HOOSIER HEAVY HYBRID Center of Excellence (H^3CoE) at Purdue University

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June 16th, 2014

Project ID # TI023

Overview

Timeline

- Start – Oct 2011
- Finish – Sept 2016

Budget

- >$2,000,000 total
  - $1,000,000 from DOE
  - >$1,000,000 from Purdue, Industry Partners
- DOE funding to date
  - $ received
  - $126,097 spent (travel + fellowship stipends
- Purdue costshare
  - $91,217 spent (fellowship tuition & overhead)
- Cummins funding
  - $183,000

Barriers

- Barriers addressed
  - Lack of trained engineers and scientists: not enough trained in key areas of advanced energy efficiency vehicle technologies
  - Lack of advanced technology curricula: curricula specific to advanced vehicle technologies not available at a sufficient number of universities.

Partners

- Purdue – lead
- Industry – to date

ESN ENERGY SYSTEMS NETWORK

Cummins

Relevance - Objective

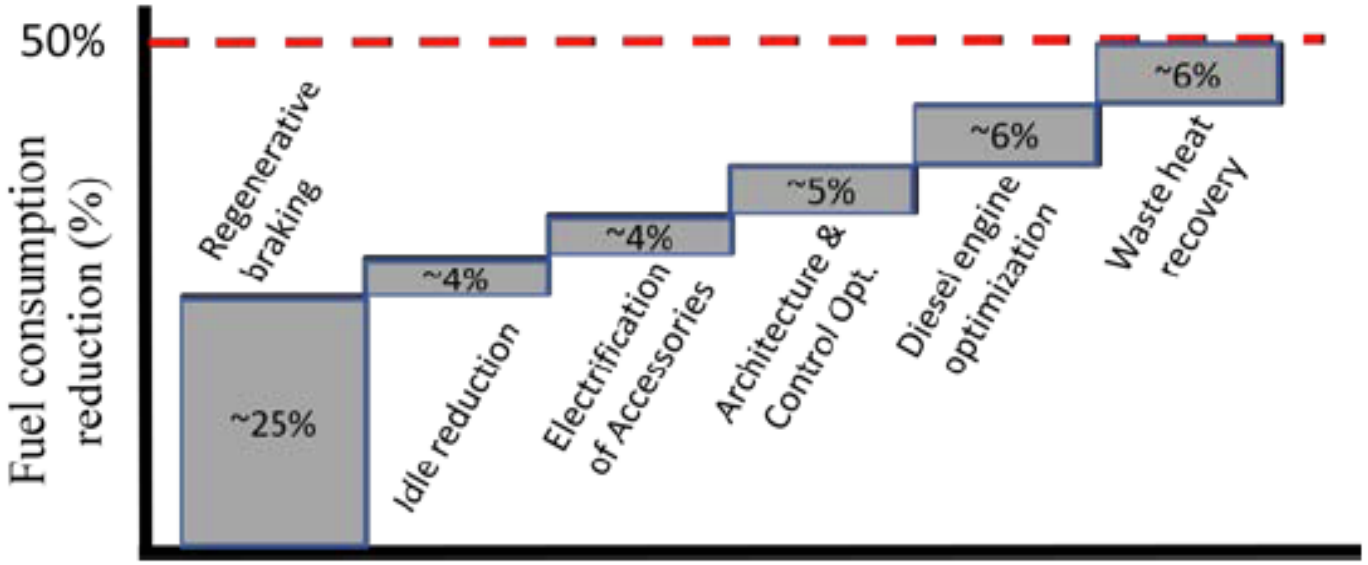
Establish a GATE Center of Excellence that provides multidisciplinary engineering training for graduate students in advanced automotive technology to overcome technology barriers preventing the development and production of cost-effective vehicles for the US market.

Relevance - Motivation

- 21M barrels/day oil usage in U.S.
- 7.6M barrels/day in China, but 9% annual growth
  - Bus market: 11% annual growth rate
  - Heavy truck: 32% annual growth rate
- Heavy vehicle (average)
  - 6.2mpg (vs. 21 for auto/light truck)
  - 74,000 miles/year (vs. 11,000 for auto/light truck)
  - 12,000 gallons/year (vs. 570 for auto/light truck)
- Growth in fuel use tied to heavy vehicles…also target for reduction

Relevance - Motivation

Fuel consumption reduction possibilities for medium/heavy vehicle



Challenges:

- Large braking energy rates
- Engine stop/start (large start torque; aftertreatment management)
- Packaging constraints
- Sub-systems not optimized for hybrids use
- Large diversity of vehicle sizes & duty cycles

Deployment Strategy

- Provide H^3CoE Research Fellowships & industry-driven/funded projects to address challenges and unique opportunities for medium/heavy-duty hybrid vehicles
  - 10 Fellowships have been awarded
  - Biggest challenge: industry co-support of projects, resulting in drop of requirement for this to award fellowships (still a preferred outcome)
- Deploy/enhance course content, and provide a Hybrid Vehicle Systems Certificate (HVSC).
  - New HEV course, offered in Fall ‘12 (again in Fall ’13 & ‘14)
  - Certificate program final approval in Fall 2012 (1st interdisciplinary certificate at Purdue!)

Deployment Strategy

- Partner with regional industry partners that manufacture medium/heavy-duty hybrid vehicle components.
  - Strong partnership with Cummins
    - Co-funding of two projects:
      - Enabling Plug-In Capability and Engine Optimization for a Heavy-Duty Hybrid Vehicle System via Advanced Power Electronics ($158K)
      - Model-Based Heavy Hybrid Vehicle Design Optimization and Control ($25K)
    - $1M in support of “Cummins Power Lab” in new Purdue facility
  - Others developing more slowly
- Use the web to provide information, including fellowship and certificate program details, and research projects.
  - Website launched in Spring ‘13, used to advertise program to current/future/pending students

Progress – Certificate Program

- Final approval in Fall ’12
- 1st Interdisciplinary certificate program at Purdue!
- Students required to:
  - take 1 class in each area
  - attend one poster show/workshop
- Status
  - 15 currently in program
  - 6 have completed program

Architecture (complete one)
ABE 69100/ME 69700 *Hydraulic Power Trains & Hybrid Systems*
ECE 59500 *Hybrid Electric Vehicles*
Energy Storage or Controls (complete one)
CHE 50000 *Intro to Energy Storage Systems*
MSE 59700 *Design & Simulation of Rechargeable Batteries*
ME 57500 *Theory & Design of Control Systems*
Prime Mover (i.e. motor/engine) (complete one)
ECE 61000 *Energy Conversion*
ABE 59100/ME 59700 *Design & Modeling of Fluid Power Systems*
ME 54000 *Internal Combustion Engines*

- 8 additional fellowships have been awarded since last review
  - From 3 different schools of Engineering
  - Includes efforts in both electric and hydraulic hybris

Name of GATE Fellow	Major Professor	Academic Area	Project Title
Michael Sprengel	Monika Ivantysynova	Agricultural and Biological Engineering	Advanced high efficiency hydraulic hybrid power train architectures and controls
Paul Kalbfleisch	Monika Ivantysynova	Agricultural and Biological Engineering	Investigation of noise reduction of pumps and motors through computational design optimization
Abhishek Saxena	Peter Meckl	Mechanical Engineering	Design of Testing Protocols for Performance Evaluation of a Diesel-Electric Hybrid Vehicle
Dan Horvath	Steve Pekarek	Electrical and Computer Engineering	Brushless Claw Pole Machines for Generation and Actuation
Jamal Alsawalhi	Scott Sudhoff	Electrical and Computer Engineering	Rotatonally Asymmetric Permanent Magnet Machines for Hybrid Vehicle Drives
Sashankh Ravi	Dionysios Aliprantis	Electrical and Computer Engineering	Optimal Design of Asymmetric Switched Reluctance Motor Drives for Heavy Hybrids
Jagdish Hiremath	Peter Meckl	Mechanical Engineering	Control of Urea Injection in Selective Catalytic Reduction for a Diesel-Electric Hybrid Vehicle
Ashish Vora	Greg Shaver	Mechanical Engineering	Model-Based Heavy Hybrid Vehicle Design Optimization and Control
Xing Jin	Greg Shaver	Mechanical Engineering	Model-Based Heavy Hybrid Vehicle Design Optimization and Control
Minyu Cai	Oleg Wasnyczuk	Electrical and Computer Engineering	Enabling Plug-In Capability and Engine Opt. for a HD Hybrid Vehicle System via Adv. Power Electronics

Enabling Plug-In Capability via Adv. Power Electronics

- Converter topologies compared via simulation: full-bridge isolated converter w/ active clamp chosen (Fig. 1)
- Transformer & inductor designed (Fig. 2)
- Prototype being built to establish performance (Fig. 3)

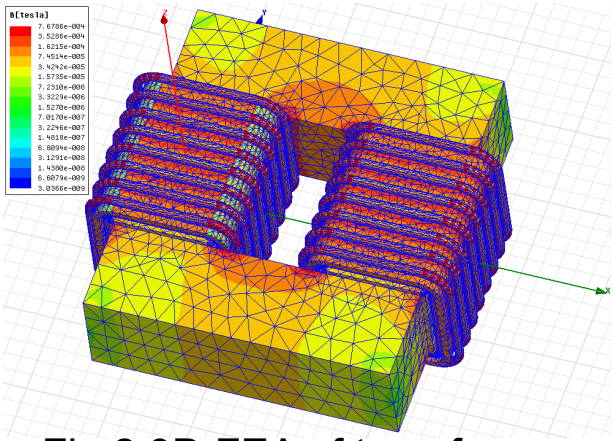


Fig.2 3D FEA of transformer

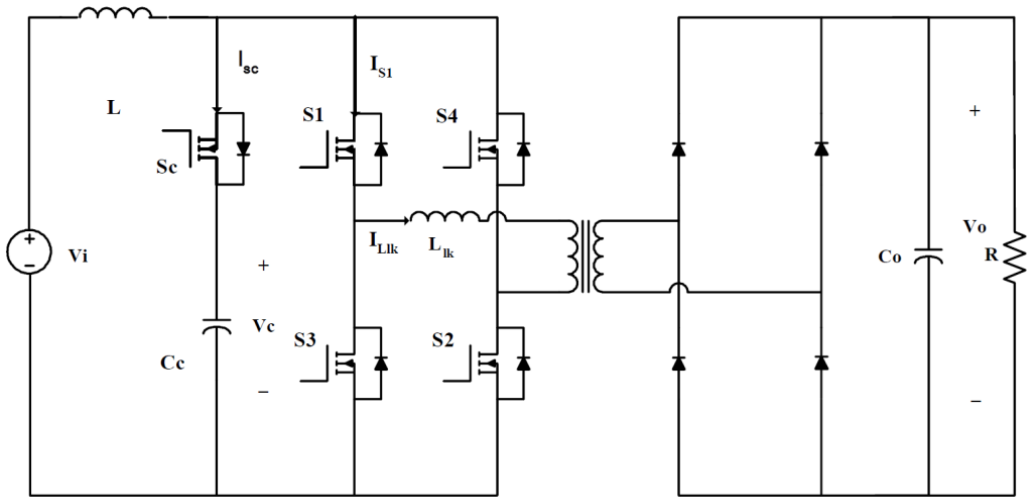


Fig.1 Full-bridge isolated converter w/ clamp

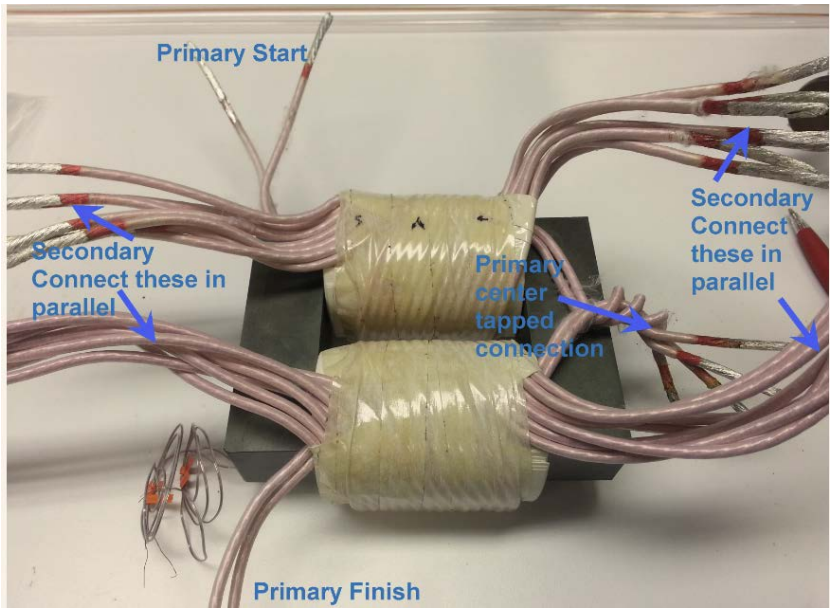
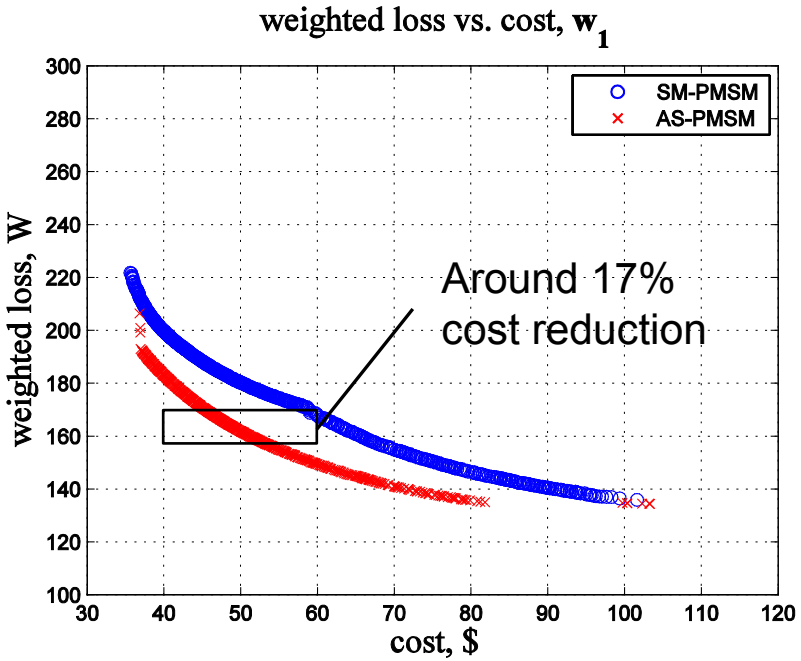
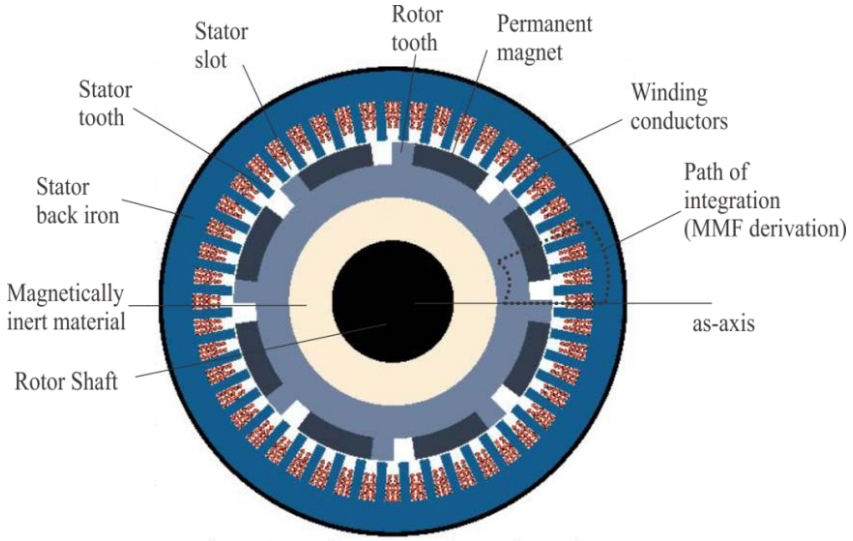


Fig.3 Photo of transformer

Asymmetric Salient PMSM for Traction Applications

- Challenge:
  - Improve Constant Power Speed Range Performance of Permanent Magnet Machines For Traction Applications
- Solution
  - Asymmetric Salient Permanent Magnet Synchronous Machine
- Preliminary Results
  - For the same requirements, the proposed machine yields a 17% cost reduction





Future Work

- Apply to Heavy Hybrid Vehicle Application
- 3-D FEA Validation
- Thermal Modeling
- Investigate Pole Tapering

Advanced High Efficiency Hydraulic Hybrid Powertrain Architectures and Controls

- Challenge:
  - Combating perception that hydraulics are old fashioned
  - Addressing noise issues
- Solution
  - Novel “blended” hydraulic hybrid transmission (Fig. 1) & controls, with experimental validation (Fig. 2)

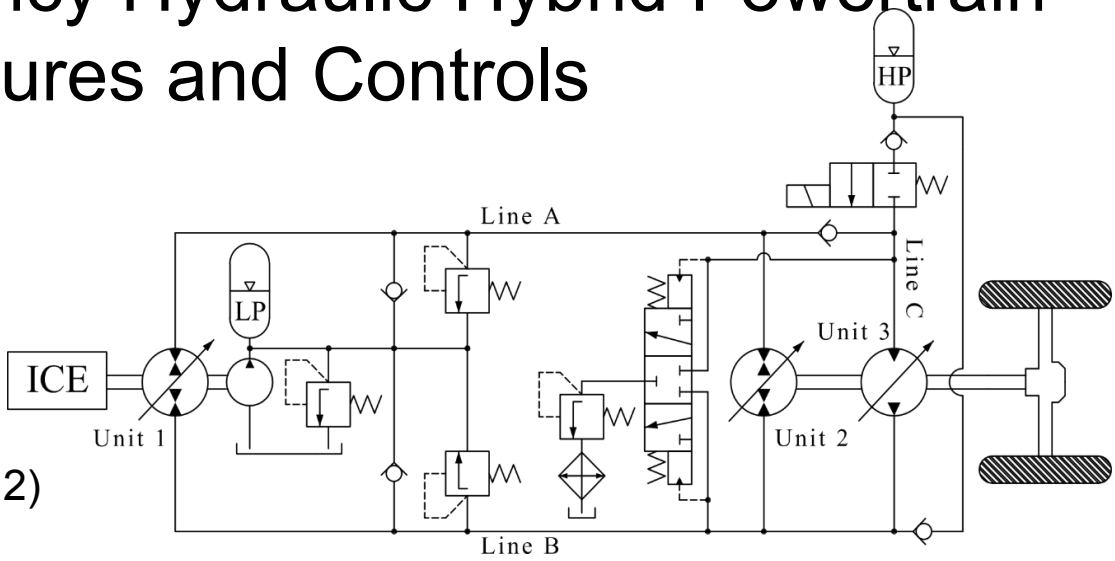
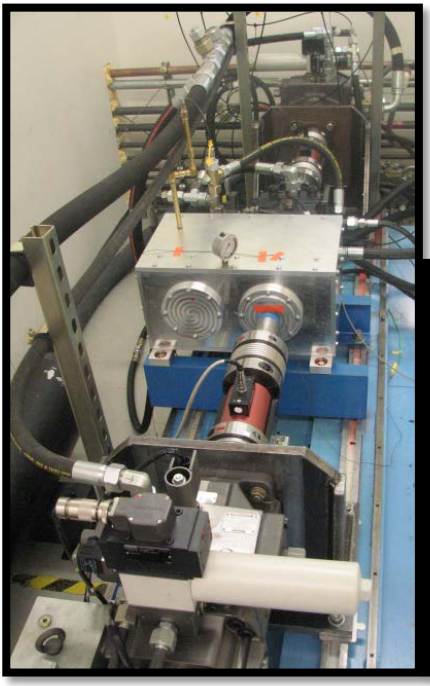


Fig. 1 Novel architectures



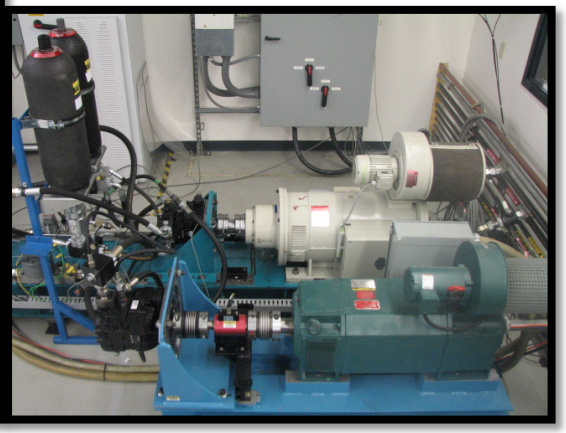


Fig. 2 Hardware in the Loop Transmission Testing

Future Work:

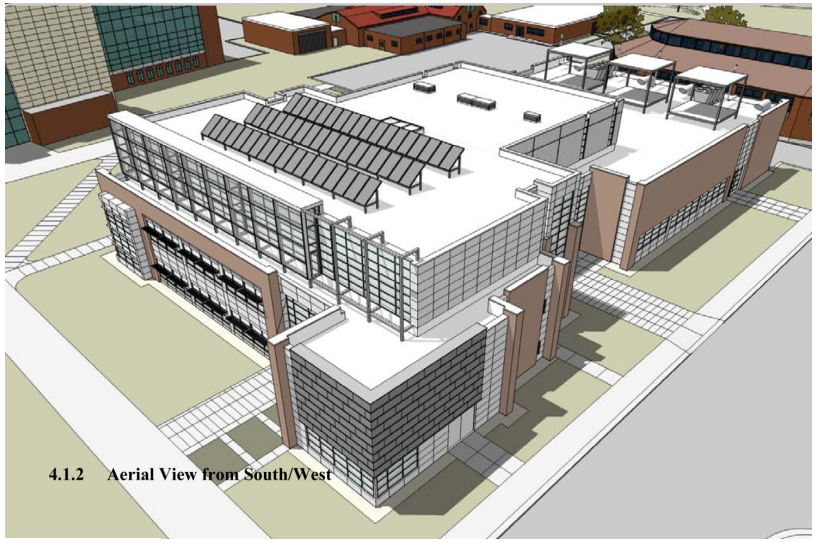
- Develop high fidelity simulation models of both conventional and hybrid transmissions
- Use dynamic programming for control to determine full potential of strategies
- Develop & experimentally demonstrate various power management strategies

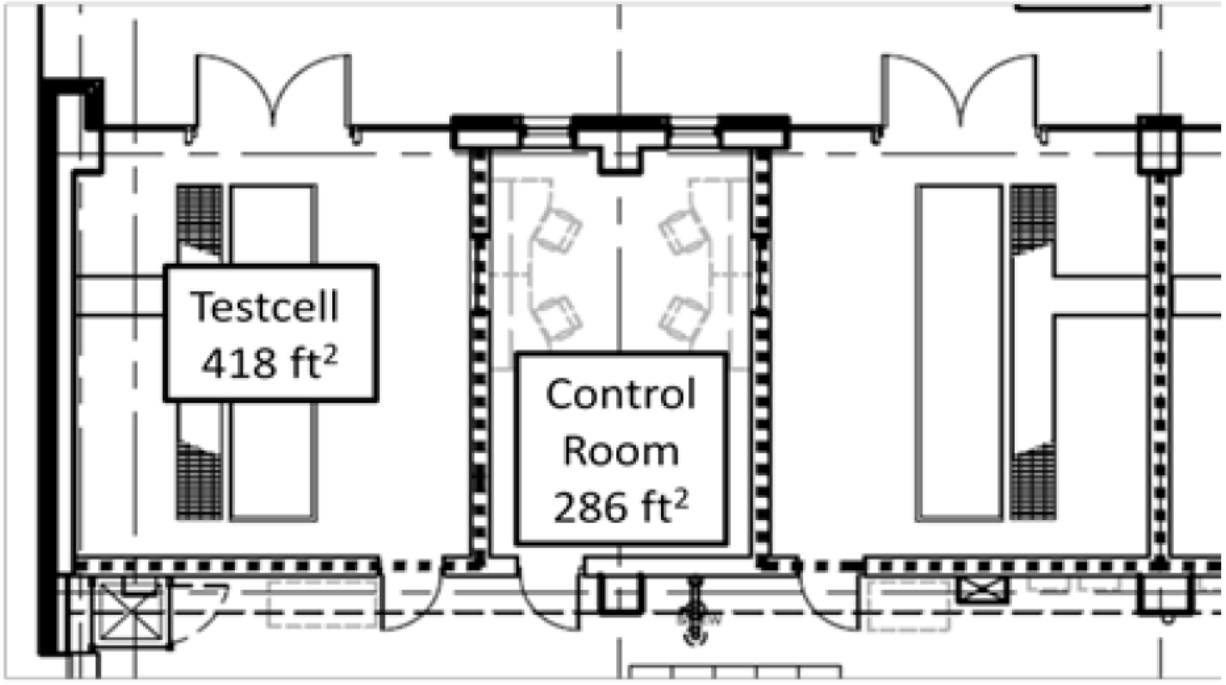
Progress – Poster Show & Workshop

- Poster Show and Workshop participants, November 1st, 2013

Progress - Opened New Herrick Labs

- Phase 1 (of 2)
- 52,000 sq. ft.
- Includes 4 powertrain test cells for advanced medium & heavy duty hybrid powertrains





Layout for cells 1 and 2, the "Cummins Power Lab"

Collaborators & Coordination w/ Other Institutions

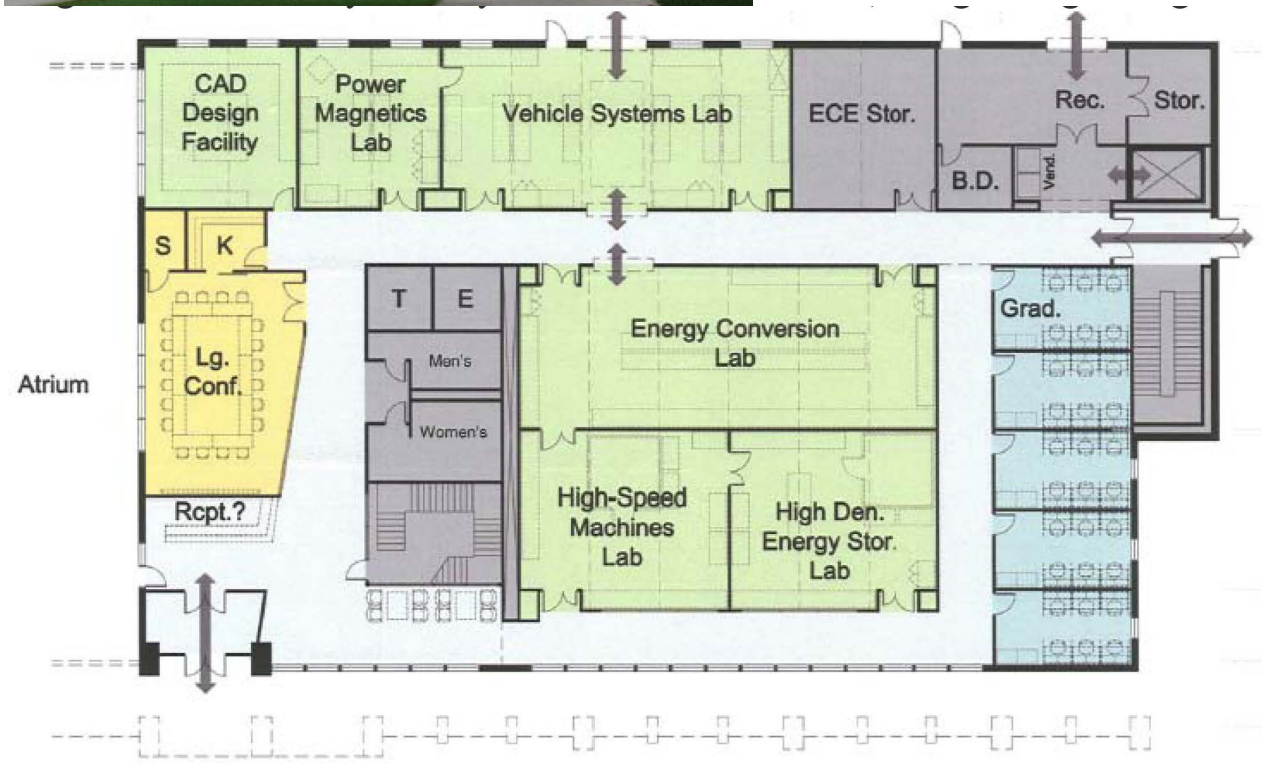
- Cummins
  - Co-sponsoring two research projects
- Allison, Precision Air, John Deere
  - In discussion regarding research project co-sponsorship.
- The Ohio State University
  - Professors Giorgio Rizzoni and Marcello Canova gave seminars at the Fall 2013 Poster Show and Workshop

Future Work and Activities

- Continue regular poster shows/workshops, and industry co-funded research projects.
- Continue growth of # of students in certificate program.

Future Work: Open New Wang Hall

- Scheduled to open in September 2014.
- Will be key asset for projects focused on hybrid electric vehicles



Includes expanded Labs for:

- Power Magnetics
- Vehicle Systems Energy Conversion, and
- High Density Storage

Summary

- Purdue GATE Hoosier Heavy Hybrid Center of Excellence (H^3CoE) project initiated in Oct. 2011.
- Focus on medium and heavy-duty hybrid vehicles.
  - Certificate program: 15 current students + 6 have that have completed program
  - Industry co-funded research projects: 2 with Cummins
  - H3CoE Fellowship program: 10 current fellows
- New facilities will enhance/enable efforts of H3CoE
  - New Herrick Labs w/ 4 hybrid powertrain testcells opened August 2013
  - Wang Hall opens Fall 2014