Research Direction and Projects from the Center for Compact and Efficient Fluid Power (CCEFP)

Georgia Institute of Technology | Milwaukee School of Engineering | North Carolina A&T State University | Purdue University
University of Illinois, Urbana-Champaign | University of Minnesota | Vanderbilt University

Prof. Kim Stelson
Director, Center for Compact and Efficient Fluid Power
University of Minnesota

Energy Efficient Hydraulics and Pneumatics Conference
November 29, 2012

CCEFP Mission

CHANGING THE WAY FLUID POWER IS RESEARCHED, APPLIED AND TAUGHT

CCEFP Vision Statement

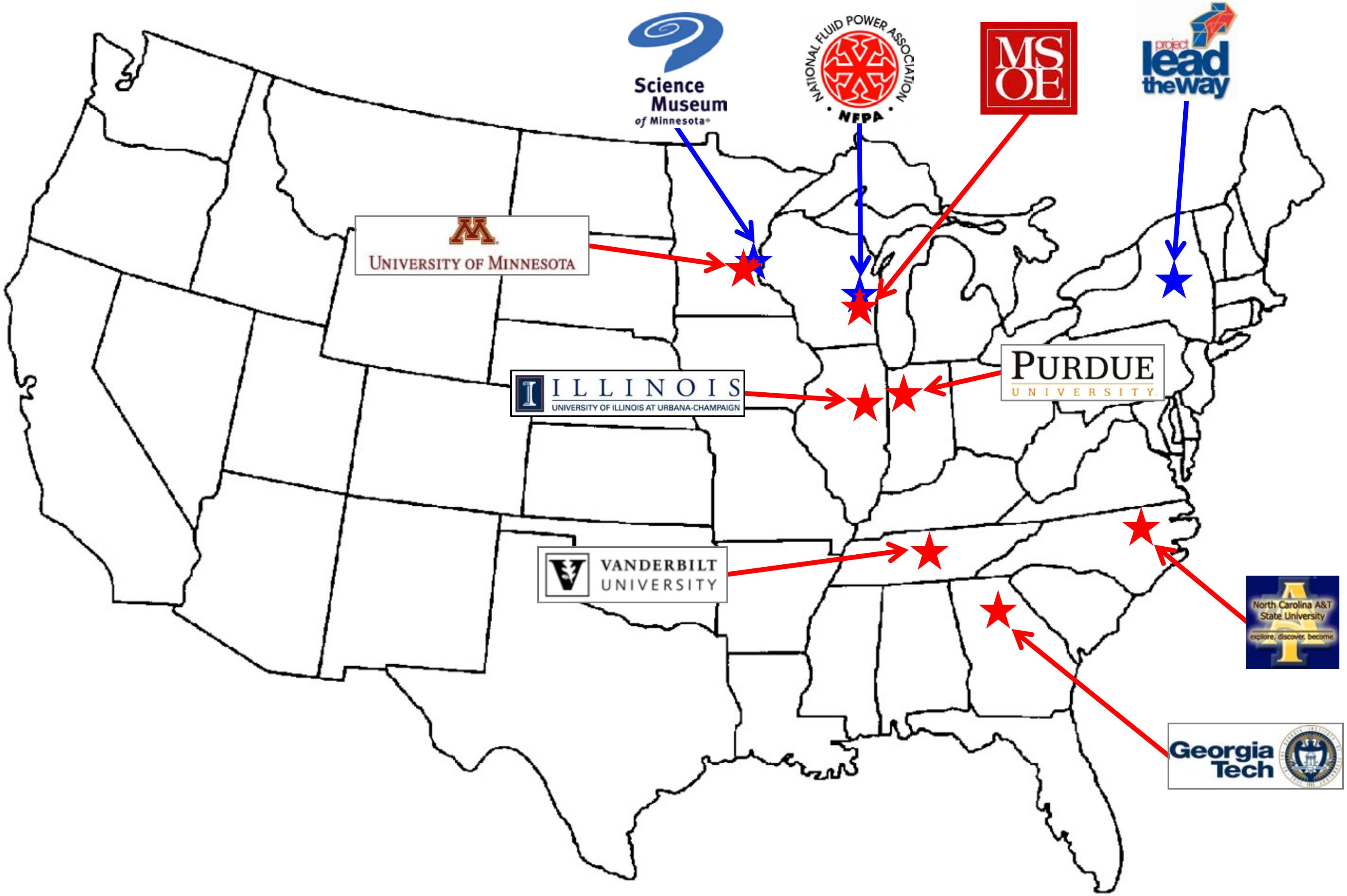
Making fluid power <u>compact</u>, <u>efficient</u> and <u>effective</u>

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

Major goals

1. Doubling fuel efficiency in current applications
2. Expand fluid power use in transportation
3. Create portable, un-tethered human-scale fluid power applications
4. Ubiquity - fluid power that can be used anywhere

CCEFP Locations



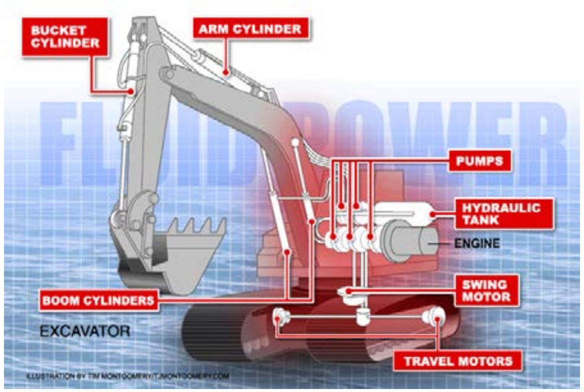
FY 7-8 CCEFP-Funded Projects

Project #	Project Name	Principal Investigator
1A.1	Technology Transfer Process for Energy Management Systems	Alleyne (UIUC)
1A.2	Control and Prognostics for Hybrid Displacement Control Systems	Ivantysynova (Purdue)
1B.1	Next Steps towards Virtual Prototyping of Pumps and Motors	Ivantysynova (Purdue)
1D	Microtextured Surfaces for Low Friction / Leakage	King (UIUC)
1E.3	Actively Controlled Digital Pump/Motor	Lumkes (Purdue)
1E.5	System Configuration & Control Using Hydraulic Transformers	Li (Minnesota)
1E.6	High Performance Valves Enabled by Kinetic Energy	Lumkes (Purdue)
1F.1	Variable Displacement External Gear Machine	Vacca (Purdue)
1G.1	Energy Efficient Fluids	Michael (MSOE)
2B.2	Miniature HCCI Free-Piston Engine Compressor	Durfee (Minnesota)
2B.3	Free-Piston Engine Hydraulic Pump	Sun (Minnesota)
2B.4	Controlled Stirling Thermocompressor	Barth (Vanderbilt)
2C.2	Advanced Strain Energy Accumulator	Barth (Vanderbilt)
2F	MEMS Proportional Valve	Chase (Minnesota)
2G	Fluid-Powered Surgery & Rehabilitation via Compact, Integrated Systems	Webster (Vanderbilt)
3A.1	Tele-operation Efficiency Improvements by Operator Interface	Book (Georgia Tech)
3A.3	Human Performance Modeling and User Centered Design	Jiang (NCAT)
3B.3	Active Vibration Damping of Mobile Hydraulic Machines	Vacca (Purdue)
3D.1	Leakage/Seal Friction Reduction in Fluid Power Systems	Salant (Georgia Tech)
3D.2	New Directions in the Rheology of Elastohydrodynamics	Bair (Georgia Tech)
3E.1	Pressure Ripple Energy Harvester	Cunefare (Georgia Tech)

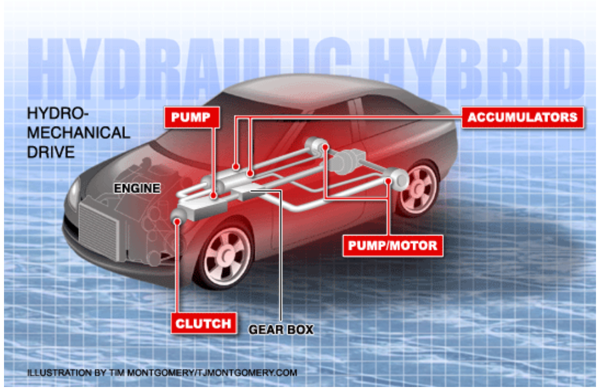
= New Project for FY 7-8

More than $8M per year in funding
Industry has a lead role in the project solicitation and selection process

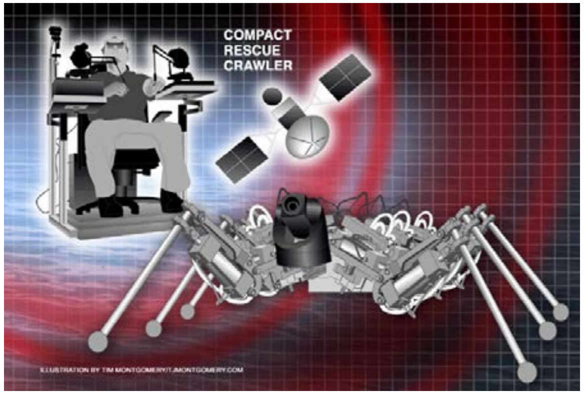
CCEFP Test Beds



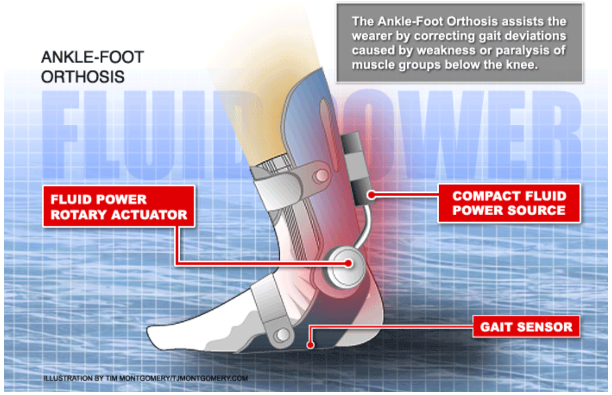
Test Bed 1: Mobile Heavy Equipment



Test Bed 3: Highway Vehicles



Test Bed 4: Mobile Human Scale Equipment



Test Bed 6: Human Assist Devices

Department of Energy Fluid Power Energy Study

- **DOE funded survey of 31 industry partners led by:**
  - Dr. Lonnie Love (Oak Ridge National Lab and CCEFP Scientific Advisory Board)
  - Eric Lanke and Peter Alles (NFPA)
- **Findings:**
  - Fluid power transmits 2.0 - 3.0% of the energy consumed in the US
  - Average fluid power efficiency is 21%
- **What does this mean?**
  - Huge potential for energy cost savings and emissions reductions
  - Extending the use of energy saving fluid power technologies to new industries and applications will provide additional savings

A 1% reduction is the nation's energy use is worth $20B

Off-Road Hybrid Hydraulic Systems

- Caterpillar unveiled the first model in its new line of hybrid excavators, the Cat® 336E H on October 16
- A hydraulic hybrid swing system captures the excavator's upper structure swing brake energy in accumulators and then releases the energy during swing acceleration
- Additional changes to lower fuel consumption include engine power management and Cat Adaptive Control System (ACS) valve which intelligently manages restrictions and flows to seamlessly control machine motion with no loss of power
- End users can expect the 336E H to use up to 25% less fuel compared to a standard 336E

Test Bed 1: Excavator

Excavator Test Bed has been fitted with variable displacement pumps

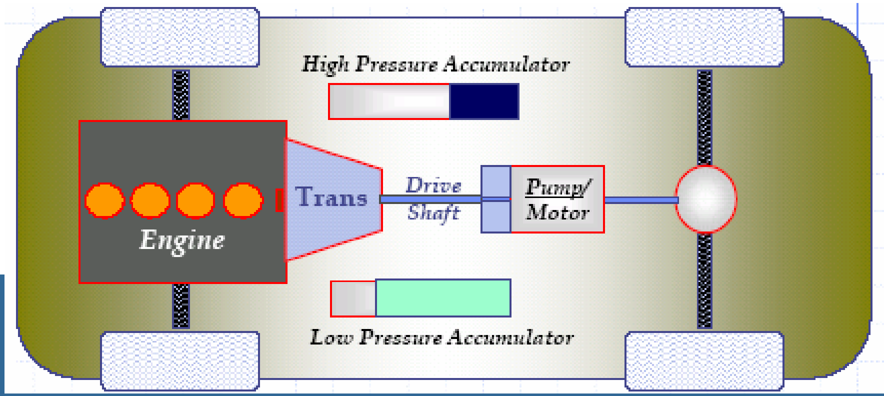
Displacement Controlled Fluid Power Systems for Off-Highway Vehicles

40+% fuel savings!

- Displacement control eliminates throttling valves and their losses
- 40% fuel savings verified in field tests at Caterpillar
- Hybridization, energy efficient fluids and improved human machine interface will save even more energy
- The technology is simpler, lighter, cheaper and more efficient than competing designs

Parallel Hybrid Hydraulic Systems

- Bosch Rexroth and Eaton sell parallel hybrid hydraulics systems targeted at refuse vehicles. Approximately 200 in use today.
- Some hydraulics manufacturers are increasing their focus on off-highway vehicles which are in their traditional markets.
- A startup, Lightning Hybrids, recently started production of a parallel hybrid hydraulic system initially targeting retrofits in the light and medium truck market.



Series Hybrid Hydraulic Systems

- Parker Hannifin's RunWise Series Hybrid Hydraulic System:
  - Series hybrid hydraulic up to 45 mph and direct mechanical transmission above 45 mph.
  - After more than a year in service, the pre-production fleet of Autocar E3 refuse trucks in south Florida have reduced fuel consumption by 43% (75% fuel economy improvement) and have 99% uptime. The City of Miami announced on Tuesday that they had ordered 29 more vehicles.

Power Split Hybrid Hydraulic Systems

- CCEFP researcher Monika Ivantysynova helped Parker Hannifin develop a hybrid hydromechanical transmission (HMT) for medium duty commercial vehicles.
- It functions like the Prius power split transmission with both hydraulic and mechanical paths for power transfer
- The hybrid HMT provides 50-70% better fuel economy than a conventional package delivery vehicle
- UPS ordered 40 package delivery vehicles with Freightliner chassis and Parker's hybrid HMT in October

Test Bed 3: Hybrid Hydraulic Passenger Vehicle

Project Goals:

- Develop hybrid hydraulic powertrains for ***passenger vehicles***
- Acceleration: 0-60mph in 8 seconds (0.37g) ***(High power density)***
- Fuel economy: 70 mpg on federal test cycles ***(High efficiency)***
- Package size: compatible with vehicles such as Honda Civic, Ford Focus, etc. ***(Compact)***

Generation I: Polaris Ranger ATV

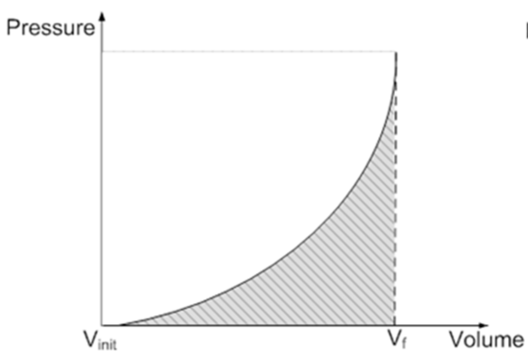
- Polaris Ranger all terrain vehicle
- Downsized diesel engine (~ 20kW)
- UMN designed, built, and installed a new hydro-mechanical power split transmission
- Hybridized with composite accumulators
- Full engine management

Generation II: Ford F150

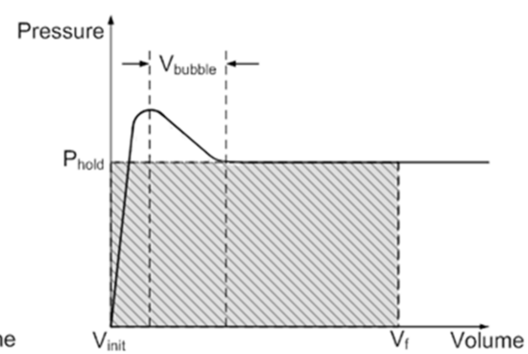
- Industry-led project
- Ford F150 full-size pickup truck
- Hydro-mechanical transmission from *Folsom Technology International (FTI)*
- Output coupled power-split
- Will be hybridized with composite accumulators
- UMN will develop and implement controls

CCEFP Project 2C.2: Strain Energy Accumulator

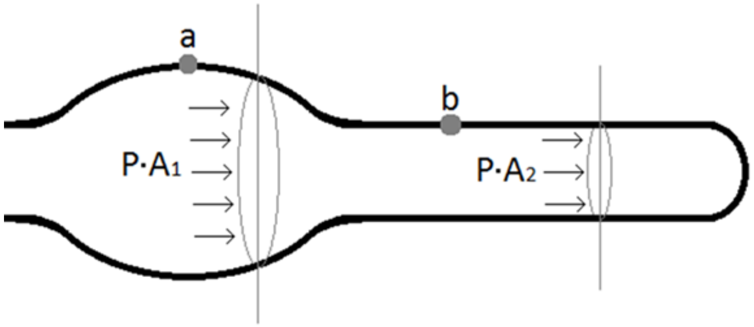
- Energy is stored in the strain of an elastomer in tension
- Increases the energy density 2-4x when compared to traditional gas charged accumulators
- Integrating the reservoir into an elastomeric accumulator promises further increases
- Eliminates gas permeation issues found in gas accumulators
- Ideal for hydraulic hybrid vehicles



Gas Accumulator

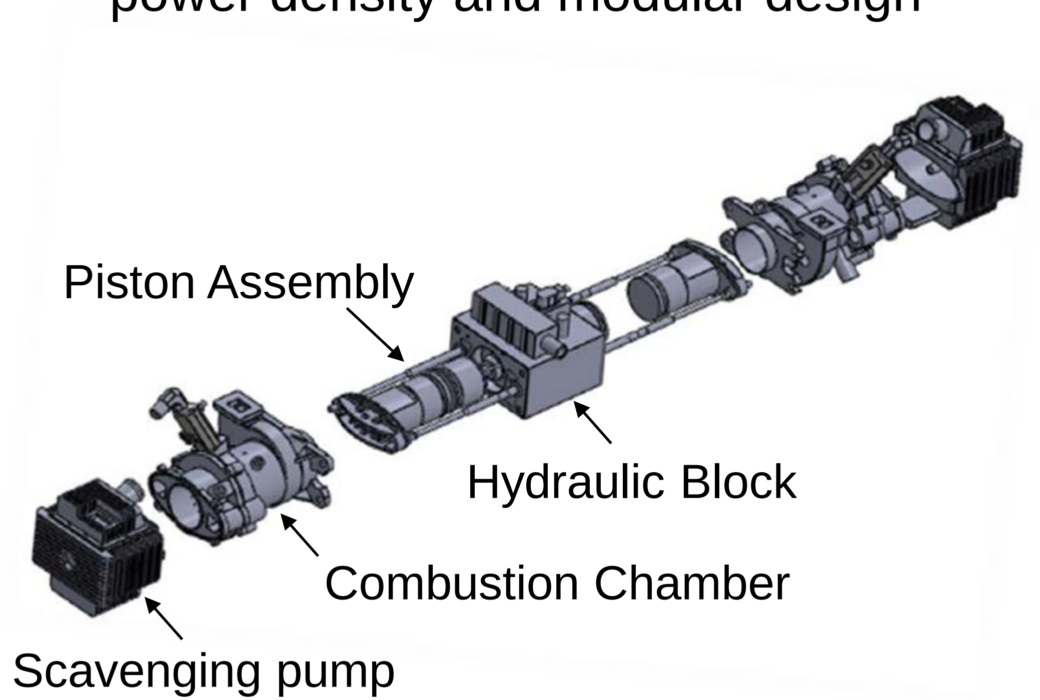


Elastomeric Bladder



CCEFP Project 2B.3: Hydraulic Free Piston Engine

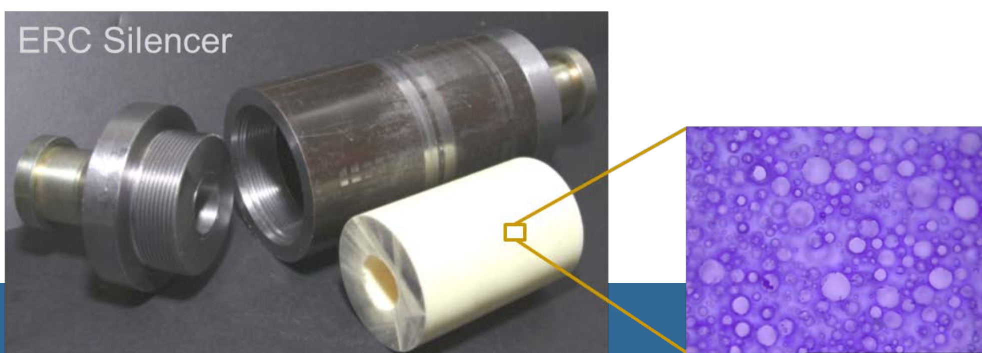
- Opposed piston, opposed cylinder homogeneous charge compression ignition (HCCI) direct injection engine with integrated hydraulic pump
- Advantages include “instant” on-off, variable compression ratio, lower fuel consumption and exhaust emissions, multi-fuel operation, high power density and modular design

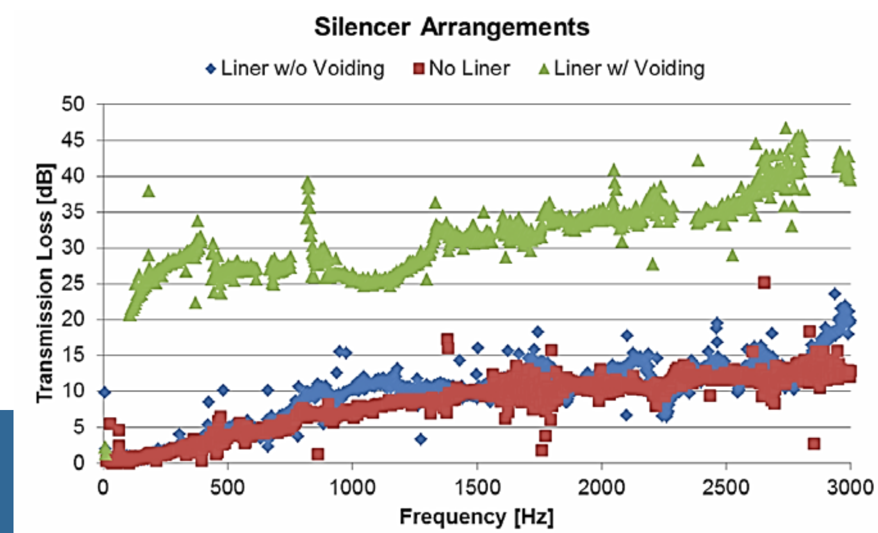


- The breakthrough is an active control strategy that acts as a “virtual crankshaft” to force the pistons to follow the desired trajectory
- Combustion testing is underway and hardware in the loop testing is planned.
- Ideal for hydraulic hybrid vehicles

CCEFP Project 3B.1: Passive Noise Control in Fluid Power

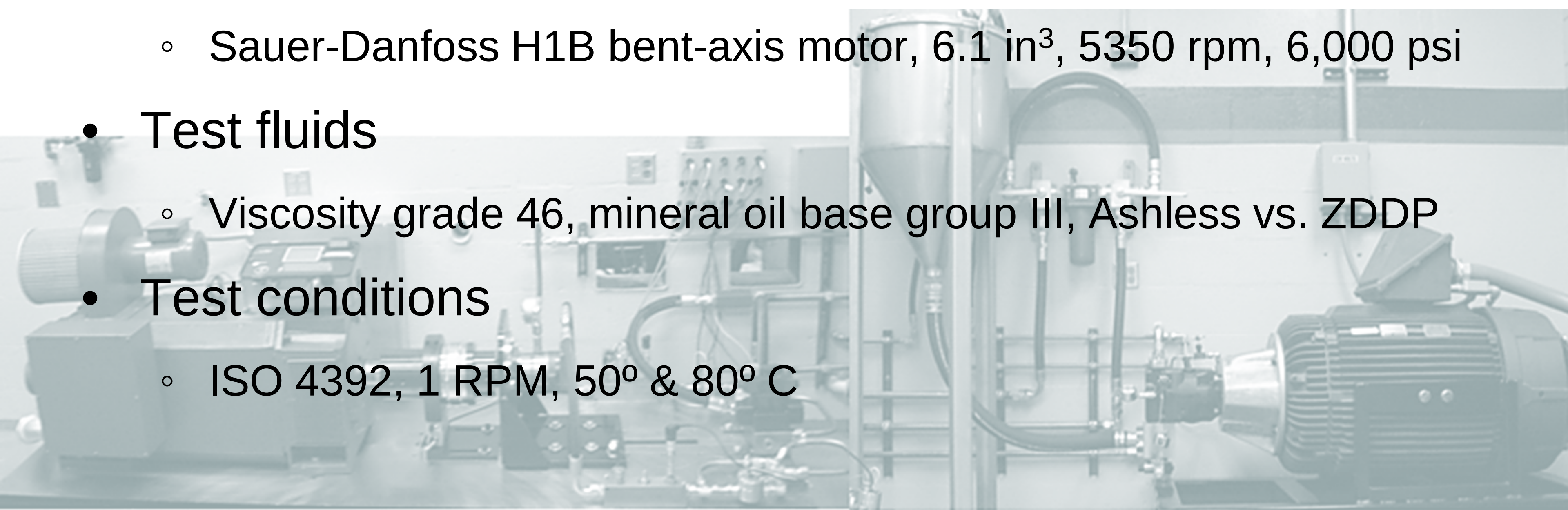
- Hydraulics can be noisy
  - Fluid-borne noise can negative effects on the equipment and the operator
  - Air-borne noise can limit market acceptability and is sometimes regulated
- Compliance in tailored compliant linings slows the speed of sound in the fluid and lowers resonance frequencies
- Devices can be more compact with higher performance than commercially available treatment methods
- Graduated project with industry-sponsored associated project ongoing





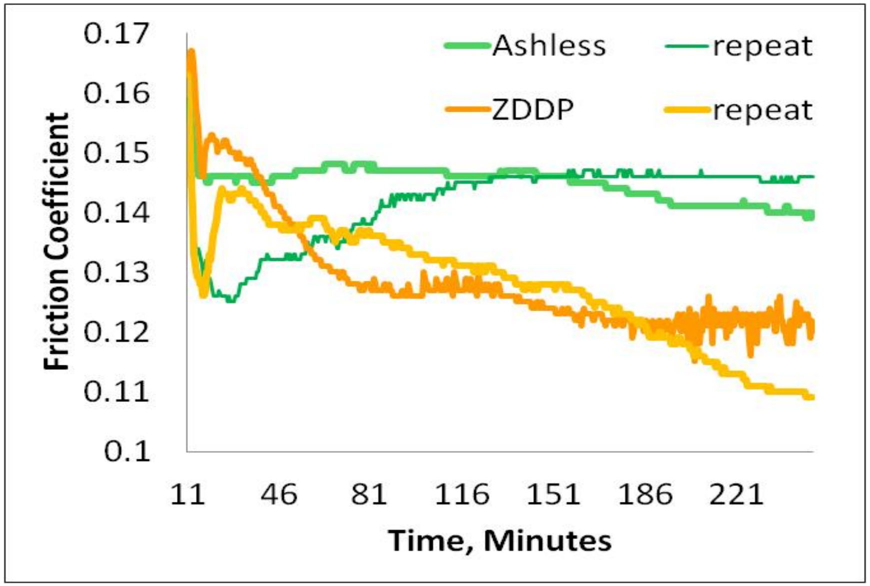
CCEFP Project 1G.1: Energy Efficient Fluids

- **Challenge**: Hydraulic motor efficiency, especially at startup, often determines the design pressure and displacement requirements in mobile hydraulic systems
- **Research goal**: Reduce friction losses in hydraulic motors under low speed and starting conditions
- Research hardware
  - Parker TG240 orbital geroler motor, 14.5 in^3, 390 rpm, 3,000 psi
  - Sauer-Danfoss H1B bent-axis motor, 6.1 in^3, 5350 rpm, 6,000 psi
- Test fluids
  - Viscosity grade 46, mineral oil base group III, Ashless vs. ZDDP
- Test conditions
  - ISO 4392, 1 RPM, 50º & 80º C



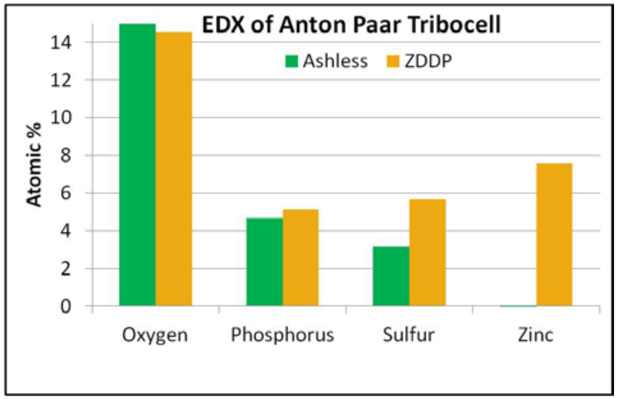
Tribometer Testing

Friction Measurements

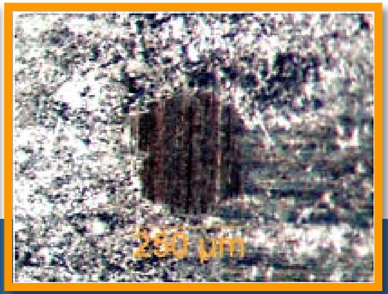


Anton Paar Tribocell

Tribometer based on the ball-on-three-plates principle

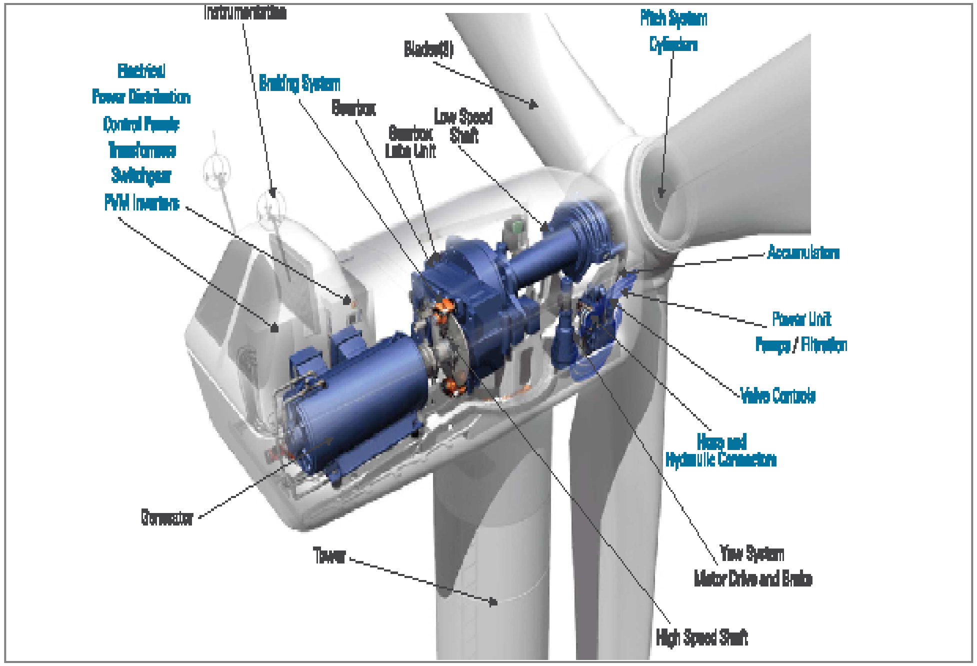


Ashless **ZDDP**



- Lower friction with zinc
- Thicker tribofilm with zinc
- Thicker tribofilm consistent with theory

ATB-α Wind Power

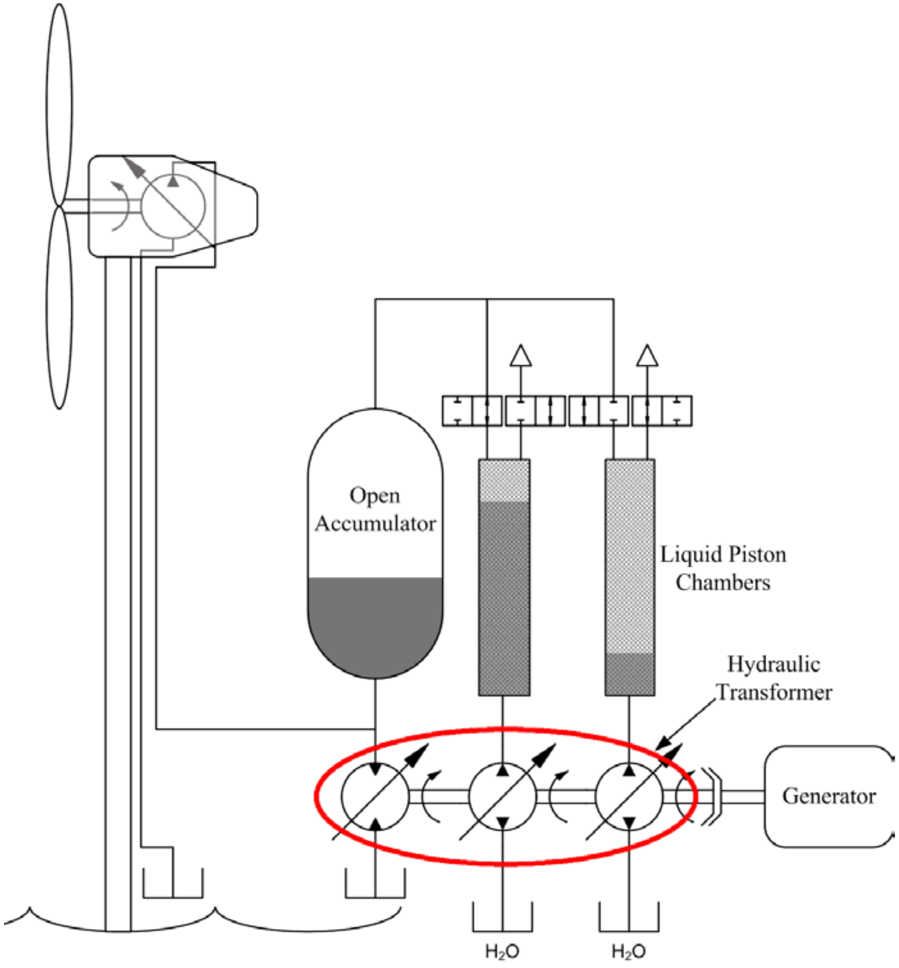


- Gearbox reliability is a significant problem and our approach *eliminates* the need for a gearbox
- Continuously variable transmission (CVT) may extract more energy
- $ per delivered kW-hr is the key metric

Replacing the gearbox with a hydrostatic transmission has the potential to improve system reliability and increase overall system efficiency

Compressed Air Energy Storage for Off-Shore Wind Turbines

- Hydraulic pump in nacelle
- Energy storage prior to electric conversion
- Constant pressure storage capable of high pressure transients
- Allows use of synchronous generator
- About 20 times the energy density of a conventional accumulator
- Technology has two licensees



Started as a CCEFP research project

CCEFP Impact

In Year 6, the Center has 48 faculty and research staff, 81 grad students, 63 undergrad researchers.

Since its inception:

- Students graduated: 104 BS, 80 MS, 28 PhD
- 107 REUs, 16 FPS and 36 RETs
- Refereed publications: 78 technical journals, 248 conference proceedings
- Intellectual property: 43 inventions disclosed, 24 patent applications filed, 2 awarded, 2 licenses issued
- $9.8M in associated project funding
- Gained international visibility

CCEFP Members and Supporters

Afton Chemical Corporation
Air Logic
Bobcat
Bosch Rexroth Corporation
Caterpillar Inc.
Concentric AB (formerly Haldex)
Deere & Company
Deltrol Fluid Products
Eaton Corporation
Enfield Technologies
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CCEFP Builds Collaborations for Innovation in Fluid Power

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