic	Small (<500 employees)	Yes	No	
Donaldson Company	Industry	Membership cash - fees for unrestricted use	Technology Transfer	Domestic	Large (>1000 employees)	Yes	No	
Eaton Corporation	Industry	Membership cash - fees for unrestricted use In-kind Equipment, Materials, or Supplies	Member of Center's Industrial Advisory Board Participation in Education Projects Technology Transfer	Domestic	Large (>1000 employees)	Yes	No	
Enfield Technologies	Industry	Membership cash - fees for unrestricted use In-kind Equipment, Materials, or Supplies	Member of Center's Industrial Advisory Board Participation in Education Projects	Domestic	Small (<500 employees)	Yes	No	
Festo Corporation	Industry	Membership cash - fees for unrestricted use In-kind Equipment, Materials, or Supplies	Member of Center's Industrial Advisory Board Participation in Education Projects Technology Transfer	Foreign	Large (>1000 employees)	Yes	No	
Fluid Power Educational Foundation	Non-Profit	Membership cash - fees for unrestricted use	None Listed	Domestic	N/A	Yes	No	

G.W. Lisk Company	Industry	Membership cash - fees for unrestricted use In-kind Equipment, Materials, or Supplies	Member of Center's Industrial Advisory Board	Domestic	Medium (500-1000 employees)	Yes	No	
Gates Corporation	Industry	Membership cash - fees for unrestricted use	Member of Center's Industrial Advisory Board	Domestic	Medium (500-1000 employees)	Yes	No	
Hagglunds Drives, Inc.	Industry	Membership cash - fees for unrestricted use	None Listed	Domestic	Small (<500 employees)	Yes	No	
Haldex Hydraulics Corporation	Industry	Membership cash - fees for unrestricted use	None Listed	Domestic	Medium (500-1000 employees)	Yes	No	
Heco Gear, Inc.	Industry	Membership cash - fees for unrestricted use	None Listed	Domestic	Small (<500 employees)	Yes	No	
Hedland Flow Meters	Industry	Membership cash - fees for unrestricted use	None Listed	Domestic	Small (<500 employees)	Yes	No	
High Country Tek, Inc.	Industry	Membership cash - fees for unrestricted use	None Listed	Domestic	Small (<500 employees)	Yes	No	
Husco International, Inc.	Industry	Membership cash - fees for unrestricted use In-kind Equipment, Materials, or Supplies	Technology Transfer	Domestic	Large (>1000 employees)	Yes	No	
Hydac Corporation	Industry	Membership cash - fees for unrestricted use	Member of Center's Industrial Advisory Board	Domestic	Small (<500 employees)	Yes	No	
Hydraquip Corporation	Industry	Membership cash - fees for unrestricted use	None Listed	Domestic	Small (<500 employees)	Yes	No	

International Fluid Power Society	Industry	Membership cash - fees for unrestricted use	None Listed	Domestic	Small (<500 employees)	Yes	Yes	
Linde Hydraulics Corp.	Industry	Membership cash - fees for unrestricted use	Member of Center's Industrial Advisory Board Technology Transfer	Domestic	Small (<500 employees)	Yes	No	
Main Manufacturing Products, Inc.	Industry	Other Support	None Listed	Domestic	Small (<500 employees)	Yes	No	
Master Pneumatic-Detroit, Inc.	Industry	Membership cash - fees for unrestricted use	None Listed	Domestic	Small (<500 employees)	Yes	No	
Mead Fluid Dynamics	Industry	Membership cash - fees for unrestricted use	None Listed	Domestic	Small (<500 employees)	Yes	No	
Mico, Inc.	Industry	Membership cash - fees for unrestricted use	None Listed	Domestic	Small (<500 employees)	Yes	No	
Moog, Inc.	Industry	Membership cash - fees for unrestricted use	None Listed	Domestic	Medium (500-1000 employees)	Yes	No	
MTS Systems Corporation	Industry	Membership cash - fees for unrestricted use In-kind Equipment, Materials, or Supplies	Member of Center's Industrial Advisory Board Participation in Education Projects Technology Transfer	Domestic	Medium (500-1000 employees)	Yes	No	
National Fluid Power Association	Non-Profit	Membership cash - fees for unrestricted use In-kind Equipment, Materials, or Supplies	Member of Center's Industrial Advisory Board Participation in Education Projects Technology Transfer	Domestic	N/A	Yes	No	
National Tube Supply Company	Industry	Membership cash - fees for unrestricted use	None Listed	Domestic	Small (<500 employees)	Yes	No	

Netshape Technologies	Industry	Membership cash - fees for unrestricted use	None Listed	Domestic	Small (<500 employees)	Yes	Yes	
Nexen Group, Inc.	Industry	Membership cash - fees for unrestricted use	None Listed	Domestic	Small (<500 employees)	Yes	Yes	
Parker Hannifen Corporation	Industry	Membership cash - fees for unrestricted use In-kind Equipment, Materials, or Supplies	Member of Center's Industrial Advisory Board Technology Transfer	Domestic	Large (>1000 employees)	Yes	No	
PHD, Inc.	Industry	Membership cash - fees for unrestricted use	None Listed	Domestic	Small (<500 employees)	Yes	No	
PIAB Vacuum Products	Industry	Membership cash - fees for unrestricted use	None Listed	Domestic	Small (<500 employees)	Yes	No	
Poclain Hydraulics	Industry	Membership cash - fees for unrestricted use In-kind Equipment, Materials, or Supplies	Member of Center's Industrial Advisory Board Technology Transfer	Foreign	Medium (500-1000 employees)	Yes	No	
Quality Control Corporation	Industry	Membership cash - fees for unrestricted use	None Listed	Domestic	Small (<500 employees)	Yes	No	
R.T. Dygert International	Industry	Membership cash - fees for unrestricted use In-kind Equipment, Materials, or Supplies	Member of Center's Industrial Advisory Board Technology Transfer	Domestic	Small (<500 employees)	Yes	No	

Ralph Rivera	Other	Membership cash - fees for unrestricted use	None Listed	Domestic	N/A	Yes	No	
RB Royal Industries, Inc.	Industry	Membership cash - fees for unrestricted use	None Listed	Domestic	Small (<500 employees)	Yes	No	
RohMax USA	Industry	Membership cash - fees for unrestricted use In-kind Equipment, Materials, or Supplies	Member of Center's Industrial Advisory Board Technology Transfer	Domestic	Small (<500 employees)	Yes	No	
Ross Controls	Industry	Membership cash - fees for unrestricted use	None Listed	Domestic	Medium (500-1000 employees)	Yes	No	
Sauer-Danfoss	Industry	Membership cash - fees for unrestricted use In-kind Equipment, Materials, or Supplies	Member of Center's Industrial Advisory Board Participation in Education Projects Technology Transfer	Domestic	Large (>1000 employees)	Yes	No	
Shell Global Solutions	Industry	Membership cash - fees for unrestricted use Other Support	None Listed	Domestic	Small (<500 employees)	Yes	Yes	
Simerics	Industry	Membership cash - fees for unrestricted use	None Listed	Domestic	Small (<500 employees)	Yes	Yes	
Sun Hydraulics	Industry	Membership cash - fees for unrestricted use In-kind Equipment, Materials, or Supplies	Member of Center's Industrial Advisory Board Technology Transfer	Domestic	Medium (500-1000 employees)	Yes	No	
Sun Source	Industry	Membership cash - fees for unrestricted use	None Listed	Domestic	Large (>1000 employees)	Yes	No	

Tennant	Industry	Membership cash - fees for unrestricted use	Technology Transfer	Domestic	Large (>1000 employees)	Yes	No	
The Toro Company	Industry	Membership cash - fees for unrestricted use	Participation in Education Projects Technology Transfer	Domestic	Large (>1000 employees)	Yes	No	
Trelleborg Sealing Solutions	Industry	Membership cash - fees for unrestricted use In-kind Equipment, Materials, or Supplies	Member of Center's Industrial Advisory Board Technology Transfer	Domestic	Medium (500-1000 employees)	Yes	No	
Veljan Hydrair Private Limited	Industry	Membership cash - fees for unrestricted use	Member of Center's Industrial Advisory Board	Foreign	Small (<500 employees)	Yes	No	
Full Members That Will Provide Support by the End of the Current Reporting Year								
INA USA Corporation	Industry	Membership cash - fees for unrestricted use	None Listed	Domestic	Small (<500 employees)	No	No	
Kepner Products, Co.	Industry	Membership cash - fees for unrestricted use	None Listed	Domestic	Small (<500 employees)	No	No	

Section 2: Affiliate Organizations - No Affiliate Organizations							
Section 3: Contributing Organizations - No Contributing Organizations							
Section 4: Sponsors of Associated Projects - 7 Sponsors of Associated Projects							
						Current Year Support	
Organization	**Sector**	**Type of Involvement**	**Sponsor's Role**	**Domestic/Foreign**	**Industry Only: Size**	**Received**	**New**
Deere & Company	Industry	Technology Transfer		Domestic	Large (>1000 employees)	Yes	No
Husco International, Inc.	Industry	Technology Transfer		Domestic	Large (>1000 employees)	Yes	No
Parker Hannifen Corporation	Industry	Member of Center's Industrial Advisory Board Technology Transfer		Domestic	Large (>1000 employees)	Yes	No
Sauer-Danfoss	Industry	Member of Center's Industrial Advisory Board Participation in Education Projects Technology Transfer		Domestic	Large (>1000 employees)	Yes	No
Defense Advanced Research Projects Agency	Federal Government	None Listed	Principally Research/Technology Transfer	Domestic	N/A	Yes	No
MSOE Fluid Power Institute	Other	None Listed	Principally Research/Technology Transfer	Domestic	N/A	Yes	Yes
Sentrinsic, LLP	Industry	None Listed	Principally Research/Technology Transfer	Domestic	Small (<500 employees)	Yes	No

Section 5: Summary

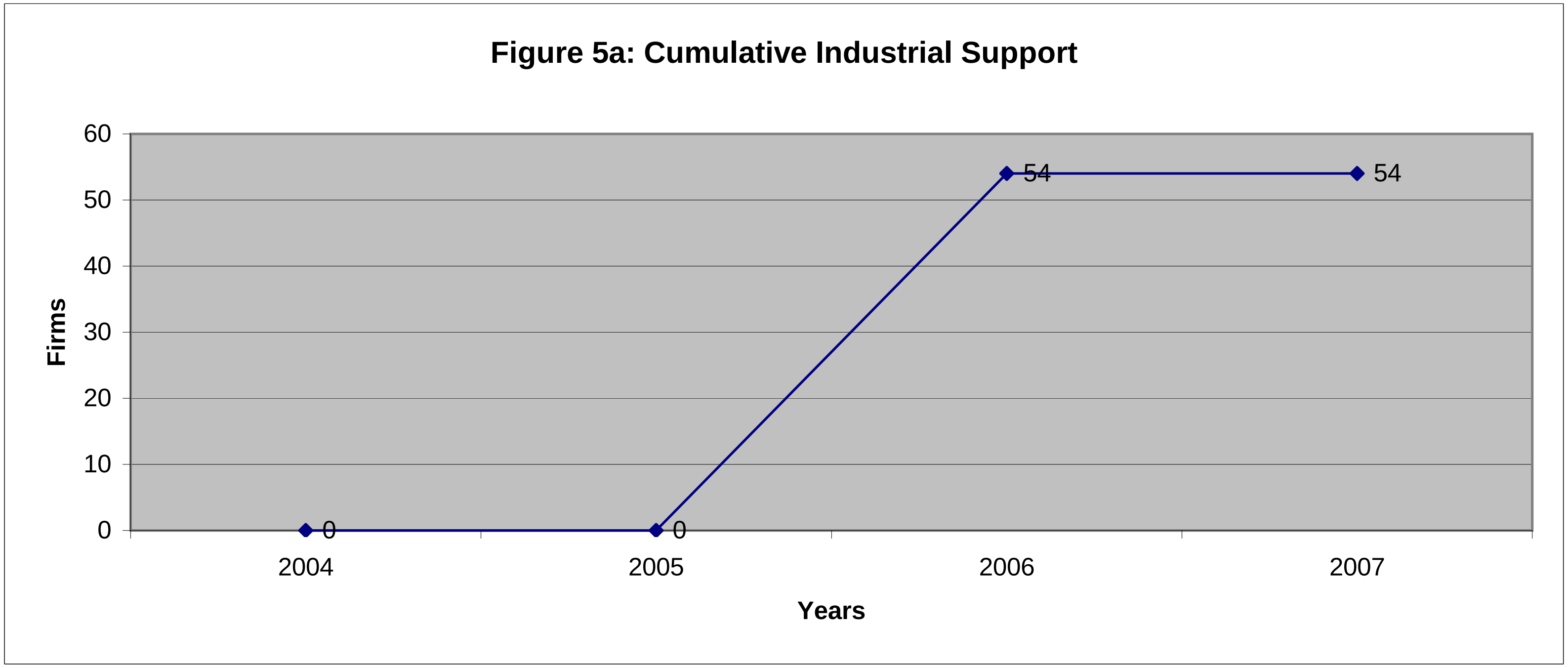
Sector	Direct Sponsorship					Indirect Sponsorship 2
	Full Memberships	**Affiliates**	**Contributing**	**Percent Foreign**	**Percent Small**	
Federal Government	0	0	0	0%	N/A	2
Industry	54	0	0	5%	57%	6
Non-Profit	2	0	0	0%	N/A	0
Other	1	0	0	0%	N/A	2
Total	**57**	**0**	**0**	**5%**	**57%**	**10**

1 - Number of companies that provided support in the previous year after submission of last year's report.

2 - Support received in the current year until deadline for production of this annual report. In FY 2006, the data time period will be the same as for direct support.

Table 5: Lifetime Full Membership History		
Organization	Award Years of Membership	Technology Transfer Activities
AAA Products International	2006,2007	None Listed
Air Logic	2006,2007	None Listed
Bimba Manufacturing Company	2006,2007	None Listed
Bobcat	2007	None Listed
Bosch Rexroth Corporation	2006,2007	Individual on Campus from Industry
Caterpillar, Inc.	2006,2007	None Listed
Command Controls Corporation	2007	None Listed
Deere & Company	2006,2007	Individual on Campus from Industry
Deltrol Fluid Products	2006,2007	Individual on Campus from Industry
Donaldson Company	2006,2007	Faculty on Site at Industry Individual on Campus from Industry
Eaton Corporation	2006,2007	Faculty on Site at Industry Individual on Campus from Industry Student on Site at Industry Test Bed
Enfield Technologies	2006,2007	None Listed
Festo Corporation	2006,2007	Individual on Campus from Industry
Fluid Power Educational Foundation	2006,2007	None Listed
G.W. Lisk Company	2006,2007	None Listed
Gates Corporation	2006,2007	None Listed
Hagglunds Drives, Inc.	2006,2007	None Listed
Haldex Hydraulics Corporation	2006,2007	None Listed
Heco Gear, Inc.	2006,2007	None Listed
Hedland Flow Meters	2006,2007	None Listed
High Country Tek, Inc.	2006,2007	None Listed
Husco International, Inc.	2006,2007	Faculty on Site at Industry Individual on Campus from Industry
Hydac Corporation	2006,2007	None Listed
Hydraquip Corporation	2006,2007	None Listed
INA USA Corporation	2006,2007	None Listed
International Fluid Power Society	2007	None Listed
Kepner Products, Co.	2006,2007	None Listed
Linde Hydraulics Corp.	2006,2007	Individual on Campus from Industry
Main Manufacturing Products, Inc.	2006,2007	None Listed
Master Pneumatic-Detroit, Inc.	2006,2007	None Listed
Mead Fluid Dynamics	2006,2007	None Listed
Mico, Inc.	2006,2007	None Listed
Moog, Inc.	2006,2007	None Listed
MTS Systems Corporation	2006,2007	Faculty on Site at Industry Individual on Campus from Industry Student on Site at Industry

Organization	Award Years of Membership	Technology Transfer Activities
National Fluid Power Association	2006,2007	Faculty on Site at Industry Individual on Campus from Industry
National Tube Supply Company	2006,2007	None Listed
Netshape Technologies	2007	None Listed
Nexen Group, Inc.	2007	None Listed
Parker Hannifen Corporation	2006,2007	Individual on Campus from Industry Test Bed
PHD, Inc.	2006,2007	None Listed
PIAB Vacuum Products	2006,2007	None Listed
Poclain Hydraulics	2006,2007	Individual on Campus from Industry
Quality Control Corporation	2006,2007	None Listed
R.T. Dygert International	2006,2007	Faculty on Site at Industry Individual on Campus from Industry
Ralph Rivera	2006,2007	None Listed
RB Royal Industries, Inc.	2006,2007	None Listed
RohMax USA	2006,2007	Individual on Campus from Industry
Ross Controls	2006,2007	None Listed
Sauer-Danfoss	2006,2007	Faculty on Site at Industry Individual on Campus from Industry Test Bed
Shell Global Solutions	2007	None Listed
Simerics	2007	None Listed
Sun Hydraulics	2006,2007	Individual on Campus from Industry
Sun Source	2006,2007	None Listed
Tennant	2006,2007	Faculty on Site at Industry Individual on Campus from Industry
The Toro Company	2006,2007	Student on Site at Industry
Trelleborg Sealing Solutions	2006,2007	Individual on Campus from Industry
Veljan Hydrair Private Limited	2006,2007	None Listed
Norgren	2006,2007	None Listed
Prince Manufacturing Corporation	2006,2007	None Listed
Schroeder Industries	2006,2007	None Listed



	Reporting Year - 3 (2004)	Reporting Year - 2 (2005)	Jun 01, 2006 - May 31, 2007 (2006)	Jun 01, 2007 - May 31, 2008 (2007)
Total Firms	**0**	**0**	**54**	**54**
Members	0	0	54	54
Affiliates	0	0	0	0
Contributing Organizations	0	0	0	0
Industry Fees	$0.00	$0.00	$110,793.00	$596,827.00
Industry Sponsored Projects	$0.00	$0.00	$0.00	$0.00
Industry Associated Projects	*	$0.00	$457,629.00	$620,235.00
Total Industry Support Inkind	$0.00	$0.00	$159,000.00	$75,000.00
Total Industry Support to Center 1	$0.00	$0.00	$110,793.00	$596,827.00

* - Associated Project support not collected in FY 2003 and 2004 but was collected starting in 2005 with a narrower definition than the one used prior to FY 2003.

1 - Excludes Associated Project Funding, as it does not go to the center.

5. INFRASTRUCTURE

5.1 CONFIGURATION AND LEADERSHIP EFFORT

The CCEFP institutional configuration is shown in Table 6. "Domestic Location of Lead, Core Partner, Outreach, and REU and RET Participating Institutions" is shown in Figure 6a. "Foreign Location of Lead, Core Partner, Outreach, and REU and RET Participating Institutions," Figure 6b, was not produced because the CCEFP has no foreign partnerships at this time.

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 and RET participating institutions is shown in Figure 6A. Note that the Center's REU students have been recruited from many minority-serving universities. The two universities in Puerto Rico have a majority of Hispanic students. Bemidji State University has a large number of American Indians. None of the REU students were recruited through NSF Diversity Program Awardees. This is not for lack of trying. Attempts were made to recruit REU students through LSAMP, AGEP and TCUP partners of the Center.

The CCEFP's Director has shown himself to be highly effective in guiding, leading and managing the CCEFP by effectively implementing key management tools in strategic planning, project selection, budgeting, progress tracking and communication. The strategic plan has gone through three iterations and now effectively identifies the Center's goals and their links to the research, education and outreach programs that are designed to reach them. Since the CCEFP's launch in June 2006, some projects have been initiated, and some projects and one test bed have been terminated to reflect the evolving strategic plan. The appropriate management structure is in place so that two or three more projects will be initiated and two or three projects will be terminated in Year 3. An effective budgeting process has been implemented where resource allocations and project efforts are closely coupled. 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. The Administrative Director has developed and uses efficient and thorough procedures for financial management, organization, communication and data gathering. The Deputy Director has a complete understanding of the CCEFP strategic plan for research and works productively with the Thrust Leaders in implementing research decisions. The Industrial Liaison extensive background in industry enhances his strong connections to the industrial supporters of the Center and his ongoing work with the Industrial Advisory Board (IAB). He is well suited to enhancing interaction between industry and universities with a newly initiated project champions program. The Education Director's position has been expanded so that we now have Education Co-Directors to handle the growing responsibilities of the position. The Education Co-Directors communicate and strategize with the Education and Outreach Director on education and outreach programs at all levels. The Education and Outreach Director has successfully engaged the Student Leadership Council (SLC), facilitating student feedback to CCEFP management and guiding 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. Central to facilitating CCEFP communication and decision-making are two internal organizations, 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 research and overall CCEFP policy. 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. Fluid mechanics, a discipline, could be in aeronautical engineering, civil engineering, chemical engineering or mechanical engineering. Conversely, mechanical engineering contains many disciplines such as controls, design, fluid mechanics, materials, manufacturing, thermodynamics, etc.

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

Institutions				Participants in ERC Activities				
				Personnel Involved in Research and Curric		REU Students by Source Institutions	K-14 Personnel	
Name and Type	Total	Female Serving	Minority Serving	Faculty	Students		Teachers	Students
I. Lead	**1**	**0**	**0**	**12**	**22**	**3**	**1**	**0**
University of Minnesota ,Minneapolis MN				12	22	3	1	0
II. Core Partners	**4**	**0**	**0**	**14**	**45**	**13**	**3**	**0**
University of Illinois at Urbana-Champaign ,Urbana IL				3	8	3	0	0
Purdue University ,West Lafayette IN				5	10	3	1	0
Georgia Institute of Technology ,Atlanta GA				4	15	2	1	0
Vanderbilt University ,Nashville TN				2	12	5	1	0
III. Collaborating (Outreach)	**3**	**0**	**1**	**9**	**30**	**5**	**1**	**0**
Milwaukee School of Engineering ,Milwaukee WI				3	17	2	0	0
North Carolina Agriculture and Technical State University ,Greensboro NC			✓	6	13	3	1	0
Science Museum of Minnesota ,Saint Paul MN				0	0	0	0	0
IV. Non-ERC Institutions Providing REU Students	**6**	**0**	**0**	**0**	**0**	**6**	**0**	**0**
University of Florida ,Gainesville FL				0	0	1	0	0
Universidad Del Turabo ,Gurabo PR				0	0	1	0	0
University of Puerto Rico ,Mayaguez PR				0	0	1	0	0
Colorado State University ,Fort Collins CO				0	0	1	0	0
Bemidji State University ,Bemidji MN				0	0	1	0	0
The Cooper Union ,New York NY				0	0	1	0	0
V. NSF Diversity Program Awardees	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Alliances for Graduate Education and the Professoriate (AGEP)	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
No AGEP Awardees were entered.								
Centers of Research Excellence in Science and Technology (CREST)	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
No CREST Awardees were entered.								
Louis Stokes Alliances for Minority Participation (LSAMP)	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
No LSAMP Awardees were entered.								
Tribal Colleges and Universities Program (TCUP)	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
No TCUP Awardees were entered.								
Other NSF Diversity Program Awardees	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
No Institutions were entered.								
VI. K-14 Institutions	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
No Institutions were entered.								
Total	**14**	**0**	**1**	**35**	**97**	**27**	**5**	**0**

Figure 6a: Domestic Location of Lead, Core Partner, Outreach, and REU and RET Participants' Institutions for the Engineering Research Center for Compact and Efficient Fluid Power

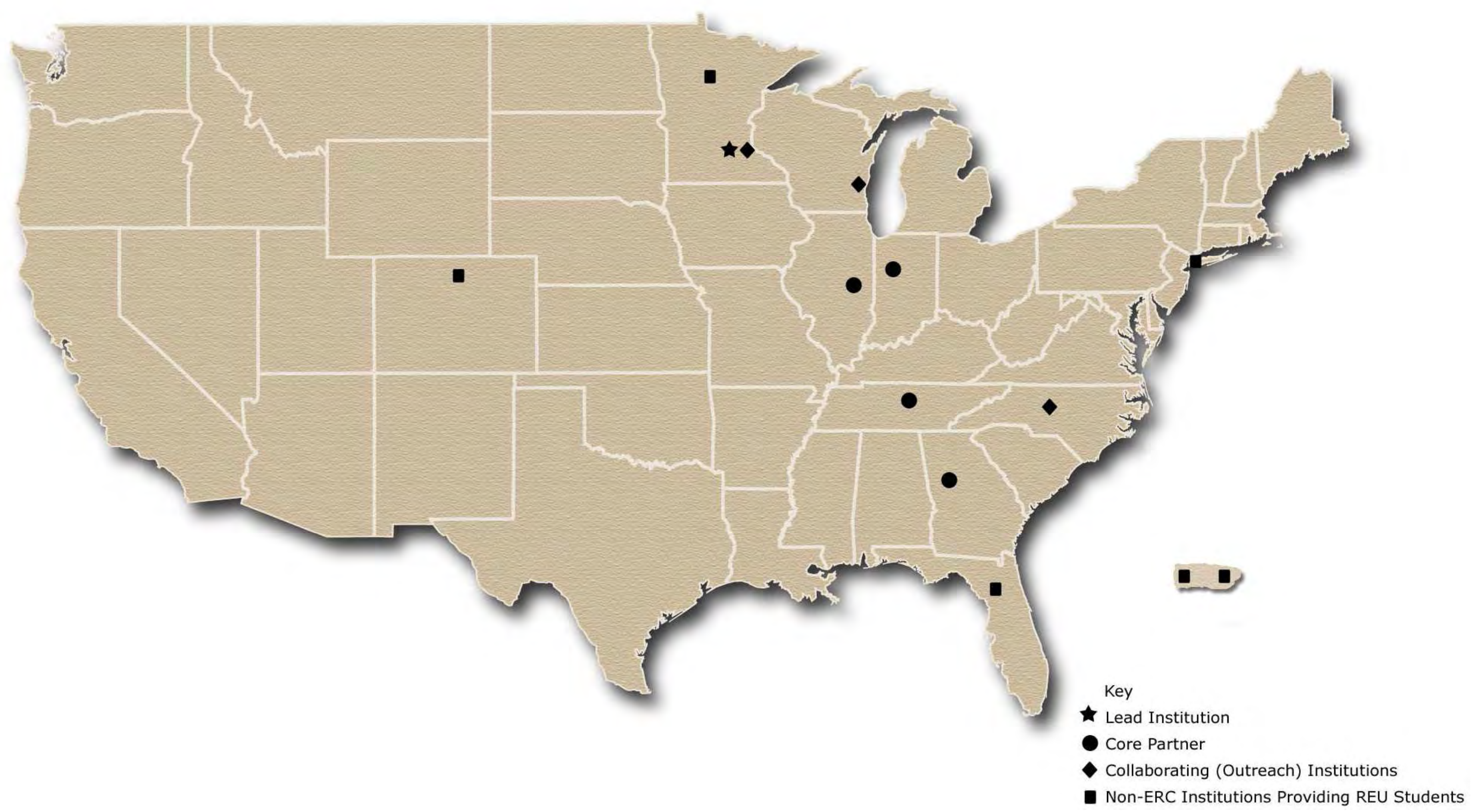


Table 2a shows the CCEFP disciplinary composition as shown by the QRC data system. It can be seen that the majority of the faculty belong to mechanical engineering, with smaller numbers belonging to aeronautical engineering, agricultural and biological engineering, chemistry and industrial engineering. To accurately show the CCEFP disciplines, an additional scheme has been developed. Table 2b shows the distribution of CCEFP disciplines among the faculty. Primary disciplines are designated by a P, and secondary disciplines are designated by an S. Only one primary discipline is designated for each researcher. All CCEFP researchers have a primary or secondary expertise in fluid power since participating in CCEFP research will develop this expertise in a short time if it is not already present. As can be seen from Table 2b, CCEFP researchers have broad expertise in the needed areas, as in appropriate for success in a multi-disciplinary systems oriented research activity. The distribution of CCEFP primary disciplines is shown in Figure 2c.

CCEFP has committed to hiring twelve new faculty members. This will greatly increased fluid power research activities at universities in the United States. These new faculty members will be carefully chosen to strengthen the research team and respond to research needs as they develop. In Year 2, two new faculty members were added to the CCEFP. Ashlie Martini has recently received her Ph.D. from Northwestern University and is an expert in tribology. She was hired by Purdue University as an Assistant Professor and will begin full-time employment at Purdue in fall 2008. Zongxuan Sun is an expert on system dynamics and controls. He received his Ph.D. from the University of Illinois at Urbana-Champaign and has been involved in automotive applications of fluid power, including hydraulic hybrid vehicles, for seven years in General Motors Research. He was hired as an Assistant Professor at the University of Minnesota and began his employment in fall 2007. Both of these faculty hires fulfill needs recognized in the Year 1 Site Visit Report. Ashlie Martini will help with the recognized need for more tribology research, and Zongxuan Sun will assist in the hydraulic hybrid passenger vehicle project and will help to recruit automotive industry members to the CCEFP.

The SLC updated its SWOT analysis in January 2008. The analysis and CCEFP leadership response are shown below.

Student Leadership Council (SLC)'s SWOT Analysis of the CCEFP, conducted January 2008

Strengths

- Diversity of Research/Multidisciplinary work
- Industry Interaction & Support
- Outreach programs
- Undergraduate opportunities
- Forum for sharing status of projects
- SLC
- Close communication between faculty and students
- Collaboration between students
- Imminent impact of research goals

CCEFP response: The SLC has done a great job of identifying key strengths within the Center. Going forward the Center must continue to nurture these strengths so that the students reach their full potential.

Weaknesses

- Isolated
    - Geographically
    - Institutionally
    - Physical Resources
- Lacking experience of physical production (student level)

CCEFP response: With seven universities located in seven different states the Center can understand why SLC students may feel somewhat isolated. Several regularly scheduled activities were specifically designed to address this issue, including annual student retreats, student representation at the annual meeting and NSF site visit, student participation at the CCEFP booth during the upcoming IFPE ConExpo, and joint research projects with students from different locations. Without exception, every time the students get together new relationships are formed that improve the effectiveness and potential of the CCEFP.

Lacking the personal experience of making physical parts and prototypes is a common problem for many graduate students. Fortunately, all Center institutions have model shops within their boundaries which are well qualified to assist in this area. External prototype procurement is another alternative the Center will utilize when the level of sophistication requires it.

Opportunities

- Synergy
- International Fluid Power presence
- Entrepreneurial opportunities
- Career Positions/Student Leadership/Networking
- Societal, environmental and economical benefits
- Cultural Diversity
- Expansion of outreach program
- Collaborative learning between institutions on related projects
- Student specialization in fluid power
- Innovative fluid power applications
- Undergraduate mentoring

CCEFP response: From potential overseas research assignments with notable foreign research centers, to internships at one of the many industry member companies, the CCEFP experience provides opportunities for students. Also with opportunities to give back to society through outreach, mentoring, diverse cultural interaction, and the real possibility of entrepreneurial enterprise, potential for student growth is limitless. The most lasting impact the Center will have on fluid power will be the educated workforce of students who contribute to fluid power long after they have graduated. It is incumbent upon the Center leadership to create an environment where the students feel both challenged and supported.

Threats

- Management of projects/resources institutionally and center-wide
- Loss of interest or Maintaining Vision (Students/Faculty/Industry)
- Spread too thin (re: Balancing research/visits/meetings/outreach programs)
- Lack of synchronization of efforts between universities on closely related projects
- Student turnover (graduating students and recruiting new students)
- Availability of and access to resources
- Disagreements on how funding should be used and how it should be divided among all schools

CCEFP response: The SLC has rightfully identified many of the same threats that the CCEFP leadership team did during early planning stages last year. Project management techniques like scoping the project, identifying major milestones and regular progress tracking updates have been deployed into all research projects. Similarly, allocating budgets based on deliverables not location has become the standard CCEFP practice. The Center also conducted "skip meetings" during visits to other partner/outreach institutions locations where the leadership team met with the students without the faculty advisor being present. One of the outcomes was to limit the number of demands on students' time with respect to meetings, visits, updates, and other activities.

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5.2 DIVERSITY EFFORT AND IMPACT

The Center has an active and diverse research and educational program among its seven academic institutions in addition to the outreach network of educational partnerships. The Center also has a strong diversity and underrepresented minority initiative.

In its first year the CCEFP has shown positive growth in the areas of women and those of ethnically diverse backgrounds. Table 7a indicates the percentage of the Center's diversity statistics in comparison to the national average within other ERCs. Line by line, the CCEFP tells a promising story.

While the numbers of female undergraduate and graduate students within the Center are shown to be less than the ERC average, they are nonetheless comparable to national statistics for women in mechanical engineering. (The American Society for Engineering Education [ASEE] reports that only 12.5% of students in mechanical engineering programs are women.) The percentage of women in the fluid power industry is probably even lower. Though there are no statistics collected by the industry to point to, there seem to be a disproportionately low number of women engaged in fluid power based on observations of how many women are in corporate leadership positions, attend fluid power conferences, and/or participate in standards development committees In contrast, it is important to note that women play key roles in the Center's leadership and faculty—a positive message. The Center recognizes its potential to expand on this message by making an increasingly positive impact among women (through recruitment and through opportunities within the Center) as they consider study and career choices in mechanical engineering and fluid power.

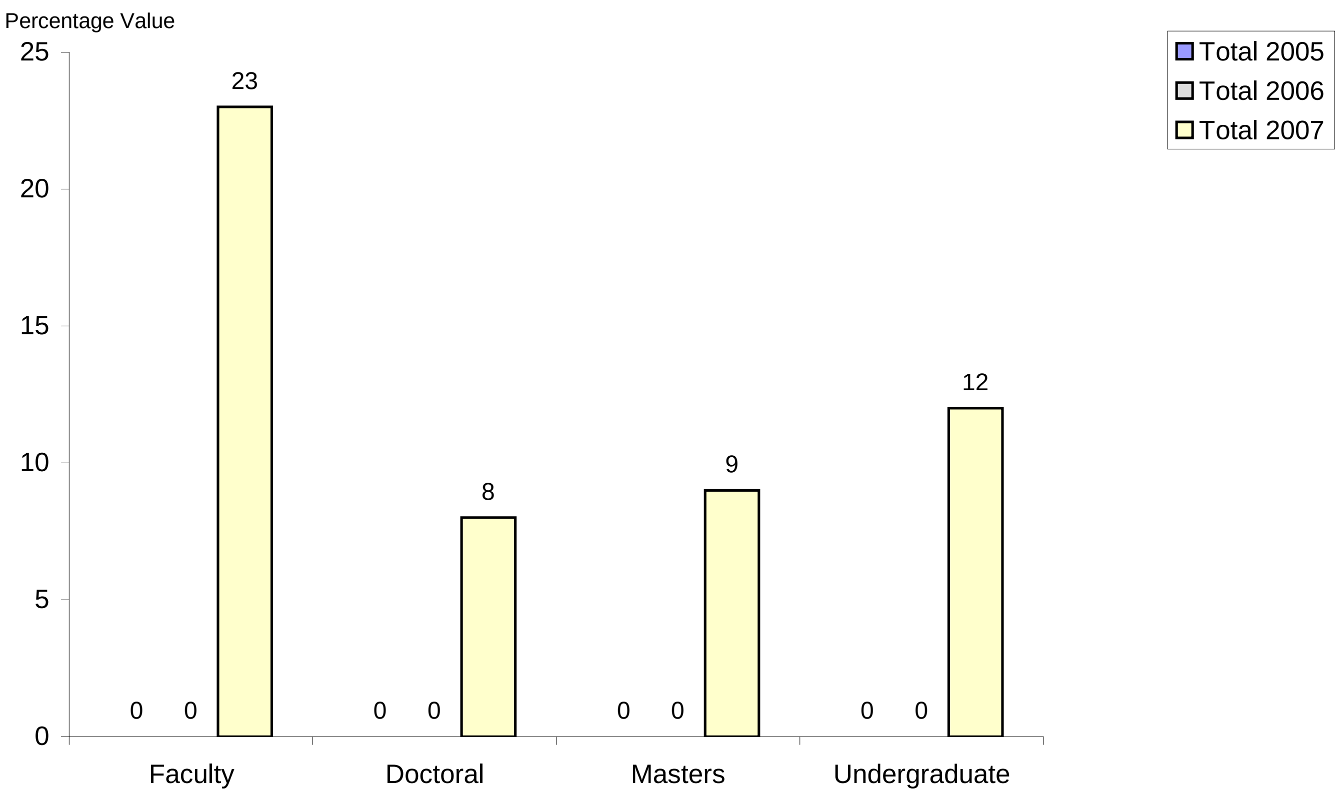
The Center's statistics reflect a low representation of persons with disabilities compared with other ERCs. This may be due to underreporting or because the percentage of people within the Center is still small when compared to other ERCs. However, the CCEFP continues to have a strong and diverse population of faculty and students who are underrepresented racial minorities. In each category, the Center exceeds the average with the exception of Hispanic or Latino faculty and master's students. With successes and lessons learned gleaned from Years 1 and 2, the CCEFP will continue to strive to improve the number of women, underrepresented minorities and persons with disabilities that participate in the Center's research and educational activities.

Table 7a: Diversity Statistics for ERC faculty and students

	Total ERC Personnel				Foreign			
	Faculty	Doctoral Students	Masters Students	Undergraduate Students	Faculty	Doctoral Students	Masters Students	Undergraduate Students
Women								
Center Total	8	2	3	8	1	1	0	0
Center Percent	23%	8%	9%	12%	3%	14%	0%	0%
National Percent	7.3%	17.3%	21.9%	20.5%	N/A	N/A	N/A	N/A
Persons with Disabilities								
Center Total	0	0	0	1	0	0	0	0
Center Percent	0%	0%	0%	1%	0%	0%	0%	0%
National Percent	8.8%	0.7%	3.2%	2.6%	N/A	N/A	N/A	N/A

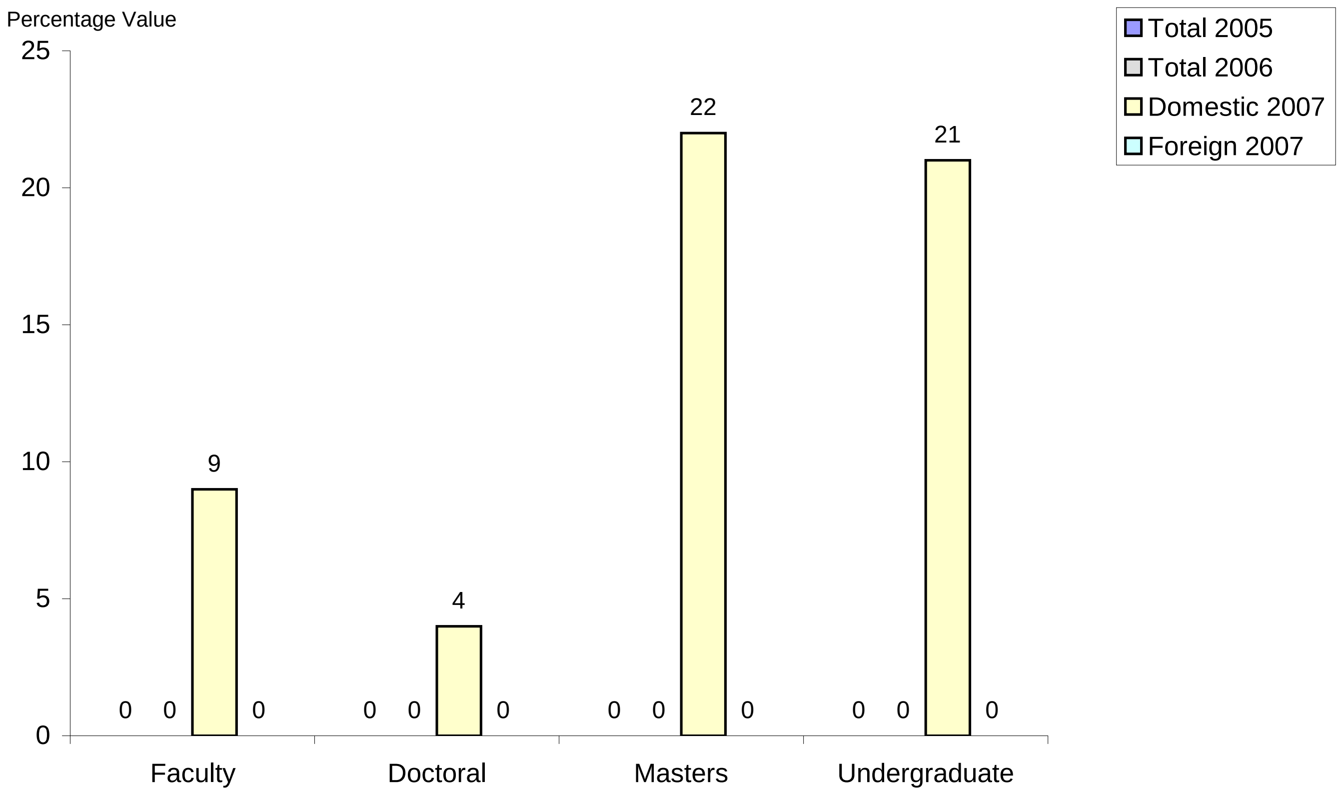
	U.S. Citizens and Permanent Residents only				Foreign			
	Faculty	Doctoral Students	Masters Students	Undergraduate Students	Faculty	Doctoral Students	Masters Students	Undergraduate Students
Underrepresented Racial Minorities								
Center Total	3	1	7	14	0	0	0	0
Center Percent	9%	4%	22%	21%	0%	0%	0%	0%
National Percent	3.0%	1.8%	2.7%	5.1%	N/A	N/A	N/A	N/A
Hispanic/Latinos								
Center Total	0	1	0	6	0	0	0	0
Center Percent	0%	4%	0%	9%	0%	0%	0%	0%
National Percent	3.3%	1.8%	2.5%	6.3%	N/A	N/A	N/A	N/A

Figure 7b: Women in the ERC



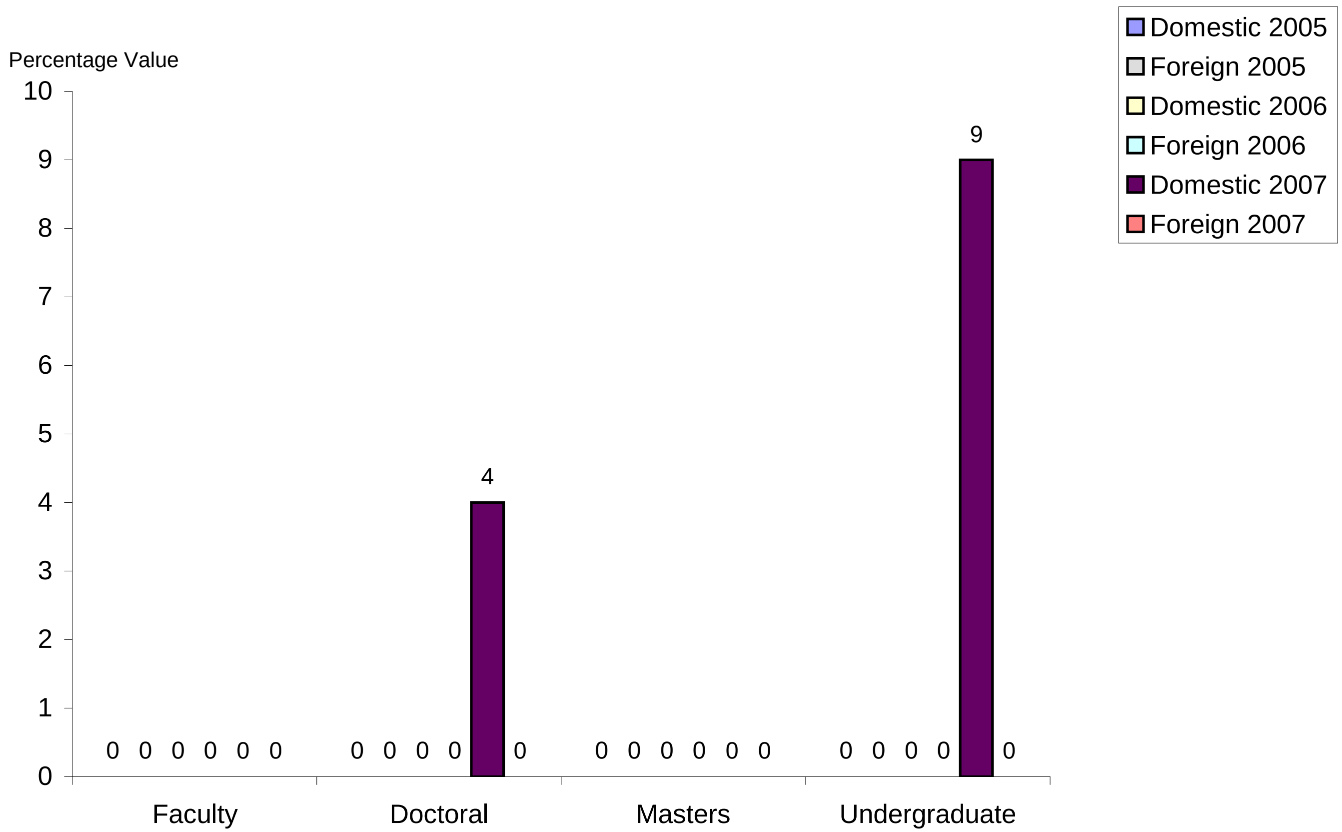
Averages	Faculty	Doctoral	Masters	Undergraduate
National Engineering	7.3%	17.3%	21.9%	20.5%
All ERC's 2006	17.69%	28.17%	30.30%	34.91%

Figure 7c: Underrepresented Racial Minorities in the ERC



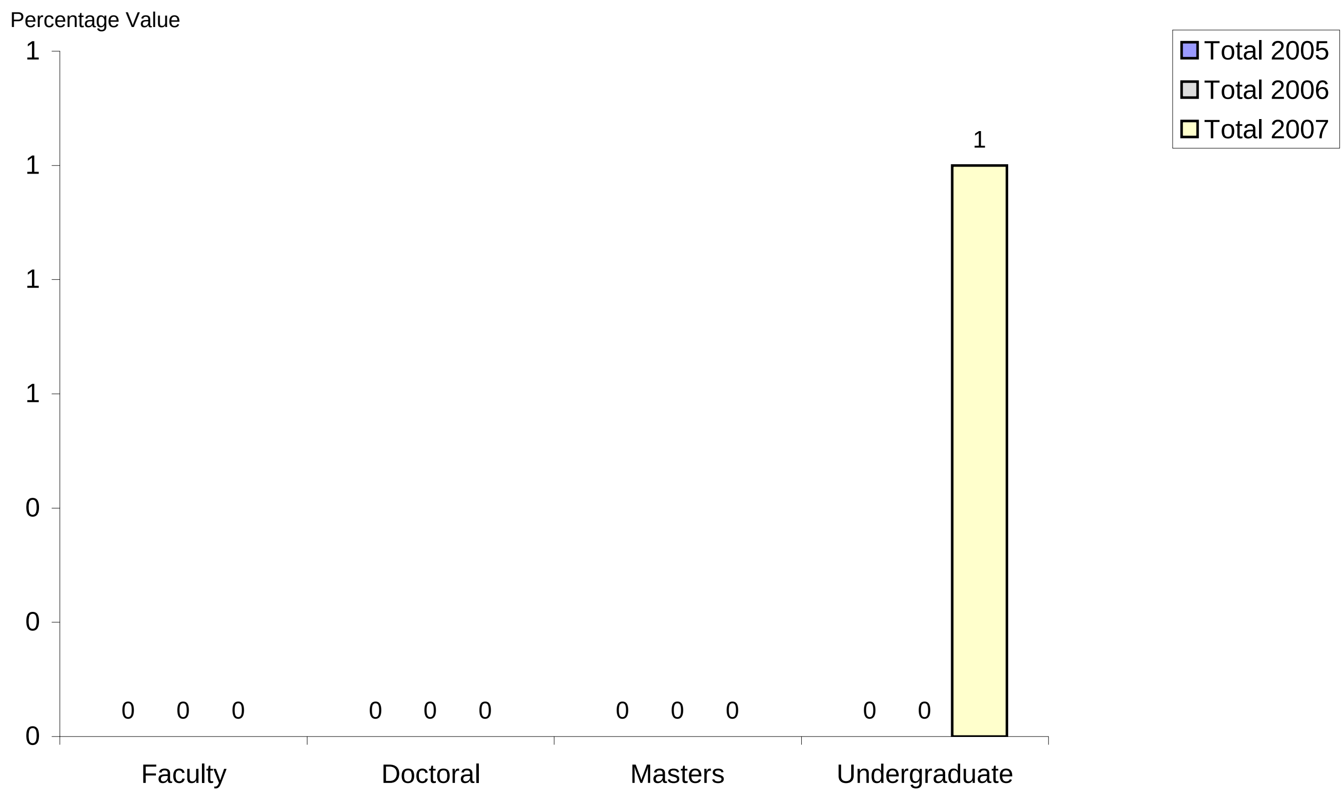
Averages	Faculty	Doctoral	Masters	Undergraduate
National Engineering	3.0%	1.8%	2.7%	5.1%
All ERC's 2006	5.90%	5.08%	12.81%	18.93%

Figure 7d: Hispanics/Latinos in the ERC



Averages	Faculty	Doctoral	Masters	Undergraduate
National Engineering	3.3%	1.8%	2.5%	6.3%
All ERC's 2006	8.18%	5.00%	8.87%	13.31%

Figure 7e: Persons with Disabilities in the ERC



Averages	Faculty	Doctoral	Masters	Undergraduate
National Engineering	8.8%	0.7%	3.2%	2.6%
All ERC's 2006	0.36%	0.40%	0.25%	0.20%

Table 7f: Center Diversity, by Institution

Institution	Females		Underrepresented Racial Minorities 1		Hispanics 1	
	#	%	#	%	#	%
Lead Institution						
University of Minnesota	10	21%	4	9%	0	0%
Core Partner						
Georgia Institute of Technology	3	12%	2	8%	0	0%
Purdue University	3	9%	2	8%	2	6%
University of Illinois at Urbana-Champaign	3	16%	2	11%	1	5%
Vanderbilt University	1	5%	0	0%	2	10%
Collaborating (Outreach) Institutions						
Milwaukee School of Engineering	1	4%	0	0%	1	4%
North Carolina Agriculture and Technical State University	6	26%	16	76%	0	0%
Science Museum of Minnesota	1	25%	0	0%	0	0%
Non-ERC Institutions Providing REU Students						
Bemidji State University	0	0%	0	0%	0	0%
Colorado State University	0	0%	0	0%	0	0%
The Cooper Union	0	0%	0	0%	0	0%
Universidad Del Turabo	0	0%	0	0%	1	100%
University of Florida	1	100%	1	100%	0	0%
University of Puerto Rico	0	0%	0	0%	1	100%

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

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 unique aspect of these efforts lies in Center-supported work to increase the number of Native Americans choosing STEM-related study tracks. Note that 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, and the large population of Native Americans in Minnesota and its surrounding states. Also regionally based, the Youth Science Team project at the Science Museum of Minnesota engages a broadly diverse group—the team itself and the student groups it instructs. In both of these initiatives, the Center plans 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 FIRST teams support broad STEM initiatives while drawing on fluid power examples. Both PLTW and FIRST involve diverse student populations. Year 2 marked progress in developing fluid power content for selected PLTW courses and in creating the prototype of a pneumatics workshop for FIRST teams. Both initiatives will be expanded in Year 3.

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. As a part of these efforts, the CCEFP has been represented at the National Science Foundation's Educator's Awardee's Conference, The HBCU-UP Research Conference, SACNAS, AISES National Conference, and will be an exhibitor at the Florida LSAMP Research Conference in February 2008.

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. As one example, CCEFP staff interact with the High Tech Girls Society (HTGS), a Minneapolis Public School network of high school girls in the Minneapolis Public Schools who are part of the Project Lead The Way program. And, in casting a much wider net, both the Center's website and its presence on Internet job boards for its intern and REU programs describe and promote the work of the CCEFP and extend its outreach opportunities. At the institutional level, The Center also works through the LSAMP and AGES programs of its collaborating institutions. CCEFP also works with associated Deans and Department Chairs to increase diversity through faculty hiring.

In sum, 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 as well as in fluid power research and the industry it serves. The Center recognizes that the research and educational opportunities led and funded by the Center forge the links needed in reaching this goal.

Diversity Programs

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

Northstar LSAMP

The CCEFP has helped to launch the activities of the new Northstar LSAMP program at the University of Minnesota by assisting with Native American recruitment. Collaborative efforts between the National Center for Earth-surface Dynamics and the University of Minnesota Institute of Technology's Academic Programs in Excellence in Science and Engineering have led to the formation of the Northstar AISES Alliance which, in turn, will provide additional opportunities to the students of the local Minnesota AISES Chapters. The Center is on the planning committee to bring the AISES National Science Fair back to Minnesota in 2009

GIDAA Science Camp

In its first year, the Center partnered with the NSF's National Center for Earth-surface Dynamics *gidakiimanaaniwigamig* (Our Earth Lodge) Native American Youth Science Immersion Program which annually brings over 200 youth from local middle and high schools to Native American math and science camps and also engages them in after school and weekend programs. These programs provide students with a mix of lab science and field science experiences. Program highlights include an introduction to scientific methods and a focus on Native American culture. During the fall camp, the CCEFP presented a workshop on hydraulic and pneumatic principles. Students had hands-on opportunities to test these principles using kits that included syringes, hoses and air balloons.

Workshops and Lab Tours

Center faculty and students hosted or participated in several workshops around the country that reached a diverse audience of students and teachers. The Center held lab tours and/or sessions on fluid power, its principles and it components.

Purdue University

Fall 2007

Eighty-one students (including 45 females) from the Future Farmers of American visited Purdue's Agricultural and Biological Engineering Department. Faculty of the Center had students interact with the hydraulic and pneumatic trainers during the tour.

University of Minnesota
Fall 2007
Faculty of the CCEFP presented an interactive fluid-power workshop for students in preparation for the 2008 FIRST Robotics competition. Based on the positive response, this workshop will be presented to a much broader student audience in the fall of 2008 And, in additional work with FIRST, the CCEFP has received funding from the University of Minnesota's Foundation to host the first all-Native American FIRST Robotics Team. (This team also has participated and appreciated the fluid power workshop.)

Georgia Tech
CCEFP faculty and students from Georgia Tech hosted an outreach workshop for high school students who are preparing for the FIRST Robotics Competition and/or the VEX Robotics Competition. A diverse group of over 50 students and teachers attended. During the event. a 25-minute presentation on fluid power principles was followed by a design challenge in which the students built a pneumatically actuated catapult.

Education and Outreach Activity Log

January 2008	Outreach	Native FIRST Team: 1st team meeting and FP workshop	Durfee, Gust, Burger
January 2008	Recruiting	University of Texas, Austin Prairie View A&M University University of Texas, Pan American	Burger
December 2007	Outreach	FP workshop: FIRST Splash	Durfee
November 2007	Outreach	GIDAA Science Camp: Hydraulics and Pneumatics Workshop (<45 students, ½ female, all Native American)	Burger
November 2007	Outreach	GATech: Fluid Power Demonstration and robotic competition (<55 students/teachers, ½ African American, ½ female students)	Paredis, Book, grad student
November 2007	Recruiting	AISES Conference attendee	Burger
October 2007	Outreach	University of Minnesota Power Puzzle: Fluid Power Workshop (<85 students, 1/3 female)	Burger
October 2007	Recruiting	SACNAS: Materials at NCED Exhibitor Booth	Pellerin
October 2007	Recruiting	Exhibitor: HBCU-UP Research Conference	Burger
October 2007	Outreach	FFA: Facility Tour at Purdue (<80 students, ½ female)	Lumkes
October 2007	Networking	CCEFP Team meetings with NSF programs at Nano-CEMMS	Western, Burger
September 2007	Networking	NSF's Education Awardee's Conference	Burger, Western
September 2007	Outreach	Fluid Power Workshop at UIUC	Durfee
August 2007	Recruiting	Exhibitor: NFPA Industry Educators Summit	Burger, Western, Durfee, Gust, Stelson
August 2007	Outreach	Fluid Power Demonstration Kit Design and Creation at CCEFP Student Retreat	Burger, Gust, SLC
June 2007	Outreach	GIDAA Science Camp	Pellerin, Burger
May 2007	Networking	GATech: AGEP Meeting with Program Director	Burger, Western
May 2007	Networking	NCA&T: LSAMP Meeting with Program Director	Burger
April 2007	Networking	NRCEN: Educators and Outreach Directors Annual Meeting	Burger
February 2007	Outreach	GIDAA Science Camp (<55 students, all Native American)	Pellerin, Burger

Table 7h: Education and Outreach Activities Log

5.3 MANAGEMENT EFFORT

CCEFP uses modern management practices for key processes such as strategic planning, project selection, budgeting, progress tracking and management communication. These practices are summarized in Table 8c below.

Strategic Planning	Project Selection	Budgeting	Progress Updating	Communication
• Annual process that drives and aligns the entire organization.	• Detailed template identifying all critical aspects of the project to assist decision makers. • Section criteria for comparison.	• Budget "rules of thumb" established and utilized for FY2 budgets.	• Focus regular updates within Thrust areas. • Annual summary completed for NSF and industry.	• Include both internal and external communication processes
• Timing needs to meet NSF requirements. Annual review should take place before the next fiscal year begins.	• Need to solicit input from industry and students.	• Simple standardized template created. • Allows room for unique exceptions.	• Simple standardized 4-Up template created.	• Separate management and executive council sessions • Website to be the main portal to the world
• Focused leadership meeting to ensure alignment and develop strategy maps.	• Portfolio Management • Project Management techniques		• Added Education and Outreach projects to the same format	• Monthly newsletter to targeted e-mail addresses • Regular localized staff meetings

= Future improvement

Table 8c: CCEFP Management Practices

Strategic Planning. Beginning in Year 2, strategic planning process is done using Strategic Alignment Maps (SAMs), a technique that is also known as balanced scorecard methodology (see www.insightformation.com). This is essentially an expansion of the three-plane diagram into five planes. The original three planes—engineered systems, enabling technology and fundamental knowledge—are augmented with two additional planes, "societal needs" and "resources." Societal needs are at the highest level and resources are at the lowest level in the diagram. The method is implemented in software that explicitly states the causal interrelationships between the components.

A systematic approach to strategic planning has several advantages. The intuitive and graphical nature of strategy maps allows poorly chosen or ill-structured projects to be spotted and eliminated or redirected. It is possible to do this with varying levels of details by zooming in and out of the maps allowing inter-relationships to be seen in more or less detail as needed. The method is intuitive and allows participants at all levels of the organization to clearly understand where their role fits in the overall scheme. Further, risk minimization can be implemented in a strategic map, with individual project risk levels contributing to an assessment of overall risk.

Figure 1 on page 25 shows the SAM for the goal, "migrate fluid power into the transportation sector." As can be seen from the figure, the contribution of each project to this overall goal is clearly delineated. We are currently in the process of developing SAMs for each CCEFP goal.

Project Selection. The strategic plan provides a blueprint for project selection where the most important criterion is whether or not the project is strategically aligned with CCEFP goals. The original project list, as specified in the proposal, was shaped in part by reference to a survey conducted among fluid power manufacturers and distributors by the National Fluid Power Association of industry needs and interests as well as by the expertise of the Center's faculty. The subsequent budget cut, supplement and recombining of the supplement with the main budget provided opportunities to modify the project makeup to increase alignment. In spring 2008, a new and systematic project selection process will be implemented. Gaps in actions needed to reach Center goals, identified during the ongoing strategic planning process, will be filled with the launch of two-three new projects selected for their close alignment. Resources for these projects will be obtained by re-budgeting, where several projects will be discontinued, having been identified as underperforming, misaligned or complete. Proposals will be solicited based on descriptions of the needed research. The same budgeting process will be used for new and existing projects. To drive consistency a standardized two-page template has been developed that must be completed for any project submission. The first page of the template is shown in figure 8d. All existing projects were subjected to the same scrutiny as well. Items that must be addressed include overall project goals, strategic alignment, project scope, resources required, summary of existing related work, etc.

2Q: Compact XYZ

[Please include designated project number]

1. Executive summary: [*single page, please include all items* **]**

Research Team

Project Leader:	[Prof. First Name Last Name, *Department Name*]
Other Faculty:	[Prof. First Name Last Name, *Department Name*]
	[Prof. First Name Last Name, *Department Name*]
	[Prof. First Name Last Name, *Department Name*]
Post Doc(s):	[Insert Name(s)]
Graduate Students:	[Insert Name(s)]
Undergraduate Students:	[Insert Name(s)]
Industrial Partner(s):	[Company Name(s)]

Statement of Project Goals

Short statement of functional objectives (what problem will be solved; or what will be developed; include metric for success if possible)

Example 1: The goal of the project is to develop a chemo-fluidic fueled compact motor suitable for powering a hydraulic pump. The system is expected to be capable of delivering 2KW power and has a footprint that fits on a palm.

Example 2: Develop a validated sealing model capable of predicting seal behavior up to 10000psi, and which captures thermal-structure coupling effects.

Project Role in Support of Strategic Plan

How does the project address the barrier and sub-barriers ? [Please refer to the ERC thrust leval barrier breakdown diagrams attachment]

Example: The project will provide an accurate computation model to predict the occurrence and course of cavitation in realistic conditions. This will enable the design of cavitation-free pump inlet and valve geometry resulting in components that are more efficient and capable of higher flow (component efficiency barrier). The elimination of cavitation will also achieve fluid power systems that are quieter and have less vibration (noise and vibration barrier).

Overall Project Scope Summary

Please state "what is in scope" and "what is out of scope"

Example: This project will validate the proposed supercharger concept by a bench-top experiment, using shop-air as the energy source. The use of a portable power supply will be out-of-scope. The project will only consider sub-sonic behavior. Super-sonic flow will be out-of-scope (but may be considered as a follow on project in year 5)……

Figure 8d: CCEFP Project Proposal Template

Budgeting. The CCEFP budget is comprised of individual budgets for research, education and outreach, and management. Each project (research, education and outreach) or function (management) is assigned a line item in the budget. Available funds are calculated by combining the previous year's carry-forward with the projected funding for the next year from NSF and industry. University matching funds are not allocated in the process; this is left to the discretion on each university. Project leaders request funds using a simple template, shown in figure 8e, along with expenditure guidelines that captures the main expenses while avoiding the complexity of exact calculation.

Year 2 Budget Template - Project # _____	**TOTAL**
Faculty - up to $20,000 (utilize actual cost)	$0
1 month fully burdened salary max for the first project. 1/2 month for every additional project. Maximum of 2 faculty per project.	
Post Doctorate - up to $18,000 (utilize actual cost)	$0
3 months fully burdened salary max for each project.	
Students - $50,000 max full year salary (fully burdened)	$0
Maximum of 2 students per project	
Experimental supplies - $50,000 max	$0
Travel - $10,000 max	$0
Permanent equipment - up to $20,00	$0
Likely to be highly variable, must itemize	
Exceptions - justification required	
TOTAL =	**$0**
Please be realistic when determining your budgets. The average amount of a single project will be ~$120,000. Depending on the level of deliverables and hardware expenditures some may require less funding, some more. All budgets will be thoroughly reviewed by the research leadership council.	

Figure 8e: CCEFP Project Budget Template

After careful consideration by thrust leaders, the final budget is arrived at. This process was implemented for the first time for Year 2 funding. Although budgets decisions are always controversial, there is consensus among the thrust leaders that the final result was fair. The Center Director approves the final budget after it is endorsed by the Management Committee.

<u>Project Review</u>. A formal project review process was initiated in Year 2. It is conducted by teleconference three times a year for each research, education or outreach project. Research projects and test beds are evaluated by the Executive Committee whose members include faculty, industry, and student representatives. Education and outreach projects are evaluated by a review panel of Center staff and representatives of the Education Advisory Board. This results in around 50 overall progress reviews that must be undertaken each term. Therefore, it is critical that the information being presented is focused on recent progress. In all cases, project leaders give a ten-minute presentation followed by five minutes of questions. Again it made sense to utilize a standard uniform format (shown in figure 8f), elaborating on a four-quadrant chart where the quadrants show overall project goals, annual milestones, progress during the last period and plans for the next period with the majority of the discussion centered upon the latter two.

Project Overview • Project description, how it aligns with our strategy and the value proposition. • This information changes infrequently if at all.	**Major Milestones** • Clear identification of ~3 - 6 major milestones/deliverables for the year along with completion dates. • Update annually •Need to add how the project supports or ties into E & O.
Progress during this term • Progress realized during this term (summer, fall or spring) towards major milestones, issues/problems encountered, etc.	**Next Steps** • What is expected to be completed next term? How do you intend to resolve outstanding issues? What can the ERC EC do to help you?

Figure 8f: Four Quadrant Chart for CCEFP Project Review

Evaluators provide feedback in two ways: with the assignment of a color code (green, yellow or red) based on a traffic light system and through concise, constructive comments. “Green” means progress in on track, “yellow” means that some minor difficulties or delays have been encountered, and “red” means that some major difficulties or delays have been encountered. Project leaders get feedback in the form of an overall color assignment and collected comments. Project leaders provide a brief response to the comments and evaluation. These comments clarify any misunderstandings and provide details for future plans. For any project rated “yellow” or “red,” follow up discussions between the project leader, thrust leader and others are used in subsequently refining the plans and addressing concerns. The final summary is also shared with industry via NFPA and the IAB. A summary of the results from our initial review of research projects is shown in the figure 8g below:

Efficiency Thrust	Status	Compactness Thrust	Status
1.A1. Integrated algorithms for optimal energy use in mobile FP systems		2A . Chemofluidic Hydraulic Actuators	
1.A2. Optimum power management using displacement controlled actuators		2B. Free-Piston Engine Compressor	
1.B. Novel surface designs for improved sealing & load bearing properties		2C. Compact Energy Storage	
1.D. Nano-texturing for improved FP efficiency		2D. High Pressure, Light Weight Components Using Engineered Materials	
1.E1. On/off meter-less valve contro (Purdue)		2E. Component Integration for Compact Fluid Power Systems	
1.E2. On/off meter-less valve contro (Minn)		2F. Dynamically Scalable Fluid Power Systems	
1.G. Optimized engineered fluids			

Effectiveness Thrust	Status	Test Beds	Status
3A1. Multimodal Human Machine Interfaces (G-Tech)		TB1. Excavator	
3A1. Multimodal Human Machine Interfaces (NCAT)		TB3. Small passenger car (sUV)	
3A2. Human/Machine Interfaces – Passified chemofluidic control		TB4. Compact Rescue Robot (G-Tech)	
3A3. Human Performance Modeling and User Centered Design		TB4. Compact Rescue Robot (NCAT)	
3B1. Noise and Vibration Reduction in Fluid Power Systems		TB5. Compact hand tools	
3B2. Active Control of Hydraulic Pump Noise		TB6. Orthosis	
3C. CFD Simulations of Cavitation Flows			
3D. Leakage Reduction in Fluid Power Systems			

Figure 8g: Summary of Summer 2007 CCEFP Research Project Review

<u>Management Communication.</u> Communication is key to any management plan. This is particularly true in an organization as widely dispersed as the CCEFP. CCEFP has many stakeholders including the NSF, member universities, the fluid power industry, undergraduate students, graduate students, K-12 students and teachers, and society in general. Communication can be divided into external communication and internal or management communication. CCEFP management communication and decision making is made by the Center Leadership, Management Committee, Executive Committee, Education and Outreach Network and the Student Leadership Council.

- The most important decisions of the Center are made by the Management Committee. The Management Committee meets semi-weekly by teleconference. Its membership consists of the Director, Deputy Director and one representative of each core and outreach university. Included in the Management Committee are the Thrust Leaders of research.
- The Executive Committee is an expanded version of the Management Committee with the additional members being graduate students and industry representatives. The Executive Committee meets four times a year to make decisions on progress tracking and the initiation or termination of projects.
- The Education and Outreach Network (EON) consists of the Education Co-Directors, the Education and Outreach Director and a representative of each core and outreach university. The EON meets six times a year by teleconference. The Network serves as a conduit of information for and about the Center's education and outreach projects and provides guidance on implementing agreed upon strategies.
- The Student Leadership Council (SLC) meets monthly with facilitation provided by the Education and Outreach Director. The SLC provides a direct channel for student feedback to Center Leadership. The SLC also provides service to the Center including organizing semi-weekly webcasts on research. Each webcast consists of three twenty-minute research presentations by students. The audience for the webcasts include students, faculty and industry engineers s.

The day-to-day operation of the CCEFP is conducted by the Center Director, Deputy Director, Administrative Director, Industrial Liaison Director, Education Co-Directors and the Education and Outreach Director. Center leadership meets weekly.

There is also management communication with three external boards, the Scientific Advisory Board, the Industrial Advisory Board and the Education Advisory Board.

- The Scientific Advisory Board (SAB) consists of subject matter experts outside of the Center. The Board meets at the CCEFP Annual Meeting and provides a written feedback report similar to that provided by the NSF Site Visit Team on the Center's research projects.
- The Industrial Advisory Board (IAB) meets monthly via telephone conference calls with the Industrial Liaison Director. Its members include representatives of companies supporting the CCEFP at the principal or sustaining level. During these discussions, IAB members provide guidance and perspectives on the Center's research, education and outreach projects, and take leadership roles in areas including the industry champions program.
- The Education Advisory Board conducts quarterly conference calls, making recommendations to the Center's Education Co-Directors for program prioritization and project design. Its members include faculty outside of the Center's other project areas, industry representatives and a public high school teacher.
- External communication is important to all stakeholders including NSF, industry, the scientific and engineering communities, students of all ages, and the general public. External communication uses multiple media including meetings, webcasts, print media, e-mail, the World Wide Web, video and television. 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 with industry. The Site Visits are always held at Minnesota, and the Annual Meeting rotates between partner universities. The 2007 Annual Meeting was held at Georgia Tech and the 2008 Annual Meeting will be held at Milwaukee School of Engineering. Web casts are another valuable form of communication. The SLC organizes a one-hour web cast every other week featuring three student research projects. The web cast is viewed by many member companies. CCEFP used print media for industry member, industrial intern and REU recruitment. CCEFP will produce its first published annual report in spring 2008. FP Monthly, the CCEFP e-mail newsletter, has a circulation of thousands. The CCEFP website, ccefp.org, is being continuously expanded and improved. The promise of fluid power is being communicated to a wider public with two half-hour public television programs. These programs will also be distributed by DVD.

Financial Tables. Table 8 shows the planned functional budget for Year 2. The research budget shows a fairly even distribution between the three thrust areas and test beds. The overall budget was determined using a process described in the budgeting section above. The percentage distribution of the functional budget is shown in Figure 8a. The major expense is research, being roughly half of the budget, with the funding for other functions distributed as shown. It is expected that this distribution will roughly continue into the future with only minor modifications. As an example, equipment costs tend to be larger in the earlier years of a Center and decrease in later years.

In future years, modest growth is expected in NSF funding, university matches and industry funding. Industry funding grew from $650,000 in Year 1 to $703,000 in Year 2, a growth of 8.2%. A major unrealized opportunity for increased funding is through associated projects. The existing associated projects were mostly initiated before the Center was founded. In the spring of 2008, a major initiative will be launched to encourage member companies to supplement their support with associated projects. Increasing associated projects is an important approach to achieving self-sufficiency.

Table 8: Functional Budget										
Source of Support										
Function	Direct Support							Direct Support Total	Associated Projects	Total
	ERC Program	Industry	State	University	Other NSF	Other Government	Other			
Compactness	330,122	66,024	0	44,016	0	0	0	440,162	216,487	656,649
Effectiveness	445,115	89,024	0	59,348	0	0	0	593,487	134,050	727,537
Efficiency	392,687	78,537	0	52,358	0	0	0	523,582	468,531	992,113
Test Beds	335,377	67,075	0	44,717	0	0	0	447,169	0	447,169
Research Total	1,503,301	300,660	0	200,439	0	0	0	2,004,400	819,068	2,823,468
General & Shared Equipment	225,098	0	0	62,638	0	0	0	287,736	0	287,736
New Facilities/ New Construction	0	0	0	0	0	0	0	0	0	0
Education Programs	329,202	28,968	0	204,032	0	0	0	562,202	0	562,202
Tech Transfer/ Industrial Collab	0	232,303	0	0	0	0	0	232,303	0	232,303
Leadership/ Administration/ Management	305,728	0	0	53,952	0	0	0	359,680	0	359,680
Center Related Travel	31,315	30,124	0	46,159	0	0	0	107,598	0	107,598
Indirect Cost	921,157	4,772	0	82,780	0	0	0	1,008,709	0	1,008,709
Residual Funds Remaining	0	106,173	0	0	0	0	0	106,173	0	106,173
Total	3,315,801	703,000	0	650,000	0	0	0	4,668,801	819,068	5,487,869

Figure 8a: Functional Budget (chart)

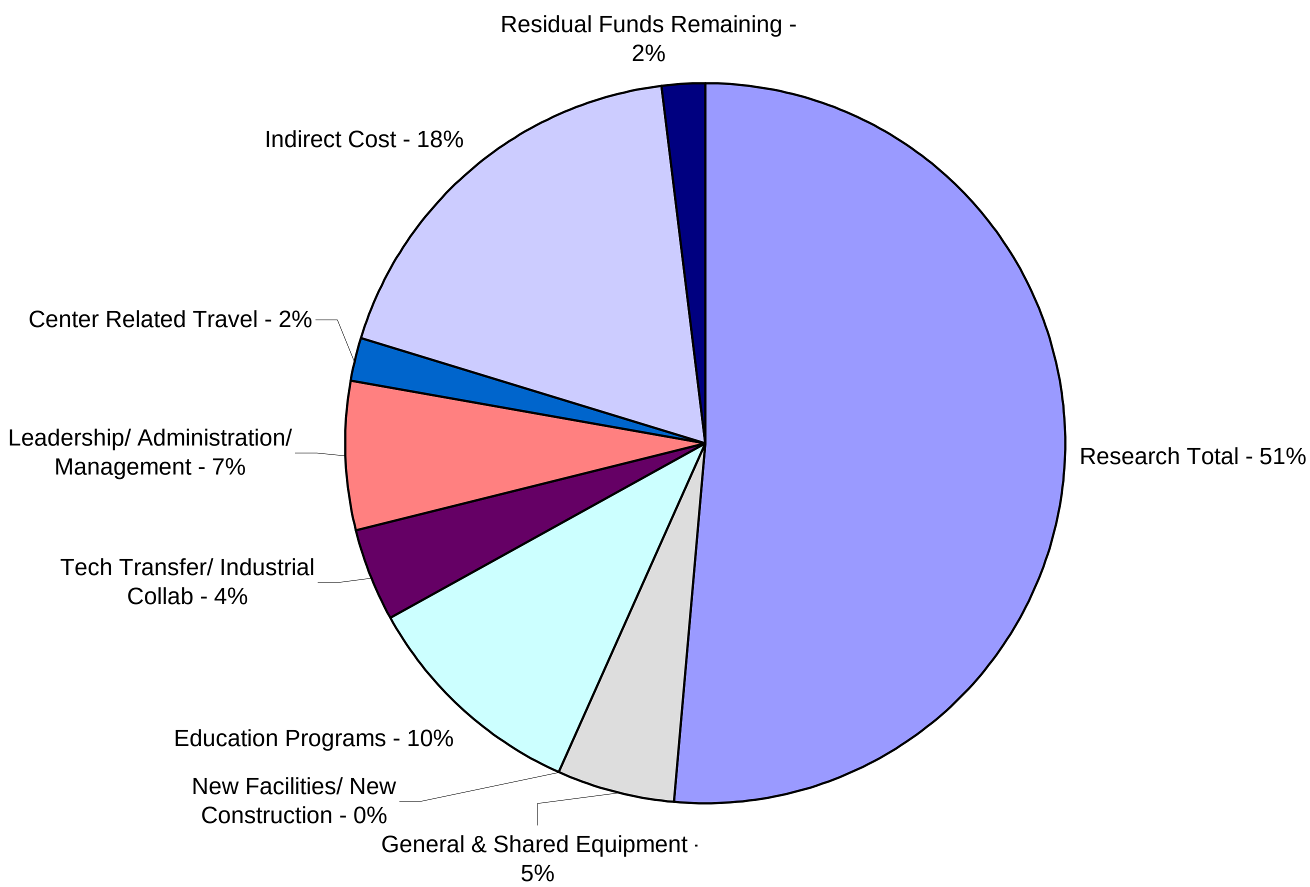


Table 8b shows Year 2 distribution by university. The largest recipient of direct cash funding is the lead university with 30% of the total. The difference between the lead and core university funding is largely due to the additional expenses of Center administration. Year 1 residual funding was carried forward and allocated to projects in Year 2, but is not reflected in the figures in Table 8b. This causes some distortion since the residuals were unevenly distributed between universities.

Table 8b: Distribution of Current Award Year Budget, by Institution, FY08

Institution	Direct Cash	Associated Projects	Percent of Total Direct Cash	Percent of Total Associated Projects
University of Minnesota	$1,371,291	$28,833	30%	4%
Georgia Tech	$668,207	$180,537	15%	22%
Milwaukee School of Engineering	$273,331	$20,000	6%	3%
North Carolina A & T	$406,421	$0	9%	0%
Purdue University	$759,075	$439,698	16%	54%
UIUC	$608,645	$0	13%	0%
Vanderbilt University	$418,030	$150,000	9%	17%
Science Museum of Minnesota	$100,000	$0	2%	0%
Grand Total	$4,605,000	$819,068	100%	100%

Table 9 shows the sources of support for the Center. Table 9a shows the funding history of the Center and has only two entries: the base award and the REU supplement for Year 1. Table 9b shows the cost sharing by institution verifying that all institutions have met or exceeded their cost sharing obligation.

Table 9a: History of ERC Funding of the Center

Award Number	Award Type	Award Title	Award Duration	Amount	Status	Final Report Approved?
0540834	Base	Center for Compact and Efficient Fluid Power	5 years	$17,470,000	In progress	N/A
0540834	REU Supplement		1 year	$65,801	Completed	

Table 9b: Cost Sharing by Institution

	Award Year 1		Award Year 2		Cumulative
Institution	**Committed**	**Actual**	**Committed**	**Actual**	
U. of Minnesota	$180,180	$180,180	$182,000	-	$362,180
Georgia Tech	$112,860	$112,859	$129,000	-	$241,860
Milwaukee School of Eng.	$0	$0	$10,800	-	$10,800
Purdue	$112,860	$112,860	$129,000	-	$241,860
UIUC	$112,860	$131,129	$123,200	-	$236,060
Vanderbilt	$75,240	$75,240	$76,000	-	$151,240

Table 10 shows the annual expenditures and budgets. All expenditure categories show modest growth except for equipment expenses which will decrease. The isolated expenditure of $100,000 is for the Science Museum of Minnesota. Table 10a shows the residual amounts from Year 1. Of the total residual of about $1.9 million, $0.8 million had been encumbered in Year 1.

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	$1,909,689	$106,173
Committed, Encumbered, Obligated Funds	$795,442	$0
Residual Funds Without Specified Use	$1,114,247	$106,173

Table 9: Sources of Support									
Type of Support	Early Cumulative Total 1	Reporting Year - 4	Reporting Year - 3	Reporting Year - 2	Jun 01, 2006 - May 31, 2007	Jun 01, 2007 - May 31, 2008			Cumul. Total 2
						Rec'd.	Prom.	Total	
TOTAL Cash Support, All Sources 3	**$0**	**$0**	**$0**	**$0**	**$4,280,265**	**$4,636,301**	**$32,500**	**$4,668,801**	**$6,933,204**
TOTAL Unrestricted Cash	**$0**	**$0**	**$0**	**$0**	**$2,370,576**	**$4,464,327**	**$32,500**	**$4,496,827**	**$6,867,403**
NSF ERC Base Award	$0	$0	$0	$0	$1,946,020	$3,250,000	$0	$3,250,000	$5,196,020
U.S. Industry	$0	$0	$0	$0	$50,793	$504,327	$32,500	$536,827	$587,620
Foreign Industry	$0	$0	$0	$0	$60,000	$60,000	$0	$60,000	$120,000
State	$0	$0	$0	$0	$0	$0	$0	$0	$0
U.S. University	$0	$0	$0	$0	$313,763	$650,000	$0	$650,000	$963,763
Foreign University	$0	$0	$0	$0	$0	$0	$0	$0	$0
Other NSF (Not ERC Program)	$0	$0	$0	$0	$0	$0	$0	$0	$0
Other U.S. Government (Not NSF)	$0	$0	$0	$0	$0	$0	$0	$0	$0
Foreign Government	$0	$0	$0	$0	$0	$0	$0	$0	$0
Other Source.	$0	$0	$0	$0	$0	$0	$0	$0	$0
TOTAL Restricted Cash	**$0**	**$0**	**$0**	**$0**	**$0**	**$65,801**	**$0**	**$65,801**	**$65,801**
NSF ERC Program Special Purpose Awards and Supplements	$0	$0	$0	$0	$0	$65,801	$0	$65,801	$65,801
U.S. Industry	$0	$0	$0	$0	$0	$0	$0	$0	$0
Foreign Industry	$0	$0	$0	$0	$0	$0	$0	$0	$0
State	$0	$0	$0	$0	$0	$0	$0	$0	$0
U.S. University	$0	$0	$0	$0	$0	$0	$0	$0	$0
Foreign University	$0	$0	$0	$0	$0	$0	$0	$0	$0
Other NSF (Not ERC Program)	$0	$0	$0	$0	$0	$0	$0	$0	$0
Other U.S. Government (Not NSF)	$0	$0	$0	$0	$0	$0	$0	$0	$0
Foreign Government	$0	$0	$0	$0	$0	$0	$0	$0	$0
Other Source.	$0	$0	$0	$0	$0	$0	$0	$0	$0
TOTAL Associated Projects 4	**$0**	**$0**	**$0**	**$0**	**$1,229,280**	**$819,068**	**$0**	**$819,068**	**$2,048,348**
U.S. Industry	$0	$0	$0	$0	$457,629	$620,235	$0	$620,235	$1,077,864
Foreign Industry	$0	$0	$0	$0	$0	$0	$0	$0	$0
State	$0	$0	$0	$0	$0	$0	$0	$0	$0
Other NSF (not ERC program)	$0	$0	$0	$0	$113,333	$28,833	$0	$28,833	$142,166
Other US Government (not NSF)	$0	$0	$0	$0	$653,318	$150,000	$0	$150,000	$803,318
Foreign Government	$0	$0	$0	$0	$0	$0	$0	$0	$0
Other (specify source)	$0	$0	$0	$0	$5,000	$20,000	$0	$20,000	$25,000
TOTAL Reserve/Carryover Funds 2	**$0**	**$0**	**$0**	**$0**	**$1,909,689**	**$106,173**	**$0**	**$106,173**	**N/A**
NSF/ERC Program 2	$0	$0	$0	$0	$1,023,980	$0	$0	$0	N/A
U.S. Industry 2	$0	$0	$0	$0	$587,207	$106,173	$0	$106,173	N/A
Foreign Industry 2	$0	$0	$0	$0	$0	$0	$0	$0	N/A
State 2	$0	$0	$0	$0	$0	$0	$0	$0	N/A
U.S. University 2	$0	$0	$0	$0	$298,502	$0	$0	$0	N/A
Foreign University 2	$0	$0	$0	$0	$0	$0	$0	$0	N/A
Other NSF (Not ERC Program) 2	$0	$0	$0	$0	$0	$0	$0	$0	N/A

Table 9: Sources of Support									
Type of Support	Early Cumulative Total 1	Reporting Year - 4	Reporting Year - 3	Reporting Year - 2	Jun 01, 2006 - May 31, 2007	Jun 01, 2007 - May 31, 2008			Cumul. Total 2
						Rec'd.	Prom.	Total	
Other U.S. Government (Not NSF) 2	$0	$0	$0	$0	$0	$0	$0	$0	N/A
Foreign Government 2	$0	$0	$0	$0	$0	$0	$0	$0	N/A
Other Source. 2	$0	$0	$0	$0	$0	$0	$0	$0	N/A
TOTAL In-Kind Support, All Sources	**$0**	**$0**	**$0**	**$0**	**$226,591**	**$252,500**	**$55,000**	**$307,500**	**$534,091**
TOTAL Value of In-Kind Equipment	**$0**	**$0**	**$0**	**$0**	**$159,000**	**$30,000**	**$45,000**	**$75,000**	**$234,000**
U.S. Industry	$0	$0	$0	$0	$159,000	$30,000	$45,000	$75,000	$234,000
TOTAL Value of New Facilities in Existing Buildings	**$0**	**$0**	**$0**	**$0**	**$57,591**	**$193,000**	**$0**	**$193,000**	**$250,591**
U.S. University	$0	$0	$0	$0	$57,591	$193,000	$0	$193,000	$250,591
TOTAL Value of Visiting Personnel	**$0**	**$0**	**$0**	**$0**	**$10,000**	**$29,500**	**$10,000**	**$39,500**	**$49,500**
Foreign University	$0	$0	$0	$0	$10,000	$29,500	$10,000	$39,500	$49,500
Percent Non-ERC Program Cash	**N/A**	**N/A**	**N/A**	**N/A**	**94.17**	**29.18**	**37.14**	**29.32**	**76.37**
Grand Total (Cash + In-Kind)	**$0**	**$0**	**$0**	**$0**	**$4,506,856**	**$4,888,801**	**$87,500**	**$4,976,301**	**$7,467,295**

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

2 - 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.

3 - Cash Total = The sum of Unrestricted Cash, Restricted Cash, and Residual Funds for a particular NSF Award Year, but NOT Indirect 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.

4 - In 2003 -2004 Associated Projects Data was not collected.

Explanation of Residual Funds entry in Direct Sources of Support - Cash

A small portion of residual funds will be carried forward to year three to be used for any unexpected expenses that may arise.

Table 10: Annual Expenditures and Budgets							
Expenses Proposed and Residual Budget	Early Cumulative Total*	Reporting Year - 4 Expend.	Reporting Year - 3 Expend.	Reporting Year - 2 Expend.	Jun 01, 2006 - May 31, 2007 Expend.	Jun 01, 2007 - May 31, 2008 Budget	Proposed Budget
Salaries	$0	$0	$0	$0	$1,052,557	$2,135,848	**$2,345,803**
Faculty	$0	$0	$0	$0	$219,229	$413,537	**$454,891**
Postdocs	$0	$0	$0	$0	$106,172	$253,548	**$278,903**
Students	$0	$0	$0	$0	$384,120	$994,427	**$1,093,870**
Research Staff	$0	$0	$0	$0	$17,301	$42,060	**$46,266**
Administration/Management	$0	$0	$0	$0	$304,473	$359,680	**$395,648**
Other Salaries	$0	$0	$0	$0	$21,262	$72,596	**$76,225**
Fringe Benefits	$0	$0	$0	$0	$224,701	$455,643	**$501,207**
Salaries and Fringe Benefits Total	$0	$0	$0	$0	$1,277,258	$2,591,491	**$2,847,010**
Other Expenses	$0	$0	$0	$0	$1,093,318	$1,971,137	**$1,942,872**
General Operating Expenses	$0	$0	$0	$0	$291,244	$438,035	**$457,437**
Facilities	$0	$0	$0	$0	$0	$0	**$0**
Major Isolated Expenses	$0	$0	$0	$0	$0	$100,000	**$100,000**
Equipment	$0	$0	$0	$0	$99,085	$287,736	**$187,028**
Indirect Costs	$0	$0	$0	$0	$646,310	$1,008,709	**$1,109,580**
Other	$0	$0	$0	$0	$56,679	$136,657	**$88,827**
Residual Funds Remaining	$0	$0	$0	$0	$1,909,689	$106,173	**$105,118**
Total	$0	$0	$0	$0	$4,280,265	$4,668,801	**$4,895,000**
Residual Funds Spent	$0	$0	$0	$0	$0	$1,908,683	**$0**
ERC Program	$0	$0	$0	$0	$0	$1,023,980	**$0**
Other NSF	$0	$0	$0	$0	$0	$0	**$0**
Other Federal	$0	$0	$0	$0	$0	$0	**$0**
Industry	$0	$0	$0	$0	$0	$587,207	**$0**
Other	$0	$0	$0	$0	$0	$297,496	**$0**

* For Centers in operation for more than 5 years

Explanation of Residual Funds entry in Annual Expenditures and Budget

Residual funds for year one were high due to it being our start-up year. Invoicing procedures were delayed for several months, so a large portion of this amount was obligated.

Year two residual funds will be a small amount left over from our industry membership fees, and kept on hand for unexpected last minute expenses. The same justification holds true for year three.

Table 11: Modes of Cash Support by Industry and Other Practitioner Organizations to the Center

Organization	Reporting Year - 2			Jun 01, 2006 - May 31, 2007			Jun 01, 2007 - May 31, 2008 Received		
	Fees and Contributions	Sponsored Projects	Associated Projects 1	Fees and Contributions	Sponsored Projects	Associated Projects 1	Fees and Contributions	Sponsored Projects	Associated Projects 1
AAA Products International				1,000	0	0	1,000		
Air Logic				1,000	0	0	1,000		
Army Research Office				0	0	53,318			
Bimba Manufacturing Comp				6,000	0	0	6,000		
Bobcat							15,000		
BorgWarner				0	0	47,950			
Bosch Rexroth Corporation				50,000	0	0	50,000		
Caterpillar, Inc.				50,000	0	0	50,000		
Command Controls Corpora				1,000	0	0	1,000		
Deere & Company				15,000	0	62,503	15,000		96,487
Defense Advanced Researc						600,000			150,000
Deltrol Fluid Products				5,000	0	0	5,000		
Donaldson Company				12,000	0	0	12,000		
Eaton Corporation				50,000	0	0	50,000		
Enfield Technologies				5,000	0	0	5,000		
Festo Corporation				40,000	0	0	40,000		
Fluid Power Educational Fou				1,000	0	0	1,000		
G.W. Lisk Company				15,000	0	0	15,000		
Gates Corporation				40,000	0	0	40,000		
Georgia Institute of Technolo				0	0	5,000			
Hagglunds Drives, Inc.				6,000	0	0	6,000		
Haldex Hydraulics Corporati				6,000	0	0	6,000		
Heco Gear, Inc.				2,000	0	0	2,000		
Hedland Flow Meters				1,000	0	0	1,000		
High Country Tek, Inc.				1,000	0	0	1,000		
Husco International, Inc.				40,000	0	76,000	40,000		79,050
Hydac Corporation				5,000	0	0	5,000		
Hydraquip Corporation				6,000	0	0	6,000		
INA USA Corporation				1,000	0	0	1,000		
International Fluid Power So				1,000	0	0	1,000		
Kepner Products, Co.				1,000	0	0	1,000		
Linde Hydraulics Corp.				5,000	0	0	5,000		
Main Manufacturing Product				5,000	0	0	0		
Master Pneumatic-Detroit, In				1,000	0	0	1,000		
Mead Fluid Dynamics				1,000	0	0	1,000		
Mico, Inc.				1,000	0	0	1,000		
Moog, Inc.				15,000	0	0	15,000		
MSOE Fluid Power Institute									20,000
MTS Systems Corporation				7,500	0	0	15,000		
National Fluid Power Associ				50,000	0	12,500	50,000		
National Tube Supply Comp				1,000	0	0	1,000		
Netshape Technologies							11,250		
Nexen Group, Inc.				1,000	0	0	1,000		
Norgren				12,000	0	0			
Parker Hannifen Corporation				50,000	0	203,676	50,000		276,124

Table 11: Modes of Cash Support by Industry and Other Practitioner Organizations to the Center									
Organization	Reporting Year - 2			Jun 01, 2006 - May 31, 2007			Jun 01, 2007 - May 31, 2008 Received		
	Fees and Contributions	Sponsored Projects	Associated Projects 1	Fees and Contributions	Sponsored Projects	Associated Projects 1	Fees and Contributions	Sponsored Projects	Associated Projects 1
PHD, Inc.				6,000	0	0	6,000		
PIAB Vacuum Products				1,000	0	0	1,000		
Poclain Hydraulics				15,000	0	0	15,000		
Prince Manufacturing Corpo				6,000	0	0			
Quality Control Corporation				1,000	0	0	1,000		
R.T. Dygert International				5,000	0	0	5,000		
Ralph Rivera				2,000	0	0	2,000		
RB Royal Industries, Inc.				2,000	0	0	1,000		
RohMax USA				5,000	0	0	5,000		
Ross Controls				5,000	0	0	5,000		
Sauer-Danfoss				50,000	0	0	50,000		163,574
Schroeder Industries				1,000	0	0			
Sentrinsic, LLP				0	0	5,000			
Sentrinsic, LLP									5,000
Shell Global Solutions				1,500	0	0	12,000		
Simerics							750		
Sun Hydraulics				15,000	0	0	15,000		
Sun Source				12,000	0	0	12,000		
Tennant				12,000	0	0	12,000		
The Toro Company				12,000	0	0	12,000		
Trelleborg Sealing Solutions				30,000	0	0	15,000		
Veljan Hydrair Private Limite				5,000	0	0	5,000		
Total	**$0**	**$0**	**$0**	**$698,000**	**$0**	**$1,065,947**	**$703,000**	**$0**	**$790,235**

1 - In 2003 -2004 Associated Projects Data was not collected.

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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.

Major equipment enhancements have been seen throughout the CCEFP universities. Three major additions of research equipment have been listed as infrastructure nuggets. These are the instrumented treadmill at Illinois Urbana-Champaign, the hydraulic dynamometer with regeneration at MSOE and the experimental setup for fluid power noise evaluation at Georgia Tech. Two infrastructure additions are currently under construction, and will be reported on in detail in next year's progress report. These are a major upgrade in the hydraulic experimental capabilities at Purdue and the construction of a hydrostatic engine dynamometer at Minnesota. The hydrostatic dynamometer project is receiving $60,000 in component donations from industry.

The University of Minnesota has made major investments in research facilities for fluid power. The research space has been doubled and is currently 4000 square feet. The university has invested $77,000 to renovate this space. CCEFP member companies have donated $130,000 in fluid power equipment to help with the facilities upgrade.

The headquarters space at the lead university occupies 1700 square feet. It is a short walk from the mechanical engineering building, the location of the major research facilities. The University of Minnesota has spent $40,000 upgrading the headquarter space. Extensive videoconferencing infrastructure exists among CCEFP universities, but the technology of web casting is displacing videoconferencing. Web casting is used frequently for center wide overview presentations, research presentations, and progress reporting. The major technical shortcoming of web casting is the poor audio quality. This problem has been solved by combining web casting with teleconferencing.

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 3

FOR NSF USE ONLY

ORGANIZATION **Univeristy of Minnesota**	PROPOSAL NO.	DURATION (MONTHS) Proposed / Granted
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR	AWARD NO.	

A. SENIOR PERSONNEL: PI/PD, Co-PI´S, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-months CAL	ACAD	SUMR	Funds Requested By Proposer	Funds Granted by NSF
0. First Name M Last Name Title	CAL	ACAD	SUMR		
1. Kim A Stelson Dr.	1.00	0.00	2.00	$45,108	
2. Perry Li Dr.	0.00	0.00	2.00	$26,596	
3. William Durfee Dr.	0.00	0.00	1.50	$22,554	
4. TBA - new faculty	0.00	0.00	1.00	$8,445	
5.	0.00	0.00	0.00	$0	
(4) TOTAL SENIOR PERSONNEL (1-6)				**$102,703**	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. 1) POST DOCTORAL ASSOCIATES	9.00	0.00	0.00	$46,000	
2. 0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	0.00	0.00	0.00	$0	
3. 7) GRADUATE STUDENTS				$164,024	
4. 4) UNDERGRADUATE STUDENTS				$12,000	
5. 2) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				$100,000	
6. 0) OTHER				$0	
TOTAL SALARIES AND WAGES (A+B)				**$424,727**	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				$148,654	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A+B+C)				**$573,381**	
D. PERMANENT EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000)					
TOTAL EQUIPMENT				**$38,259**	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				$27,000	
2. FOREIGN				$0	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS $0					
2. TRAVEL $0					
3. SUBSISTENCE $0					
4. OTHER $0					
(0) TOTAL NUMBER OF PARTICIPANTS				**$0**	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				$30,000	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				$10,000	
3. CONSULTANT SERVICES				$10,000	
4. COMPUTERS SERVICES				$0	
5. SUBAWARDS				$2,491,945	
6. OTHER				$75,000	
TOTAL OTHER DIRECT COSTS				**$2,616,945**	
H. TOTAL DIRECT COSTS (A THROUGH G)				**$3,255,585**	
I. INDIRECT COSTS (SPECIFY RATE AND BASE)					
Name of indirect cost item / Amount / Rate					
48.5% of TDC less equipment, GRA student frir $244,415	48.50%	**$503,948**			
TOTAL INDIRECT COSTS				**$244,415**	
J. TOTAL DIRECT AND INDIRECT COSTS (H+I)				**$3,500,000**	
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)				$3,500,000	
M. COST SHARING: PROPOSED LEVEL AGREED LEVEL IF DIFFERENT $				$0	

PI/PD NAME	DATE	**FOR NSF USE ONLY**
PIFullName	12/31/94	INDIRECT COST RATE VERIFICATION

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Volume I, Appendix I

Glossary of Acronyms and special Terms

VOLUME I, APPENDIX I

Glossary of Acronyms and Special Terms:

ABE ……………	Agricultural and Biological Engineering
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
CCEFP …………	Center of Compact and Efficient Fluid Power
CFD ……………	Computational Fluid Dynamics
CNT ……………	carbon nano-tubes
CPES …………...	Center for Power Electronic Systems
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
FFA …………….	Future Farmers of America
FIRST ………….	For Inspiration and Recognition of Science and Technology
FLUENT ®……..	Commercial Computational Fluid Dynamics Code
FP ………………	fluid power
FY ……………...	fiscal year
GIDAA ………...	Gidakiimanaaniwigamig (Our Earth Lodge)
GT ……………..	Georgia Institute of Technology
H & P …………..	hydraulics and pneumatics
HBCU ………….	Historically Black College and University
HEPA ………….	High-Efficiency Particulate Air
HP ……………...	horsepower
HTGS ………….	High Tech Girls Society
IAB …………….	Industrial Advisory Board
IC ………………	internal combustion
LES …………….	large eddy simulation

LS ……………..	load sensing
LSAMP ………..	Louis Stokes Alliance for Minority Participation
LSHT …………..	low-speed high-torque
MACM ………...	Multi-Aspect Component Models
ME ……………..	Mechanical Engineering
MSOE ………….	Milwaukee School of Engineering
Nano-CEMMS …	Nanoscale Chemical-Electrical-Mechanical Manufacturing Systems
NCAT ………….	North Carolina Agricultural and Technical State University
NFPA …………..	National Fluid Power Association
NRCEN ………...	National Science Foundation's Research Centers Educators Network
NSF …………….	National Science Foundation
OMG SysML …..	modeling language for OMG technology
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
SEM ……………	scanning electron microscopy
SLC …………….	Student Leadership Council
SMM …………..	Science Museum of Minnesota
STEM ………….	Science Technology Engineering and Mathematics
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
VEX ……………	Visual Editor for XML
VIATRA ……….	Visual Automated Model Transformations

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VOLUME I, APPENDIX II

AGREEMENTS AND CERTIFICATIONS

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, NSF Grant EEC #0540834 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. The Center will invoice each Member no less than sixty (60) days before each payment is due. Checks should be made payable to University of Minnesota and mailed to ERC for Compact and Efficient Fluid Power at 1100 Mechanical Engineering, 111 Church St., Minneapolis, MN 55455. 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 J 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 J. 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 ADDRESS	**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/Adminstrative: 200 Oak Street SE, Suite 450 Minneapolis, MN 55455	Sponsored Projects Admin- Tyra Darville-Layne 612-626-7634 darvi001@umn.edu	
Financial: Mechanical Engineering 111 Church St. SE Minneapolis, MN 55455	Stephanie Bettermann 612-624-4993 sbetter@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 Research Center

Name Kevin McKoskey, CRA
Senior Grants Manager
Title

Date: 12-17-07

CERTIFIED AOR

MEMBER

Name

Title

Date:

Private Sector Firms

AAA Products International
Air Logic
Aladco
Bimba Manufacturing Co.
Bobcat *
Bosch Rexroth Corp
Caterpillar Inc.
Command Controls Corp.
Deere & Co. *
Deltrol Fluid Products
Donaldson Co. Inc..
Eaton Corp.
Enfield Technologies
Festo Corp.
G.W. Lisk Co., Inc..
Gates Corp.
HÃgglunds Drives Inc.
Haldex Hydraulics Corp.
HECO Gear, Inc..
Hedland Flow Meters
High Country Tek, Inc.
HUSCO International, Inc..
HYDAC Corp.
Hydraquip Corp.
INA USA Corp. *
Kepner Products Co *
Linde Hydraulics Corp.
MAIN Mfg. Products Inc..
Master Pneumatic-Detroit, Inc.
Mead Fluid Dynamics
MICO, Inc.orporated
Moog Inc..
MTS Systems Corp.
National Fluid Power Association
National Tube Supply Co.
Netshape Technologies, Inc. *
Nexen Group, Inc..
Parker Hannifin Corp.
PHD, Inc.
PIAB Vacuum Products
Poclain Hydraulics
Quality Control Corp.
R. T. Dygert International
RB Royal Industries, Inc.
RohMax USA, LP
Ross Controls
Sauer-Danfoss
Schroeder Industries LLC

Shell Global Solutions
Simerics
Sun Hydraulics Corp
Sun Source (STS Operating, Inc..)
Tennant
The Toro Co.
Trelleborg Sealing Solutions U.S. Inc..
Veljan Hydrair Private Ltd.

Non-private sector firms
Fluid Power Educational Foundation
International Fluid Power Society
Ralph Rivera

* Company has either submitted dues, but not membership agreement, or submitted membership agreement, but not year 2 dues

CERTIFIED BY AOR

Kevin McKoskey, CRA
Senior Grants Manager
Office of Sponsored Projects Administration

Table 9B - Cost Sharing by Institution

	Award Year 1		Award Year 2		Cummulative
Institution	**Committed**	**Actual**	**Committed**	**Actual**	
U. of Minnesota	$180,180	$180,180	$182,000	-	$362,180
Georgia Tech	$112,860	$112,859	$129,000	-	$241,860
Milwaukee School of Eng	$0	$0	$10,800	-	$10,800
Purdue	$112,860	$112,860	$129,000	-	$241,860
UIUC	$112,860	$131,129	$123,200	-	$236,060
Vanderbilt	$75,240	$75,240	$76,000	-	$151,240

CERTIFIED BY AOR

Edward Wink
Associate VP for Research

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

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	$1,909,689	$106,173
Committed, Encumbered, Obligated funds	$795,442	$0
Residual Funds Without Specified Use	$1,114,247	$106,173

Edward F. Wink
Associate Vice President for Research
Office of Sponsored Projects Administration

VOLUME I, APPENDIX III

CURRENT AND PENDING SUPPORT DOCUMENTATION

Current and Pending Support

See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: Kim Stelson, Director

Other agencies (including NSF) to which this proposal has been/will be

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Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Center for Compact and Efficient Fluid Power

Source of Support: NSF

Total Award Amount: $17,470,000 Total Award Period Covered: 6/1/2006 - 5/31/2011

Location of Project: University of Minnesota

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr: 2

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

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*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

NSF Form 1239 (7/95) USE ADDITIONAL SHEETS AS NECESSARY

Current and Pending Support

See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: Perry Li

Other agencies (including NSF) to which this proposal has been/will be

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Center for Compact and Efficient Fluid Power

Source of Support: NSF

Total Award Amount: $17,470,000 Total Award Period Covered: 6/1/2006 - 5/31/2011

Location of Project: University of Minnesota

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr: 1.5

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

NSF Form 1239 (7/95) USE ADDITIONAL SHEETS AS NECESSARY

Current and Pending Support

See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: William Durfee

Other agencies (including NSF) to which this proposal has been/will be

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:
Center for Compact and Efficient Fluid Power

Source of Support: NSF
Total Award Amount: $17,470,000 Total Award Period Covered: 6/1/2006 - 5/31/2011
Location of Project: University of Minnesota
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr: 1.5

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

NSF Form 1239 (7/95) USE ADDITIONAL SHEETS AS NECESSARY

Current and Pending Support

See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: Monika Ivantysynova	Other agencies (including NSF) to which this proposal has been/will be

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Center for Compact and Efficient Fluid Power

Source of Support: NSF

Total Award Amount: $17,470,000 Total Award Period Covered: 6/1/2006 - 5/31/2011

Location of Project: University of Minnesota

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr: 1

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

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*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

NSF Form 1239 (7/95) USE ADDITIONAL SHEETS AS NECESSARY

Current and Pending Support

See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: Andrew Alleyne

Other agencies (including NSF) to which this proposal has been/will be

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:
Center for Compact and Efficient Fluid Power

Source of Support: NSF
Total Award Amount: $17,470,000 Total Award Period Covered: 6/1/2006 - 5/31/2011
Location of Project: University of Minnesota
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr: 1

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

NSF Form 1239 (7/95) USE ADDITIONAL SHEETS AS NECESSARY

Current and Pending Support

See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: Wayne Book

Other agencies (including NSF) to which this proposal has been/will be

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Center for Compact and Efficient Fluid Power

Source of Support: NSF

Total Award Amount: $17,470,000 Total Award Period Covered: 6/1/2006 - 5/31/2011

Location of Project: University of Minnesota

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr: 1

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

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Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support

Project/Proposal Title:

Source of Support:

Total Award Amount: $ Total Award Period Covered:

Location of Project:

Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

NSF Form 1239 (7/95) USE ADDITIONAL SHEETS AS NECESSARY

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VOLUME I, APPENDIX IV

TABLE 7: PERSONNEL

Table 7: ERC Personnel																	
					Citizenship Status									Ethnicity: Hispanic			
		Gender			Race: U.S. citizens and permanent residents only												
Personnel Type	Total	Male	Female	Gender Not Reported	NA	PI	AA	C	A	Mixed - inc. NA, PI, AA	Mixed - C, A	Not Provided	Other Non-U.S.	US/Perm	Temp	Not Reported	Disability
Total - All Institutions																	
Total	**205**	**176**	**29**	**0**	**4**	**0**	**23**	**135**	**10**	**0**	**0**	**15**	**18**	**8**	**0**	**0**	**3**
Leadership/Administration																	
Sub Total	**17**	**10**	**7**	**0**	**1**	**0**	**1**	**13**	**1**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**1**
Directors	2	2	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
Thrust Leaders	3	2	1	0	0	0	1	2	0	0	0	0	0	0	0	0	0
Research Thrust Management and Strategic Planning	0	0	0	0	0	0	0	0	0	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	3	1	2	0	0	0	0	3	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	1
Staff	7	4	3	0	1	0	0	5	0	0	0	0	1	0	0	0	0
Research																	
Sub Total	**138**	**122**	**16**	**0**	**0**	**0**	**14**	**87**	**8**	**0**	**0**	**13**	**16**	**4**	**0**	**0**	**2**
Senior Faculty	14	11	3	0	0	0	1	10	1	0	0	0	2	0	0	0	0
Junior Faculty	10	8	2	0	0	0	0	7	3	0	0	0	0	0	0	0	0
Research Staff	6	6	0	0	0	0	0	5	0	0	0	1	0	0	0	0	0
Visiting Faculty	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Industry Researchers	20	19	1	0	0	0	0	14	1	0	0	2	3	1	0	0	1
Post Docs	2	2	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0
Doctoral Students	24	22	2	0	0	0	1	12	1	0	0	3	7	1	0	0	0
Master's Students	32	29	3	0	0	0	7	18	1	0	0	4	2	0	0	0	0
Undergraduate Students	29	24	5	0	0	0	5	20	1	0	0	3	0	2	0	0	1
Outreach																	
Sub Total	**18**	**16**	**2**	**0**	**3**	**0**	**1**	**13**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Senior Faculty	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Junior Faculty	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Research Staff	4	3	1	0	0	0	0	4	0	0	0	0	0	0	0	0	0
Visiting Faculty	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Industry Researchers	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Post Docs	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Doctoral Students	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Master's Students	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Undergraduate Students	12	11	1	0	3	0	0	9	0	0	0	0	0	0	0	0	0
REU Students																	
Sub Total	**27**	**25**	**2**	**0**	**0**	**0**	**6**	**20**	**0**	**0**	**0**	**0**	**1**	**4**	**0**	**0**	**0**
NSF REU Program	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NSF/ERC Program REU	18	16	2	0	0	0	4	13	0	0	0	0	1	2	0	0	0
ERC's Own REU	9	9	0	0	0	0	2	7	0	0	0	0	0	2	0	0	0
Other Visiting College Students	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pre-College (K-14)																	
Sub Total	**5**	**3**	**2**	**0**	**0**	**0**	**1**	**2**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**0**
Students	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Teachers (RET)	5	3	2	0	0	0	1	2	0	0	0	2	0	0	0	0	0
Teachers (non-RET)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Personnel Type	Total	Gender			Citizenship Status: Race: U.S. citizens and permanent residents only								Citizenship Status	Ethnicity: Hispanic			Disability
		Male	Female	Gender Not Reported	NA	PI	AA	C	A	Mixed - inc. NA, PI, AA	Mixed - C, A	Not Provided	Other Non-U.S.	US/Perm	Temp	Not Reported	
University of Minnesota - Lead Institution																	
Total	**47**	**37**	**10**	**0**	**4**	**0**	**0**	**35**	**4**	**0**	**0**	**1**	**3**	**0**	**0**	**0**	**1**
Leadership/Administration																	
Sub Total	**12**	**6**	**6**	**0**	**1**	**0**	**0**	**10**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**
Directors	2	2	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
Thrust Leaders	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Research Thrust Management and Strategic Planning	0	0	0	0	0	0	0	0	0	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	3	1	2	0	0	0	0	3	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	1
Staff	5	2	3	0	1	0	0	4	0	0	0	0	0	0	0	0	0
Research																	
Sub Total	**19**	**16**	**3**	**0**	**0**	**0**	**0**	**12**	**3**	**0**	**0**	**1**	**3**	**0**	**0**	**0**	**0**
Senior Faculty	5	3	2	0	0	0	0	5	0	0	0	0	0	0	0	0	0
Junior Faculty	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Research Staff	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Visiting Faculty	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Industry Researchers	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Post Docs	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Doctoral Students	7	6	1	0	0	0	0	4	1	0	0	0	2	0	0	0	0
Master's Students	3	3	0	0	0	0	0	1	1	0	0	1	0	0	0	0	0
Undergraduate Students	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Outreach																	
Sub Total	**12**	**11**	**1**	**0**	**3**	**0**	**0**	**9**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Senior Faculty	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Junior Faculty	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Research Staff	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Visiting Faculty	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Industry Researchers	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Post Docs	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Doctoral Students	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Master's Students	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Undergraduate Students	12	11	1	0	3	0	0	9	0	0	0	0	0	0	0	0	0
REU Students																	
Sub Total	**3**	**3**	**0**	**0**	**0**	**0**	**0**	**3**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
NSF REU Program	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NSF/ERC Program REU	2	2	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
ERC's Own REU	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Other Visiting College Students	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pre-College (K-14)																	
Sub Total	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Students	0	0	0	0	0	0	0	0	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
Teachers (non-RET)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Personnel Type	Total	Gender			Citizenship Status									Ethnicity: Hispanic			Disability
					Race: U.S. citizens and permanent residents only								Other Non-U.S.				
		Male	Female	Gender Not Reported	NA	PI	AA	C	A	Mixed - inc. NA, PI, AA	Mixed - C, A	Not Provided		US/Perm	Temp	Not Reported	
Total - All Core Partners																	
Total	**98**	**88**	**10**	**0**	**0**	**0**	**6**	**68**	**3**	**0**	**0**	**9**	**12**	**5**	**0**	**0**	**2**
Leadership/Administration																	
Sub Total	**4**	**3**	**1**	**0**	**0**	**0**	**1**	**2**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**
Directors	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Thrust Leaders	3	2	1	0	0	0	1	2	0	0	0	0	0	0	0	0	0
Research Thrust Management and Strategic Planning	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Industrial Liaison Officer (ILO)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Education Program Leaders	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Administrative Director	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Staff	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Research																	
Sub Total	**78**	**72**	**6**	**0**	**0**	**0**	**1**	**55**	**3**	**0**	**0**	**8**	**11**	**4**	**0**	**0**	**2**
Senior Faculty	6	6	0	0	0	0	0	5	0	0	0	0	1	0	0	0	0
Junior Faculty	5	3	2	0	0	0	0	4	1	0	0	0	0	0	0	0	0
Research Staff	3	3	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
Visiting Faculty	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Industry Researchers	18	17	1	0	0	0	0	13	1	0	0	1	3	1	0	0	1
Post Docs	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Doctoral Students	16	16	0	0	0	0	0	8	0	0	0	3	5	1	0	0	0
Master's Students	16	15	1	0	0	0	0	13	0	0	0	2	1	0	0	0	0
Undergraduate Students	13	11	2	0	0	0	1	9	1	0	0	2	0	2	0	0	1
Outreach																	
Sub Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Senior Faculty	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Junior Faculty	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Research Staff	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Visiting Faculty	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Industry Researchers	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Post Docs	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Doctoral Students	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Master's Students	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Undergraduate Students	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
REU Students																	
Sub Total	**13**	**12**	**1**	**0**	**0**	**0**	**3**	**10**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**
NSF REU Program	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NSF/ERC Program REU	8	7	1	0	0	0	2	6	0	0	0	0	0	0	0	0	0
ERC's Own REU	5	5	0	0	0	0	1	4	0	0	0	0	0	1	0	0	0
Other Visiting College Students	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pre-College (K-14)																	
Sub Total	**3**	**1**	**2**	**0**	**0**	**0**	**1**	**1**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**
Students	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Teachers (RET)	3	1	2	0	0	0	1	1	0	0	0	1	0	0	0	0	0
Teachers (non-RET)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Personnel Type	Total	Gender			Citizenship Status									Ethnicity: Hispanic			Disability
					Race: U.S. citizens and permanent residents only												
		Male	Female	Gender Not Reported	NA	PI	AA	C	A	Mixed - inc. NA, PI, AA	Mixed - C, A	Not Provided	Other Non-U.S.	US/Perm	Temp	Not Reported	
University of Illinois at Urbana-Champaign - Core Partner																	
Total	**19**	**16**	**3**	**0**	**0**	**0**	**2**	**13**	**1**	**0**	**0**	**2**	**1**	**1**	**0**	**0**	**1**
Leadership/Administration																	
Sub Total	**1**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Thrust Leaders	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Research																	
Sub Total	**15**	**13**	**2**	**0**	**0**	**0**	**0**	**11**	**1**	**0**	**0**	**2**	**1**	**1**	**0**	**0**	**1**
Senior Faculty	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Junior Faculty	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Industry Researchers	5	5	0	0	0	0	0	4	0	0	0	1	0	1	0	0	0
Doctoral Students	2	2	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
Master's Students	5	4	1	0	0	0	0	3	0	0	0	1	1	0	0	0	0
Undergraduate Students	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
REU Students																	
Sub Total	**3**	**2**	**1**	**0**	**0**	**0**	**1**	**2**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
NSF/ERC Program REU	2	1	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0
ERC's Own REU	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Purdue University - Core Partner																	
Total	**32**	**29**	**3**	**0**	**0**	**0**	**2**	**22**	**1**	**0**	**0**	**0**	**7**	**2**	**0**	**0**	**1**
Leadership/Administration																	
Sub Total	**2**	**1**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**
Thrust Leaders	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Staff	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Research																	
Sub Total	**26**	**24**	**2**	**0**	**0**	**0**	**1**	**18**	**1**	**0**	**0**	**0**	**6**	**1**	**0**	**0**	**1**
Senior Faculty	2	2	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0
Junior Faculty	2	1	1	0	0	0	0	2	0	0	0	0	0	0	0	0	0
Industry Researchers	12	11	1	0	0	0	0	8	1	0	0	0	3	0	0	0	1
Doctoral Students	3	3	0	0	0	0	0	1	0	0	0	0	2	0	0	0	0
Master's Students	6	6	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0
Undergraduate Students	1	1	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0
REU Students																	
Sub Total	**3**	**3**	**0**	**0**	**0**	**0**	**1**	**2**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**
NSF/ERC Program REU	2	2	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
ERC's Own REU	1	1	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0
Pre-College (K-14)																	
Sub Total	**1**	**1**	**0**	**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

Personnel Type	Total	Gender			Citizenship Status									Ethnicity: Hispanic			Disability
					Race: U.S. citizens and permanent residents only												
		Male	Female	Gender Not Reported	NA	PI	AA	C	A	Mixed - inc. NA, PI, AA	Mixed - C, A	Not Provided	Other Non-U.S.	US/Perm	Temp	Not Reported	
Georgia Institute of Technology - Core Partner																	
Total	**26**	**23**	**3**	**0**	**0**	**0**	**2**	**19**	**1**	**0**	**0**	**2**	**2**	**0**	**0**	**0**	**0**
Leadership/Administration																	
Sub Total	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Thrust Leaders	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Research																	
Sub Total	**22**	**20**	**2**	**0**	**0**	**0**	**0**	**17**	**1**	**0**	**0**	**2**	**2**	**0**	**0**	**0**	**0**
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
Research Staff	2	2	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
Industry Researchers	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Post Docs	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Doctoral Students	4	4	0	0	0	0	0	2	0	0	0	1	1	0	0	0	0
Master's Students	5	5	0	0	0	0	0	4	0	0	0	1	0	0	0	0	0
Undergraduate Students	6	4	2	0	0	0	0	5	1	0	0	0	0	0	0	0	0
REU Students																	
Sub Total	**2**	**2**	**0**	**0**	**0**	**0**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
NSF/ERC Program REU	2	2	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
Pre-College (K-14)																	
Sub Total	**1**	**0**	**1**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Teachers (RET)	1	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Vanderbilt University - Core Partner																	
Total	**21**	**20**	**1**	**0**	**0**	**0**	**0**	**14**	**0**	**0**	**0**	**5**	**2**	**2**	**0**	**0**	**0**
Research																	
Sub Total	**15**	**15**	**0**	**0**	**0**	**0**	**0**	**9**	**0**	**0**	**0**	**4**	**2**	**2**	**0**	**0**	**0**
Senior Faculty	1	1	0	0	0	0	0	1	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
Research Staff	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Doctoral Students	7	7	0	0	0	0	0	3	0	0	0	2	2	1	0	0	0
Undergraduate Students	5	5	0	0	0	0	0	3	0	0	0	2	0	1	0	0	0
REU Students																	
Sub Total	**5**	**5**	**0**	**0**	**0**	**0**	**0**	**5**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
NSF/ERC Program REU	2	2	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
ERC's Own REU	3	3	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
Pre-College (K-14)																	
Sub Total	**1**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**
Teachers (RET)	1	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0

Personnel Type	Total	Gender			Citizenship Status									Ethnicity: Hispanic			Disability
					Race: U.S. citizens and permanent residents only								Other Non-U.S.				
		Male	Female	Gender Not Reported	NA	PI	AA	C	A	Mixed - inc. NA, PI, AA	Mixed - C, A	Not Provided		US/Perm	Temp	Not Reported	
Total - Collaborating (Outreach) Institutions																	
Total	**54**	**46**	**8**	**0**	**0**	**0**	**16**	**27**	**3**	**0**	**0**	**5**	**3**	**1**	**0**	**0**	**0**
Leadership/Administration																	
Sub Total	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Directors	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Thrust Leaders	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Research Thrust Management and Strategic Planning	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Industrial Liaison Officer (ILO)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Education Program Leaders	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Administrative Director	0	0	0	0	0	0	0	0	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
Research																	
Sub Total	**41**	**34**	**7**	**0**	**0**	**0**	**13**	**20**	**2**	**0**	**0**	**4**	**2**	**0**	**0**	**0**	**0**
Senior Faculty	3	2	1	0	0	0	1	0	1	0	0	0	1	0	0	0	0
Junior Faculty	4	4	0	0	0	0	0	3	1	0	0	0	0	0	0	0	0
Research Staff	3	3	0	0	0	0	0	2	0	0	0	1	0	0	0	0	0
Visiting Faculty	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Industry Researchers	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Post Docs	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Doctoral Students	1	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Master's Students	13	11	2	0	0	0	7	4	0	0	0	1	1	0	0	0	0
Undergraduate Students	16	13	3	0	0	0	4	11	0	0	0	1	0	0	0	0	0
Outreach																	
Sub Total	**6**	**5**	**1**	**0**	**0**	**0**	**1**	**4**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Senior Faculty	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Junior Faculty	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Research Staff	4	3	1	0	0	0	0	4	0	0	0	0	0	0	0	0	0
Visiting Faculty	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Industry Researchers	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Post Docs	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Doctoral Students	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Master's Students	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Undergraduate Students	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
REU Students																	
Sub Total	**5**	**5**	**0**	**0**	**0**	**0**	**2**	**2**	**0**	**0**	**0**	**0**	**1**	**1**	**0**	**0**	**0**
NSF REU Program	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NSF/ERC Program REU	4	4	0	0	0	0	1	2	0	0	0	0	1	1	0	0	0
ERC's Own REU	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Other Visiting College Students	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pre-College (K-14)																	
Sub Total	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**
Students	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Teachers (RET)	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Teachers (non-RET)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Personnel Type	Total	Gender			Citizenship Status									Ethnicity: Hispanic			Disability
					Race: U.S. citizens and permanent residents only								Other Non-U.S.				
		Male	Female	Gender Not Reported	NA	PI	AA	C	A	Mixed - inc. NA, PI, AA	Mixed - C, A	Not Provided		US/Perm	Temp	Not Reported	
Milwaukee School of Engineering - Collaborating (Outreach) Institution																	
Total	**27**	**26**	**1**	**0**	**0**	**0**	**0**	**22**	**1**	**0**	**0**	**3**	**1**	**1**	**0**	**0**	**0**
Leadership/Administration																	
Sub Total	**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
Research																	
Sub Total	**23**	**22**	**1**	**0**	**0**	**0**	**0**	**19**	**0**	**0**	**0**	**3**	**1**	**0**	**0**	**0**	**0**
Junior Faculty	2	2	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
Research Staff	3	3	0	0	0	0	0	2	0	0	0	1	0	0	0	0	0
Industry Researchers	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Master's Students	5	5	0	0	0	0	0	4	0	0	0	0	1	0	0	0	0
Undergraduate Students	12	11	1	0	0	0	0	11	0	0	0	1	0	0	0	0	0
Outreach																	
Sub Total	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Senior Faculty	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
REU Students																	
Sub Total	**2**	**2**	**0**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**
NSF/ERC Program REU	2	2	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0
North Carolina Agriculture and Technical State University - Collaborating (Outreach) Institution																	
Total	**23**	**17**	**6**	**0**	**0**	**0**	**16**	**1**	**2**	**0**	**0**	**2**	**2**	**0**	**0**	**0**	**0**
Research																	
Sub Total	**18**	**12**	**6**	**0**	**0**	**0**	**13**	**1**	**2**	**0**	**0**	**1**	**1**	**0**	**0**	**0**	**0**
Senior Faculty	3	2	1	0	0	0	1	0	1	0	0	0	1	0	0	0	0
Junior Faculty	2	2	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
Doctoral Students	1	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Master's Students	8	6	2	0	0	0	7	0	0	0	0	1	0	0	0	0	0
Undergraduate Students	4	2	2	0	0	0	4	0	0	0	0	0	0	0	0	0	0
Outreach																	
Sub Total	**1**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Junior Faculty	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
REU Students																	
Sub Total	**3**	**3**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**
NSF/ERC Program REU	2	2	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0
ERC's Own REU	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Pre-College (K-14)																	
Sub Total	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**
Teachers (RET)	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0

Personnel Type	Total	Gender			Citizenship Status									Ethnicity: Hispanic			Disability
					Race: U.S. citizens and permanent residents only								Other Non-U.S.				
		Male	Female	Gender Not Reported	NA	PI	AA	C	A	Mixed - inc. NA, PI, AA	Mixed - C, A	Not Provided		US/Perm	Temp	Not Reported	
Science Museum of Minnesota - Collaborating (Outreach) Institution																	
Total	**4**	**3**	**1**	**0**	**0**	**0**	**0**	**4**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Outreach																	
Sub Total	**4**	**3**	**1**	**0**	**0**	**0**	**0**	**4**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Research Staff	4	3	1	0	0	0	0	4	0	0	0	0	0	0	0	0	0
Total - Non-ERC Institutions Providing REU Students																	
Total	**6**	**5**	**1**	**0**	**0**	**0**	**1**	**5**	**0**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**0**
REU Students																	
Sub Total	**6**	**5**	**1**	**0**	**0**	**0**	**1**	**5**	**0**	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**0**
NSF REU Program	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NSF/ERC Program REU	4	3	1	0	0	0	1	3	0	0	0	0	0	1	0	0	0
ERC's Own REU	2	2	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0
University of Florida - Non-ERC Institutions Providing REU Students																	
Total	**1**	**0**	**1**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
REU Students																	
Sub Total	**1**	**0**	**1**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
NSF/ERC Program REU	1	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Universidad Del Turabo - Non-ERC Institutions Providing REU Students																	
Total	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**
REU Students																	
Sub Total	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**
NSF/ERC Program REU	1	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0
University of Puerto Rico - Non-ERC Institutions Providing REU Students																	
Total	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**
REU Students																	
Sub Total	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**
ERC's Own REU	1	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0
Colorado State University - Non-ERC Institutions Providing REU Students																	
Total	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
REU Students																	
Sub Total	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
NSF/ERC Program REU	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0

Personnel Type	Total	Gender			Citizenship Status									Ethnicity: Hispanic			Disability
					Race: U.S. citizens and permanent residents only								Other Non-U.S.				
		Male	Female	Gender Not Reported	NA	PI	AA	C	A	Mixed - inc. NA, PI, AA	Mixed - C, A	Not Provided		US/Perm	Temp	Not Reported	
Bemidji State University - Non-ERC Institutions Providing REU Students																	
Total	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
REU Students																	
Sub Total	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
NSF/ERC Program REU	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
The Cooper Union - Non-ERC Institutions Providing REU Students																	
Total	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
REU Students																	
Sub Total	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
ERC's Own REU	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0

Legend:

NA: Native American/Alaska Native

PI: Pacific Islanders, e.g., Guamanian or Chamorro, Samoan

AA: African American/Black

C: Caucasian

A: Asian, e.g., Asian Indian, Chinese, Filipino, Japanese, Korean, Vietnamese, Other Asian

Mixed-Incl. NA, PI, AA: Mixed including Native American/Alaska Native, Pacific Islanders, and African American/Black

Mixed-C, A: Mixed - Caucasian and Asian

US/Perm: U.S. citizens and legal permanent residents

Non-US: Non-U.S. citizens/Non-legal permanent residents