Advanced Vehicle Technology Competition: Challenge-X
2008 DOE Merit Review

Building on 19 successful years of advanced vehicle technology competitions

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Argonne National Laboratory

This presentation does not contain any proprietary or confidential information
Outline

- Current Competition Program Introduction/Overview
- Goals and Objectives
- Approach
- Collaborations/Interactions
- Performance Measures and Accomplishments
- Next Competition Program Introduction/Overview
- Summary
DOE has had a successful 19-year history of Advanced Vehicle Technology Competitions (AVTCs):

- Methanol Marathon and Methanol Challenge (GM)
- Natural Gas (GM), Ethanol (GM), and Propane Vehicle Challenges (DaimlerChrysler)
- Sunrayce 1990
- HEV Challenge and FutureCar (with PNGV-GM/Ford/DaimlerChrysler)
- FutureTruck (GM/Ford/DaimlerChrysler)
- Challenge X (final year-GM)

→ EcoCAR (the next AVTC challenge)

AVTCs integrate key DOE vehicle technologies
Goals and Objectives

- Investigate, develop, and demonstrate a broad spectrum of advanced vehicle technologies aligned with DOE’s objectives: renewable fuels, energy diversity, advanced combustion, energy storage technology, electric machines, high power electronics, fuel cells, vehicle simulation modeling, and other critical technologies.

- Explore technical solutions that minimize petroleum consumption and reduce well-to-wheel greenhouse gas emissions relative to current production counterparts.

- Train the next generation of engineers to bring advanced technology vehicles into production while grooming future industry leaders.

- Increase public awareness through the Challenge X outreach program of the state of development and capabilities of advanced vehicle technology.
Approach to Achieving Goals/Objectives

- Establish an AVTC series in partnership with vehicle manufacturers, fuel and component suppliers for colleges and universities in North America
- Select universities with core capabilities and a high potential for success (out of 105 university applicants, only 17 were selected for Challenge X)
- Ensure a broad technology spectrum across teams selected that covers critical technologies and fuels of interest to the DOE
- Develop a rigorous competition framework based on safety and progressive development and testing of a multitude of advanced vehicle and fuel technologies
Challenge X Overview

- Four year engineering competition to develop advanced powertrain and fuel technologies with General Motors (GM)
- Based on GM’s Global Vehicle Development Process utilizing math-based design tools and simulation
- 17 North American schools re-engineer a 2005 Chevrolet Equinox with hybrid powertrains of their design
  - Increase energy efficiency and reduce fossil energy consumption based on a well-to-wheels analysis
  - Reduce criteria tailpipe emissions and greenhouse gases
  - Maintain or exceed consumer acceptability in performance, utility, and safety

<table>
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<th>Year 1</th>
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<td>Modeling and simulation</td>
<td>Sub system integration</td>
<td>99% Buyoff</td>
<td>Reliability/Durability</td>
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Diverse Industry Base Supplies the Students with Cutting Edge Technologies

**HEADLINE SPONSORS**
- U.S. Department of Energy
- General Motors

**PLATINUM SPONSORS**
- Natural Resources Canada
- The MathWorks
- National Instruments
- Freescale Semiconductor
- AVL Powertrain Engineering, Inc.
- U.S. Environmental Protection Agency
- U.S. Department of Transportation

**GOLD SPONSORS**
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- BP
- Sensors, Inc.

**SILVER SPONSORS**
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- Chevron
- Johnson Controls-SAFT Advanced Power- Electronics
- Ballard Power Systems, Inc.
- Michelin North America
- Renewable Fuels Association

**BRONZE SPONSORS**
- Caterpillar, Inc.
- Vector CANtech, Inc.
- Intrepid Control Systems, Inc.
- Hydrogenics Corporation
- MotoTron Corporation
- UGS
- XM Radio
- On Star
### Challenge X 2007 Team Technologies and Configurations

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<tr>
<th>TEAM</th>
<th>HEV ARCHITECTURE</th>
<th>ENGINE</th>
<th>FUEL</th>
<th>TRANSMISSION</th>
<th>ENERGY STORAGE</th>
<th>MOTOR</th>
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<tr>
<td>Michigan Technological University</td>
<td>Through-the-road Parallel</td>
<td>2.0-L 4 Cylinder Spark Ignition</td>
<td>Bio Diesel (B20)</td>
<td>6-Speed Automatic Transaxle</td>
<td>Cobasys, Nickel Metal Hydride - 336V</td>
<td>50 kW Solaelectric AC Induction Transaxle</td>
</tr>
<tr>
<td>The Ohio State University</td>
<td>Through-the-road Parallel</td>
<td>1.9-L GM Direct Injection Turbo Diesel</td>
<td>Bio Diesel (B20)</td>
<td>Asisin-Warner AF40 6-speed automatic transaxle</td>
<td>Panasonic, Nickel Metal Hydride - 300V</td>
<td>67 kW Ballard AC Induction Transaxle / 10.6 kW Brushless DC Generator</td>
</tr>
<tr>
<td>Pennsylvania State University</td>
<td>Through-the-road Parallel</td>
<td>2.5-L 4 Cylinder Engine</td>
<td>Bio Diesel (B20)</td>
<td>GM F40 6-Speed Engine</td>
<td>Cobasys, Nickel Metal Hydride - 336V</td>
<td>(2) 60 kW Custom AC Induction Motors</td>
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<tr>
<td>Rose-Hulman Institute of Technology</td>
<td>Power Split</td>
<td>1.9-L GM Direct Injection Turbo Diesel</td>
<td>Bio Diesel (B20)</td>
<td>Custom-Rose Hybrid 3-Mode Transaxle</td>
<td>(2) 60 kW Custom AC Induction Motors</td>
<td>150 kW AC Propulsion AC Induction</td>
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<td>Jan Diego State University</td>
<td>Through-the-road Parallel</td>
<td>1.9-L GM Direct Injection Turbo Diesel</td>
<td>Bio Diesel (B20)</td>
<td>GM F40 6-speed Engine</td>
<td>Cobasys, Nickel Metal Hydride - 36V</td>
<td>4 kW GM Belt-Alternator-Starter</td>
</tr>
<tr>
<td>Texas Tech University</td>
<td>Parallel Hybrid</td>
<td>2.4 L GM Ecotec VVT</td>
<td>Ethanol (E85) &amp; Hydrogen</td>
<td>GM 4T55E, 4-speed Automatic</td>
<td>Cobasys, Nickel Metal Hydride - 400V</td>
<td>67 kW Ballard Integrated Power Transaxle / 36 kW Siemens Permanent Magnet Generator</td>
</tr>
<tr>
<td>University of Akron</td>
<td>Series Parallel 2 by 2</td>
<td>1.9-L 4 Cylinder Engine</td>
<td>Bio Diesel (B20)</td>
<td>Direct Shift Gear Box (DSG) 6-Speed Manual</td>
<td>Nesscap, Ultracapacitor Bank - 370V</td>
<td>67 kW Ballard Integrated Power Transaxle / 36 kW Siemens Permanent Magnet Generator</td>
</tr>
<tr>
<td>University of California – Davis</td>
<td>Pre-Transmission Parallel Plug-In Hybrid Capable</td>
<td>1.5-L Atkinson Spark Ignition</td>
<td>Ethanol (E85)</td>
<td>UC Davis Custom Continuously Variable Transaxle</td>
<td>GIA Lithium Technology, Lithium Ion-346 V</td>
<td>75 kW UQM Permanent Magnet Front / 60 kW E/NDA AC Induction Rear</td>
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<td>University of Michigan</td>
<td>Series Hydraulic</td>
<td>1.9-L GM Direct Injection Turbo Diesel</td>
<td>Bio Diesel (B20)</td>
<td>Hydraulic Accumulators</td>
<td>Hydraulic 80 c.c./rev &amp; 55c/s rev Bent Axis Variable Displacement</td>
<td>(2) 67 kW Ballard AC Induction Transaxles</td>
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<td>University of Tennessee</td>
<td>Through-the-road Parallel</td>
<td>1.9-L GM Direct Injection Turbo Diesel</td>
<td>Bio Diesel (B20)</td>
<td>GM F40 6-speed Manual</td>
<td>Cobasys, Nickel Metal Hydride - 336V</td>
<td>67 kW Ballard AC Induction Transaxle</td>
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<td>University of Texas at Austin</td>
<td>Through-the-road Parallel</td>
<td>1.9-L GM Direct Injection Turbo Diesel</td>
<td>Bio Diesel (B20)</td>
<td>GM F40 6-speed Manual</td>
<td>Cobasys, Nickel Metal Hydride - 336V</td>
<td>5 kW Hitachi AC Induction Belt-Driven Alternator/ Starter</td>
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<td>University of Tulsa</td>
<td>Through-the-road Parallel</td>
<td>1.9-L GM Direct Injection Turbo Diesel</td>
<td>Bio Diesel (B20)</td>
<td>GM F40 6-speed Manual</td>
<td>Cobasys, Nickel Metal Hydride - 336V</td>
<td>67 kW Ballard AC Induction Transaxle</td>
</tr>
<tr>
<td>West Virginia University</td>
<td>Through-the-road Parallel</td>
<td>1.9-L GM Direct Injection Turbo Diesel</td>
<td>Bio Diesel (B20)</td>
<td>Asisin-Warner AF40 6-speed automatic transaxle</td>
<td>Cobasys, Nickel Metal Hydride - 336V</td>
<td>52 kW Ballard AC Induction Transaxle / 8K MS AC Induction Belt-Alternator/ Starter</td>
</tr>
</tbody>
</table>

**Key Technologies and Configurations:**

- **Plug-in hybrid**
- **RFG + light weighting**
- **H2 combustion assist, B20 powered diesel parallel hybrid**
- **Power split series hybrid**
- **Series hydraulic hybrid**
- **Dedicated fuel cell**
- **B20 powered diesel through-the-road hybrid**
- **E85 powered split parallel hybrid**
Performance Measures: Technical Accomplishments

- Mississippi State achieved 30.1 mpg gasoline equivalent (37 mpg), 48% improvement over production baseline for on road energy event.
- At the same time, Mississippi State demonstrated a 23% faster 0-60 mph acceleration time relative to production vehicle (0-60 in 7.6 sec).
- University of Waterloo emitted zero tailpipe emissions for on road emissions event.
- University of Waterloo competed successfully in every event as a dedicated fuel cell powered vehicle.
- Penn State achieved 0.06 g/mi NOx emissions utilizing a downsized B20 powered diesel engine and a urea injection system (< production vehicle).
- Virginia Tech demonstrated an impressive 77% reduction in petroleum use with their E85 – Ethanol powered split parallel hybrid.
- Utilizing Argonne National Laboratory’s GREET model, University of Wisconsin-Madison team demonstrated a 52% reduction in GHG emissions relative to production counterpart.
Technical Accomplishments: On Road Emissions Measured Real Time

Actual WVU 2007 on road emission results

- Speed
- CO
- NOx
- HC x100

MPH

Seconds

Emissions (g)
Many teams generated less HC emissions than production benchmark.

Most teams generated less CO emissions than production benchmark.
Most teams improved the production benchmark fuel economy for the on-road emissions event.

Three teams generated less NOx than production counterpart.
Performance Measures: Funding Leverage From Past AVTC’s

FutureTruck 2003-4

- DOE contributed $900K
- Ford contributed $480,878 in cash; $713,661 in kind (excluding staff time)
- Other sponsors donated $299,500 in cash; $9,162,500 in kind (excluding staff time)

- DOE cash contribution: $900,000.00
- DOE in-kind contribution: $0.00
- Total DOE Contribution: $900,000.00

- Non-DOE cash contribution: $780,378.00
- Non-DOE in-kind contribution: $9,876,161.00
- Total non-DOE Contribution: $10,656,539.00

- Total budget: $11,556,539.00

DOE contribution leveraged by 1184% for FutureTruck 2003-2004
Challenge X analysis underway and expected to show similar results
Performance Measures: Talent Development

- Of the 6000+ competition graduates, many have assumed technical and leadership positions: BAS and Two Mode HEVs, advanced combustion research, ethanol and diesel engine development, battery technology, fuel cell development, plug-in, and other transportation technology fields.

- Majority of competition graduates work in automotive field. DOE and its national laboratories have acquired talent with competition experience (ANL, ORNL, and NREL).

“I want you guys to know that Challenge X is by far the best thing I have ever done. I have been fortunate to have been involved in many valuable projects throughout my very long student career thus far, but CX was hands down the most valuable overall.”

– Melanie Fox, PSU
Performance Measures: Media Coverage

- cX 07 generated 103+ unique print news stories; 39 local TV, 95 radio, and 55 online stories – many generated from the team’s local Outreach Programs

- Key print stories appeared in *New York Magazine, Popular Mechanics, USA Today, the Wall Street Journal,* on TV shows aired on the Canadian Discovery Channel, as well as *Motorweek*

- cX 07 PR/Media efforts reached an estimated audience of over 23.3 million (some outlets do not track audiences)

- cX 07 Online coverage generated ~214 million hits (from sites such as Google, Yahoo! and MSN; on news sites such as Google News, Yahoo! News, WSJ.com, PR Newswire and Forbes.com; and on video sites such as YouTube, MetaCafe and Yahoo! Video)

- cX 08 is expected to far exceed 07 results. More than 30 media attended the competition including three documentary film crews. More than 35 stories have been generated, including a feature on Bloomberg TV’s *Night Talk*
Performance Measures: Technical Publications*


*Note: publications shown are a partial listing from 3 teams in Y3 of the competition
Performance Measures: Technical Publications*


*Note: publications shown are a partial listing from 3 teams in Y3 of the competition
Benefits Extend Throughout Government, Industry, and Academia

- AVTCs generate new strong working relationships between government sponsors, industry, and academia generating new business/collaboration/research opportunities
- Vast technology information exchange: DOE can explore technologies they may not have the resources to fund individually
- Universities gain cutting edge technology; develops highly trained, knowledgeable students

Bob Reuter
Global Chief Engineer
GM Crossover Vehicles

Rick Wagoner, Chairman and CEO of General Motors
What’s next?

EcoCAR
The Next Challenge
EcoCAR Overview

- Three year engineering competition to develop advanced powertrain and fuel technologies loosely based on CARB ZEV mandate
- Multiple hybrid technologies developed:
  - Hybrid electric vehicle — < 50-kW peak electric motor power
  - Hybrid electric vehicle — > 50-kW peak electric motor power
  - Range-extending and full-function electric vehicles
  - Hydrogen fuel cell vehicles
- Based on GM’s Global Vehicle Development Process utilizing math-based design tools and simulation: Y1 emphasis on HIL/SIL development
  - Increase energy efficiency and reduce fossil energy consumption based on a well-to-wheels analysis
  - Reduce criteria tailpipe emissions and greenhouse gases
  - Maintain or exceed consumer acceptability in performance, utility, and safety

Year 1
HIL/SIL development

Year 2
Sub system integration

Year 3
99% Buyoff
EcoCAR Competition Format

**Life Cycle Analysis, Vehicle Architecture Selection and Performance Modeling**

- Mechanical
- Electrical
- Controls

**Finalized Component Selection and Acquisition**

- CAD - Component
- Define Electrical Requirements
- Control System Design
- CAD – Routing and Integrations
- HIL Design / Setup
- Simple control and SIL / Prelim HIL

**Controls Integration and vehicle trouble shooting**

- Vehicle Modification
- Vehicle Harness / System Design
- HIL finalization setup
- Component Integration
- Vehicle Harness setup
- HIL – Safety and Fault mitigation Implementation

**Aero, Light weighting, Ride and Handling and NVH**

- Refinement and Optimization

**99% Buyoff – Vehicle Ready for Production**

**Y1 Competition**
- June 2008

**Y2 Competition**
- June 2009

**Y3 Competition**
- June 2010

**EcoCAR Competition Format**
- June 2011
- June 2010
- June 2009
- June 2008

**GM**
Summary

- Challenge X 2007 one of the most successful AVTC’s
  - 16 of 17 vehicles qualified; 16 competed in events
  - A record for second-year competition vehicles
  - Fully functional fuel cell competed in every event
- A number of teams achieved significant improvement over the production Chevrolet Equinox in all energy and emissions related comparisons utilizing RFG, E85, and B20
- Data was collected from vehicles using all powertrain, fuel, and material technologies being developed by DOE
- Challenge X 2007 produced more than the 23 million media hits, leading to one of the highest profile AVTC’s in history
- Rick Wagoner, GM CEO, showed genuine interest in the competition spending several hours with students and organizers voicing his support
- EcoCAR, the next competition, is underway and will continue the largely successful AVTC program for the U.S. DOE