U.S. Department of Energy
Energy Efficiency and Renewable Energy

freedomCAR & vehicle technologies program

Clean Energy Outlook Meeting
ASERTTI

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Omni Shoreham Hotel

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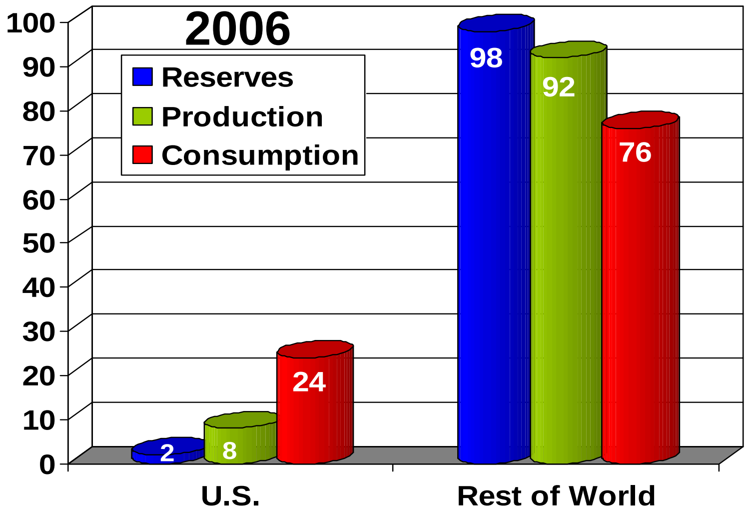
Presentation Outline

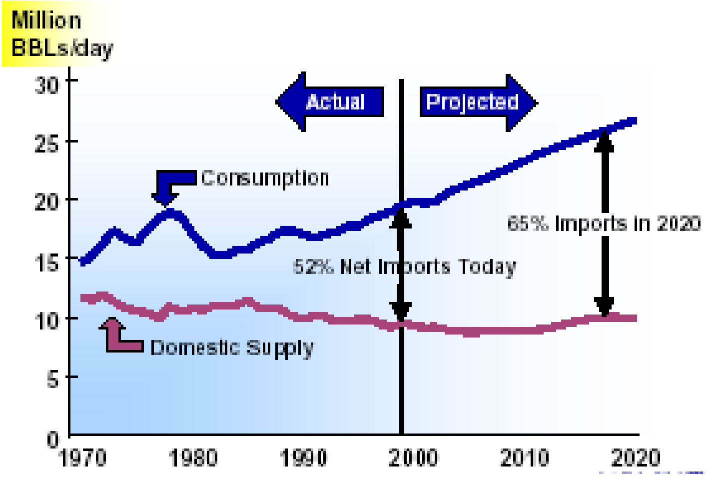
- The Oil imperative
- Vehicle Technologies Program
- Policy options and barriers to success
- Technology Options
- Deployment activities

DOE Has a Transportation R&D Program Because the Nation Has an Oil Problem

- The current high oil prices reflect the increasing global demand for a limited energy resource: China is number 2 in oil use and India is 6th…and growing
- The U.S. consumes more oil than it has and demand is growing



Reliance on domestic oil is not sustainable.
We cannot drill our way out of the problem.

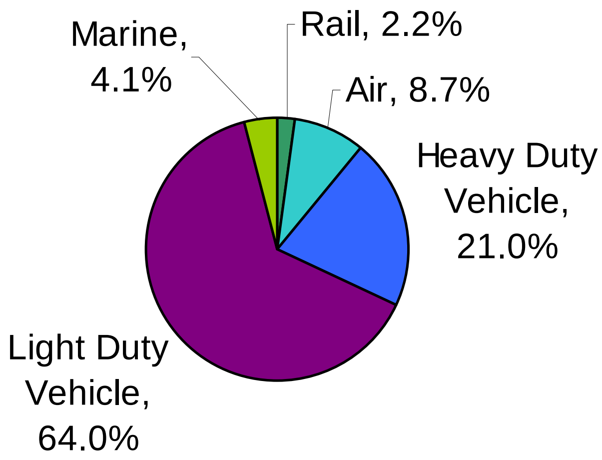


Historically, we have underestimated' the magnitude of the oil problem.
We already import more than 60%.

- Oil is predominately a transportation energy problem, with economic, environmental, and geopolitical concerns for the nation
- Oil is an energy security issue

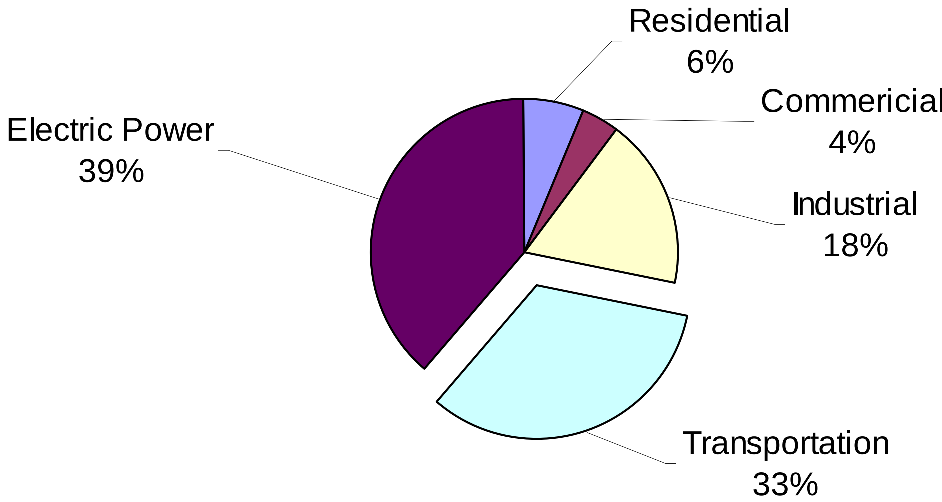
The Challenge

Transportation Petroleum Consumption by Sector



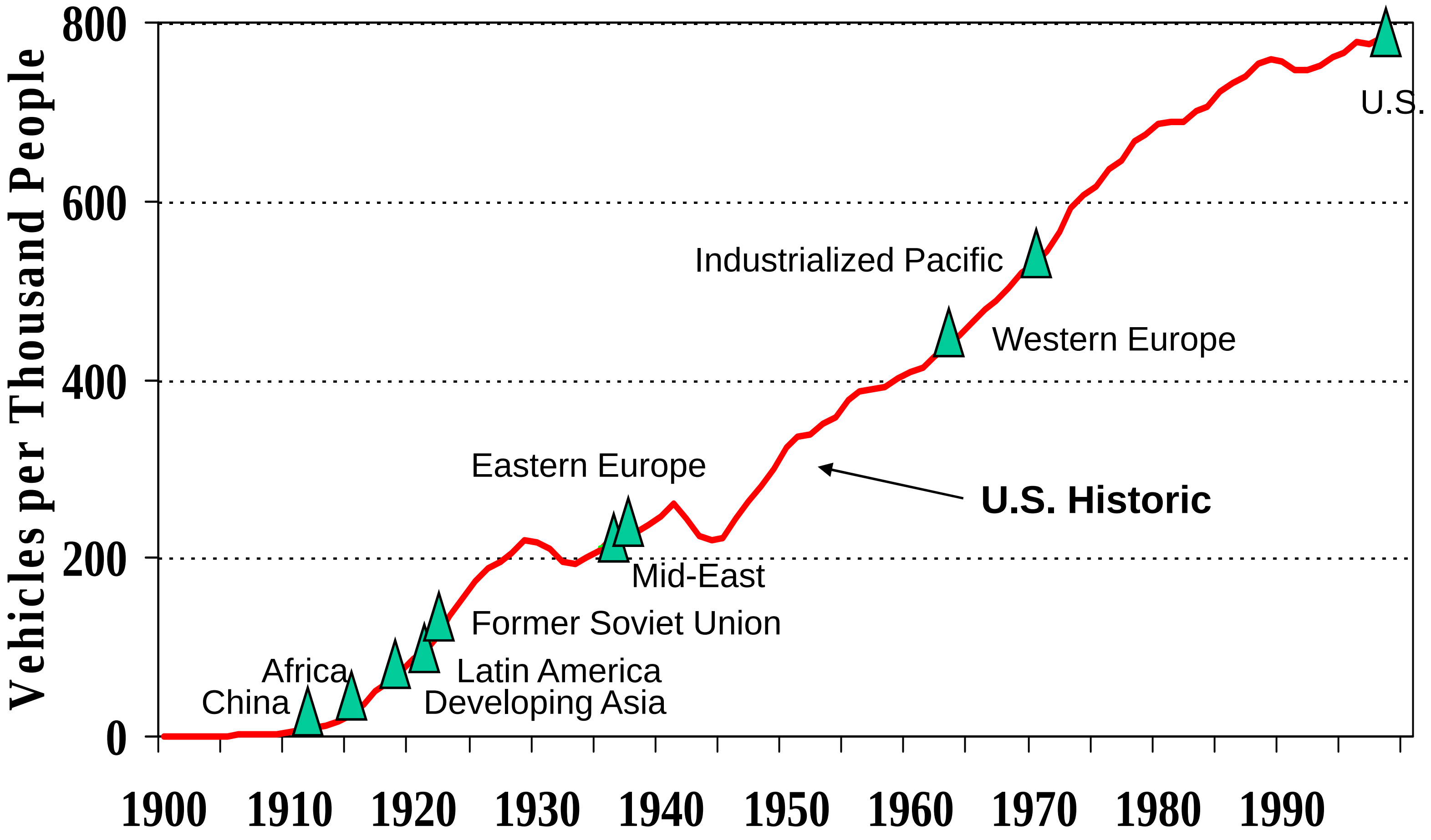
The transportation sector accounts for 2/3 of the oil use in the U.S. and is the fastest growing petroleum consuming sector.

Carbon Dioxide Emissions by End Use Sector



The transportation sector accounts for 1/3 of the CO2 released in the U.S. and one of fastest growing contributors to global warming.

Global Growth in Transportation Accelerates the Demand for Oil



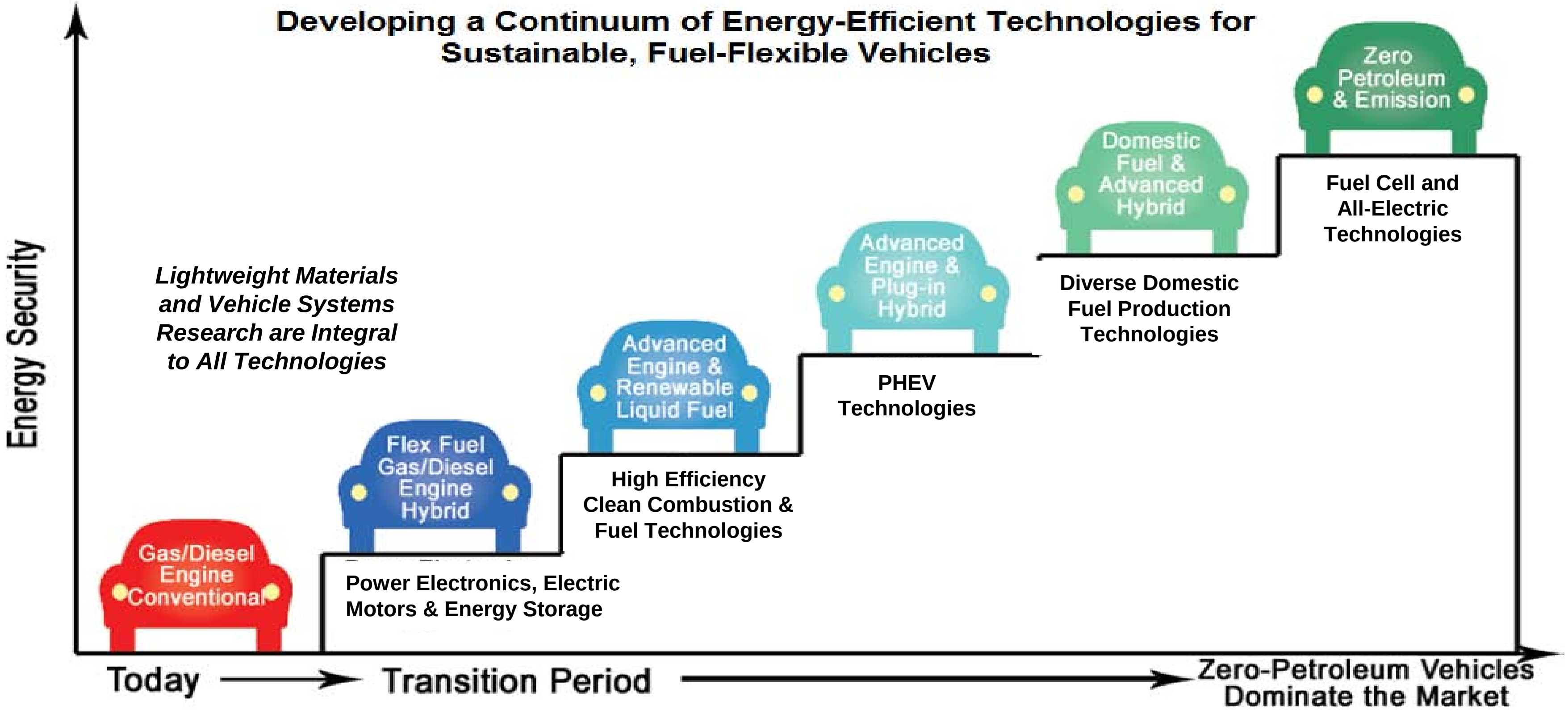
China, with 23.5 vehicles per 1000 people, is where the U.S. was in 1915

Strategic Considerations

- **Diversity:** Don't trade petroleum dependency for dependency on another resource.
- **Efficiency:** Large increases in efficiency lowers overall energy consumption.
- **Addressing greenhouse gas emissions and criteria pollutants**
- **A vehicle/fuel combination that the market will accept:**
  - Cost effective
  - Meets all typical expectations
  - Offers other advantages besides energy benefits
- **A solution capable of serving a HUGE market**
  - Current consumption 9-10MBD and growing
  - Requires multiple feedstocks/energy sources

To achieve a solution requires working with the industries that can commercialize the technology and serve the market.

Strategic Approach to Transportation Energy Security



The FreedomCAR and Fuel Partnership is "… a very effective way to develop technologies that will satisfy all of the requirements for the deployment of radically new systems in the marketplace on a large scale."

NAS/NRC Review of the Research Program of the FreedomCAR and Fuel Partnership, August 2005

Vehicle Technologies Program Budget

	FY 2008 Current Appropriation	FY 2009 Request
Hybrid Electric Systems	94,135	103,361
Advanced Combustion Engine	44,591	33,600
Materials Technology	39,636	36,903
Fuels Technology	17,836	16,122
Technology Integration	16,845	31,100
Total, Vehicle Technologies	213,043	221,086

Collaborations are Key to Addressing Transportation Challenges

FreedomCAR & FUEL Partnership

The FreedomCAR and Fuel Partnership -- focusing on the high-risk research needed to develop the necessary technologies…to provide a full range of affordable cars and light trucks that are free of foreign oil and harmful emissions.

21st CENTURY TRUCK PARTNERSHIP

21st Century Truck Partnership -- pursuing dramatically improved fuel economy with near-zero emissions through advanced combustion engines and heavy hybrid drives that can use renewable fuels.

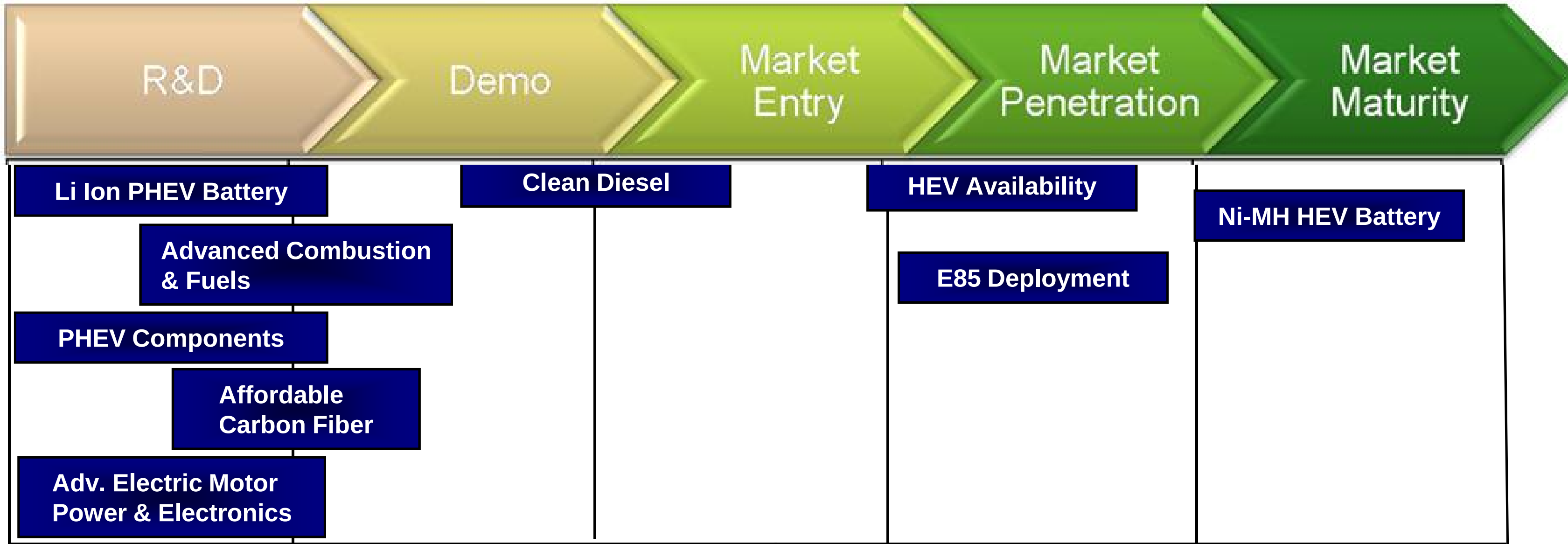
Deployment Activities

Work with Stakeholders (States, Industry, etc.) to Facilitate Moving Technology to Market:

- **Clean Cities** - supporting local decisions that contribute to the reduction of petroleum consumption
- **USAutoPARTS**– supporting the research and manufacturing development needed for technology entry to the market

Opportunities to Reduce Petroleum Use

- Two major thrusts:
  - More efficient vehicles
  - Vehicles that use non-petroleum fuels
- DOE's Vehicle Technologies R&D portfolio
  - Advanced combustion engines
  - Fuels and lubricants
  - Energy storage
  - Power electronics and electric machines
  - Lightweight materials
  - Hybrid vehicle systems
  - Deployment activities
- Two promising directions
  - Ethanol: corn today, cellulosic tomorrow
  - Plug-in hybrid vehicles



2010 Progress Goals

- HEV battery @ $500
- 45% efficient advanced combustion engine & enabling fuels
- 50% reduction in weight of body & chassis demonstrated
- Electric traction system @ &19/kW (max) & 90˚C coolant

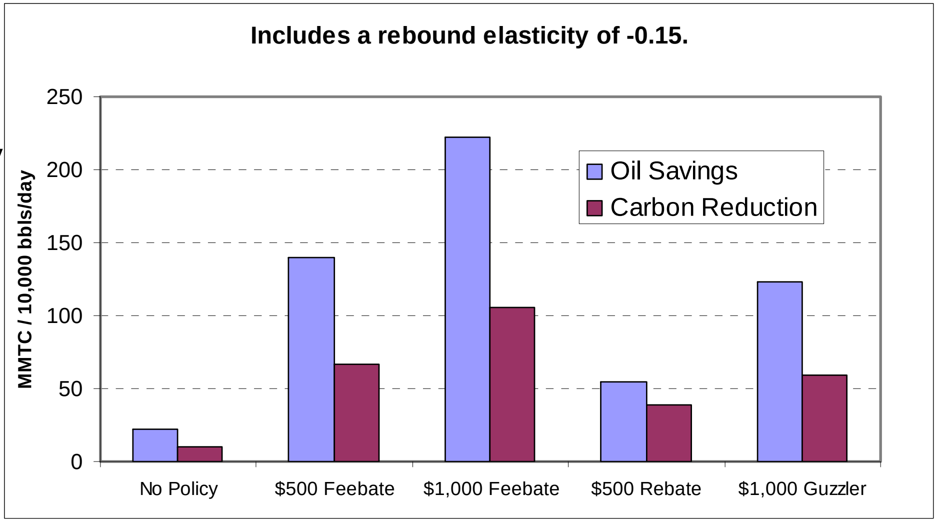
Beyond 2010

- PHEV battery @ $1700, 15 year life, 10 mile range (2012)
- PHEV 40 mile range battery @ $300/kWh (2015)
- Track engine efficiency @ 55% (2013)
- Electric traction system @ $12/kW & 105˚C coolant (2015)

DOE Technologies

Policy Options

- Higher CAFÉ standards
- Feebates
- Extend & enhance consumer incentives for purchasing technology neutral, high efficiency vehicles
  - Tax incentives at point of purchase have been shown to be more effective in motivating consumers
- Tax incentives and other inducements for establishment of domestic battery & light duty diesel engines manufacturing
- Tax incentives to offset the development cost for ethanol & PHEV charging infrastructure
- Policies to empower states to allow utilities to offer time-of-use metering & smart meters



Feebates lead to larger oil and GHG reductions than do rebates or a guzzler tax.

A recent Harvard study estimates that from 2000 to 2006, tax incentives, rising gasoline prices and social preferences increased hybrid sales by 12, 28, and 33 percent, respectively.

Giving Green to Get Green?
Consumer Adoption of Hybrid Vehicle Technology
October 2007
Kelly Sims Gallagher and Erich J. Muehlegger
Harvard

Barriers to Success

Market	Technical	Policy
• High incremental cost cost of green technology • Fuel price volatility • Cost of replacing sunk sunk investments • Pre-buys (heavy truck truck market) • Public awareness & education	• Cost • Size • Weight • Technology performance • Thermal issues • Durability/Life	• Uncertain policy environment • Uncertain regulatory environment • Domestic manufacturing capacity • Relatively low fuel prices

- Incremental costs:
  - HEV: ~$2,500-$3,500
  - PHEV: ~$10,000
  - Light Duty Clean Diesel: ~$1,000-$3,000
- Carbon Fiber costs ~$15/lb
  - (at $5/lb it would be attractive for automotive market entry)

Available Technologies: Potential Fuel Economy Improvement

Technology	Fuel Economy Improvement[1]	Estimated Cost per Vehicle	DOE Contribution	Issues
Reduced Engine Friction	2% - 5.3% (0.6 – 1.4 mpg)	\$33 - \$151	• Low friction coatings • Better lubricants	• Lubricant contributions to emissions
Cylinder Deactivation	4.2% - 6.4% (1.1 – 1.7 mpg)	\$112 - \$252		• Not useful for four cylinder engines
Improved Transmission	4.2% - 8.7% (1.1 – 2.4 mpg)	\$140 - \$350		• Manufacturing acceptance
Renewable Fuel	0.8 gal petroleum displaced per gal of E85	\$150	• Fuel deployment • Fuel production R&D	• Real cost vs. perceived cost • Lower energy value (part of real cost) • Fuel availability
Integrated Starter Generator	4.2% - 7.5% (1.1 – 2.0 mpg)	\$210 - \$350		• Manufacturing acceptance
Reduced Parasitic Losses	5% - 9.3% (1.4 – 2.5 mpg)	\$225 - \$500	• Accessory electrification • Reduced rolling resistance • Lower aerodynamic drag	• Cost • Consumer acceptance of styling changes (aero)
Vehicle Lightweighting (10% to 30% reduction)	6% - 24% (1.6 – 6.4 mpg)	\$350 - \$2,100	Materials Improvements: • light weight steel, • high strength aluminum, • Magnesium, and • composites	• Cost • Manufacturing acceptance • Potential (unwarranted) consumer safety concerns • Recyclability

1. mpg estimates based on a base vehicle fuel economy of 27 mpg.

… continued

Available Technologies: Potential Fuel Economy Improvement, cont.

Technology	Fuel Economy Improvement[1]	Estimated Cost per Vehicle	DOE Contribution	Issues
Improved Engine Mechanics	10% - 22% (mpg)	\$700 - \$1,470	• Camless Valve, Variable Compression	• Intake Throttling • Manufacturer acceptance
Mild Hybridization	10% - 15% (2.7 – 4.0 mpg)	\$1,000 - \$1,500	• NiMH Batteries • Electric Motors • Power Conversion and Management	• System Cost – reduce cost to boost consumer/manufacturer acceptance • Battery Life • Power Management – complexity, thermal tolerance
Advanced Combustion Engines	30% - 50% (8.0 – 13.5 mpg)	\$2,000 - \$3,000	• Advanced diesel engine • Emission controls – SCR catalyst, part filters • Low sulfur fuel	• Cost of engine/aftertreatment • Fuel (accessibility, consumer acceptance) • Assumed replacement of a comparable gasoline eng.
Full Hybridization	30% - 40% (8 – 10.8 mpg)	\$3,000 - \$5,000	• NiMH Batteries • Electric Motors • Power Conversion and Management	• System Cost – reduce cost to boost consumer/manufacturer acceptance • Battery Life • Power Conversion – complexity, thermal tolerance

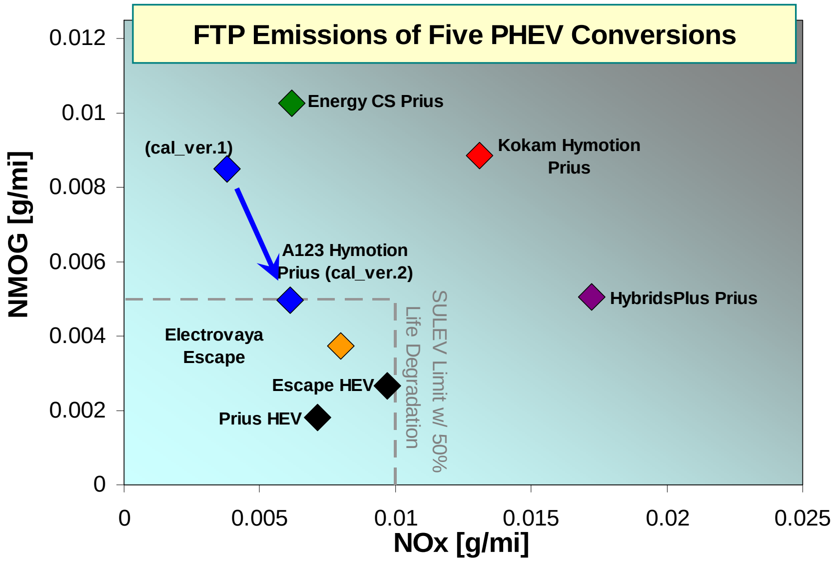
Sources: National Academy of Sciences, 2002 & preliminary findings from K.G. Duleep, 2007

Notes and Caveats:

1. *mpg estimates based on a base vehicle fuel economy of 27 mpg.*
2. *Cost and mpg estimates consistent with the National Academy of Science report, Effectiveness and Impact of Corporate Average Fuel Economy (CAFÉ) Standards, 2002, p. 31 – 55.*
3. *Results of different technologies are not necessarily additive, i.e. the mpg gain from the use of more than one technology may be less than the sum of the individual gains.*
4. *List of technologies is not considered exhaustive.*
5. *Fuel economy improvements of between 1.5 and 2.0 are believed possible, but cost would be consistent with current hybrid cost increments with improved combustion (in the range of \$3,000 to \$8,000).*

Plug-in Hybrids Capture the Imagination

- **DOE stakeholder meeting in May 2006 helped stimulate aggressive industry R&D**
- **Lessons learned in the lab and from modeling and simulation**
  – Validated that conversions can meet SULEV emissions level
  – Blended mode can be preferable to EV mode followed by charge sustaining mode
  – Electrical accessories (e.g., air conditioning) can greatly reduce AER or MPG
  – Battery energy more important than power for petroleum displacement
  – Knowing trip lengths in advance could save some additional fuel
  – Substantial petroleum displacement shown
    - 100% in EV mode, obviously
    - Up to 78% in blended mode demonstrated in lab
  – Fuel economy testing protocol needed
    - DOE lab leading the protocol procedure
    - J1711 balloting expected in summer 2008
- **Barriers to commercialization**
  – Batteries, batteries, and batteries
    - Cost
    - Safety
    - Calendar life and cycle life
  – Power Electronics
    - Cost
    - Weight
    - Volume



Data collected at Argonne National Lab

Current PHEV Activities

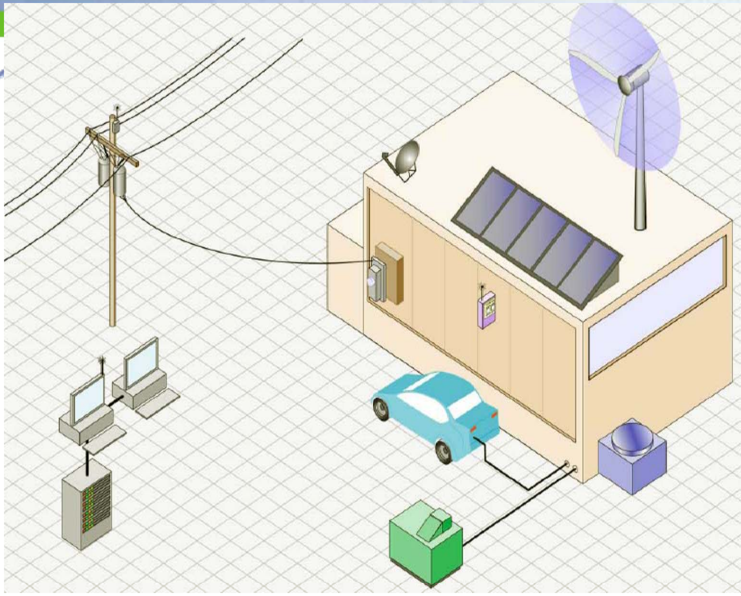
- Issued a major solicitation and competitively selected 5 industry partners to develop lithium-ion batteries for PHEVs
- Issued a major solicitation and selected 5 industry and academic partners to develop power electrics and electric motors.

- Explore the impacts and interactions of PHEVs and the electricity grid. Study consumer behavior and quantify the value proposition for different charging assumptions and energy prices.

- Collect data on PHEV performance, petroleum displacement, electricity use, battery function, and other vehicle attributes. Use data to project future PHEV national impacts.

- In December 2007, VT issued a major solicitation for PHEV Demonstration
  - Build and deploy small fleets of PHEVs in geographically dispersed regions
  - Collect data on vehicle performance, battery characteristics, fuel savings, electricity use, consumer behavior

Utilities and States will need to support Plug-In Hybrids

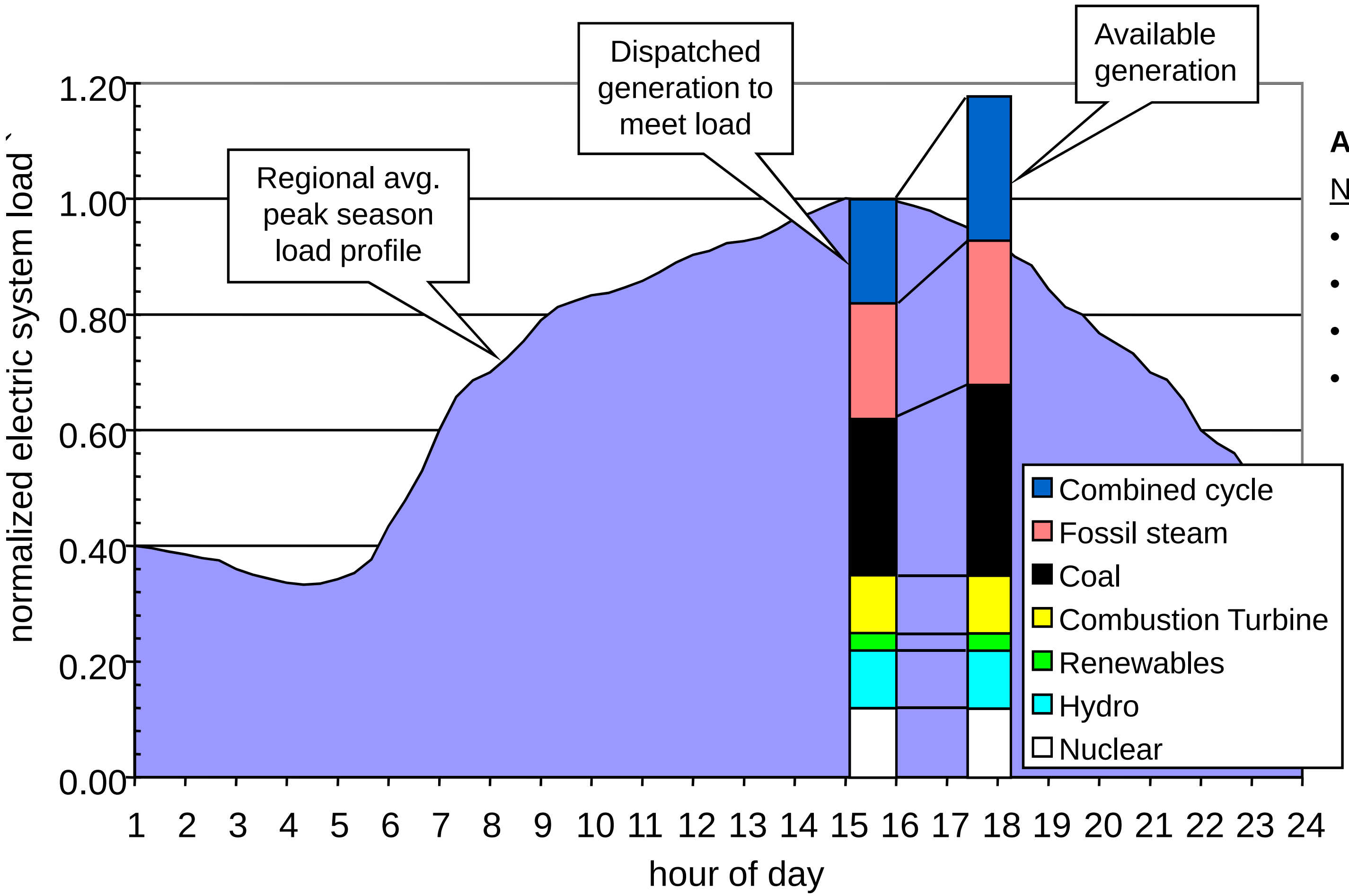


- AMI: Advanced Metering Infrastructure
  - 2-way communication portal between grid and homes
  - Enables load management, e.g. turning on/off Plug-In Hybrid Electric Vehicle (PHEV) charging

- Differential rate structures allow time of use metering and enable PHEVs to take advantage of lower rates at night and “valley-filling”

- Updates of utility codes and standards

Fundamental Approach: Fill regional peak season average



Assume:

No additional generation from:

- nuclear
- hydro
- renewables
- combustion turbines

Energy Storage

- **Lithium-ion batteries** are being aggressively pursued globally for EV/HEV applications, including several different electro-chemical and mechanical designs
  - Focus is on system integration, cost, and life
  - Safety and recycling remain to be demonstrated (for millions of laptop batteries as well)
  - Saft Li-ion technology (DOE supported R&D) will be produced in volume (TBD) for mild hybrids
  - Available technology does not meet the Administration's 40-mile electric range target for PHEVs
- **Capacitor combinations** with other battery chemistries (e.g., NiMH, Pb-Acid) are being evaluated – for potentially lower cost and shorter electric range

AESC = NEC + Nissan JV

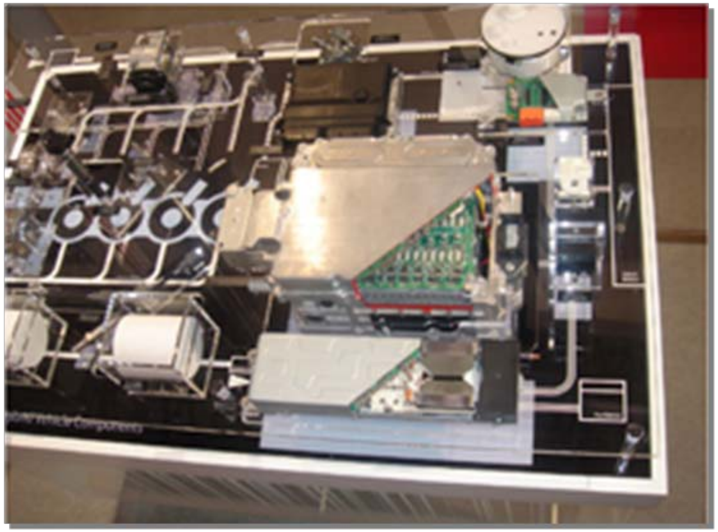
Subaru

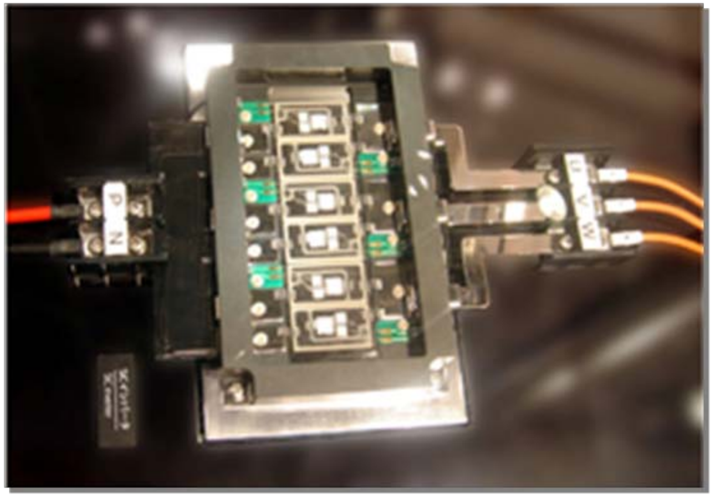
Saft/JCS

Photos by KSH

Power Electronics

- **Smaller, integrated systems**
  - Applications ranging from motorcycles to luxury cars
  - Integrated motors and power electronics available in small (motorcycle) systems
- State-of-the art power electronics is the **Denso converter** (Lexus 600h)
- Denso targeting **Silicon Carbide** (SiC) converter production for 2015+
  - Claims wafer production with the smallest level of defect density in the world, "hundreds per cm^2"
  - Cost must be reduced 50%





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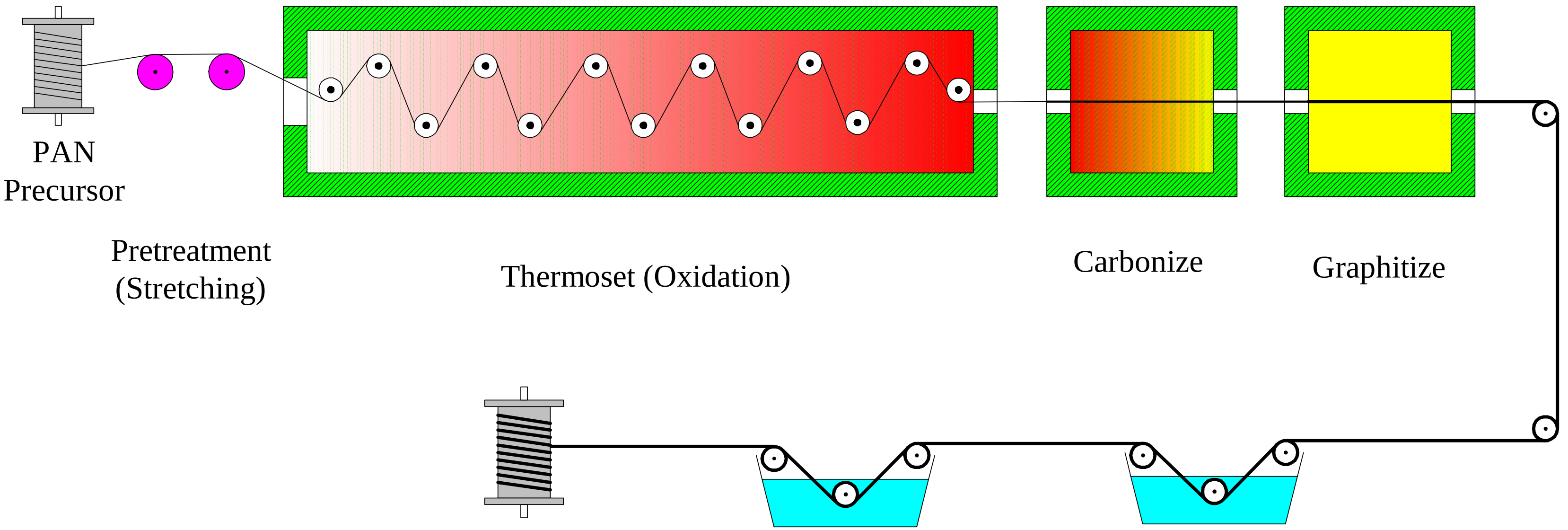
Low Cost Carbon Fiber



Typical processing sequence for PAN and pitch –based carbon fibers

Major Cost Elements	
Precursor	43%
Oxidative stabilization	18%
Carbonization	13%
Graphitization	15%
Other	11%

- Automotive cost target is $5 - $7/lb

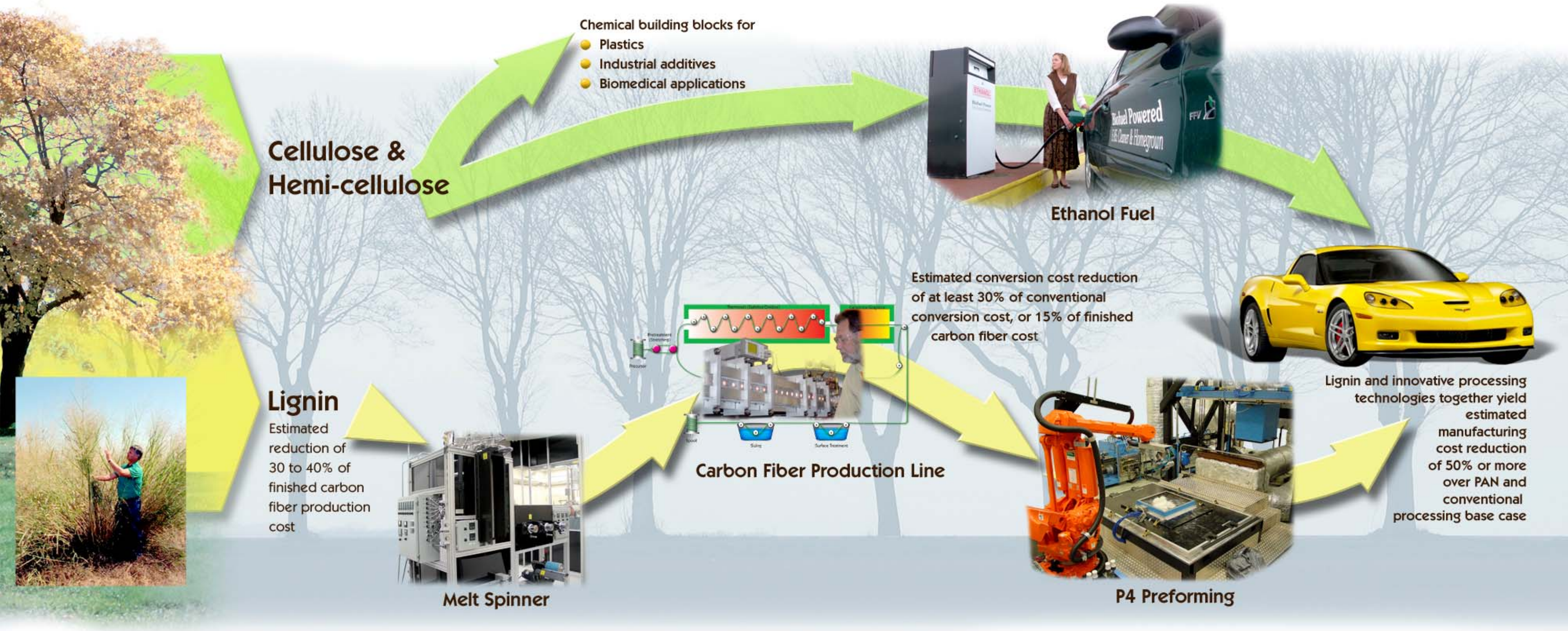
  Tensile 250 ksi, 25 Msi, 1% ultimate strain

- Oak Ridge National Laboratory (ORNL) is attempting major technological breakthroughs for major cost elements

Carbon Fiber Lignin Precursors

Project Impact

PAN	Oxidation	Carbonization	Graphitization	ST
$3.53 (44.8%)	$1.34 (17.0%)	$1.00 (12.7%)	$1.19 (15.1%)	$0.82 (10%)



Advanced Combustion and Emission Control R&D

Goal: Reduce petroleum dependence by removing critical technical barriers to mass commercialization of high-efficiency, emissions-compliant internal combustion engine (ICE) powertrains

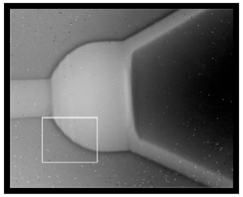
Primary directions

- ICE efficiency improvements for cars, light- and heavy-duty trucks through low-temperature combustion and minimization of thermal and parasitic losses
- Aftertreatment development integrated with combustion strategies for emissions compliance and minimization of efficiency penalty
- Coordination with fuels R&D to enable clean, high-efficiency engines using hydrocarbon-based (petroleum and non-petroleum) fuels

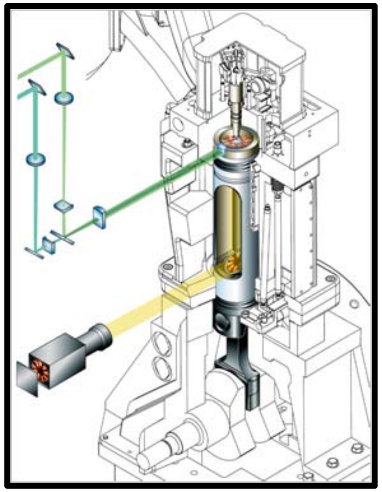
Goals	2010 (light-duty)	2013 (heavy-duty)
Engine brake thermal efficiency	45%	55%
Powertrain cost	< $30/kW	

Research Approach

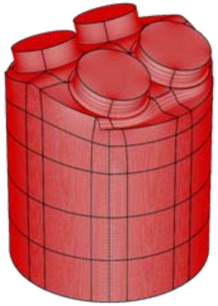
- ❑ Close collaboration between industry, national labs and universities
  - Research guided by industry needs
  - DOE/industry prototype engine projects
- ❑ Close coupled modeling and experiments
  - Multi-/single-cylinder engines & simulators
  - Advanced diagnostics
    - Optical-, laser-, and x-ray- based techniques
  - Multi-dimensional computational models
- ❑ Cross-cuts heavy-duty research



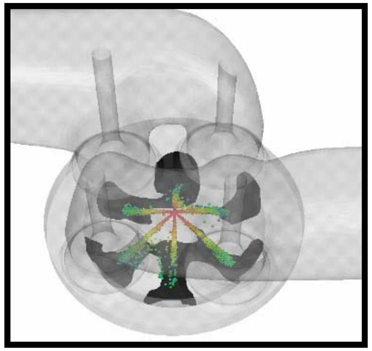
Nozzle Sac X-Ray Image



Optical Engine

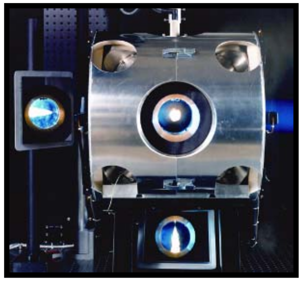


3-Million Cell LES Grid

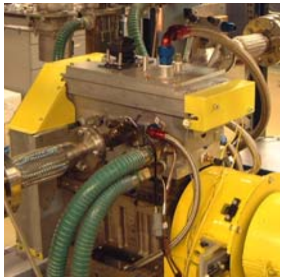


Engine Simulation

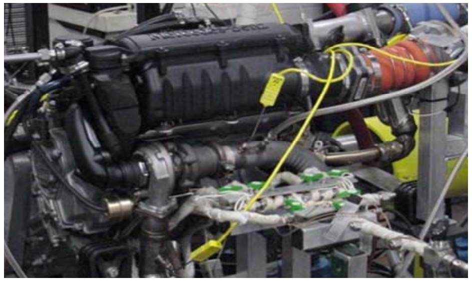
Automotive HCCI



LTC Simulator



H2 Engine



Multi-Cylinder Diesel

Advanced Heavy Hybrid Propulsion Systems (AHHPS)

Goal: **In coordination with 21st Century Truck Partnership, develop technology to enable up to an increase in fuel efficiency in Class 3-8 heavy hybrid vehicles while meeting EPA 2007 emissions standards**

Industry Partners (all projects 50/50 cost share - $25.4M total)

- Eaton/International Truck
- Oshkosh
- GM/Allison
- Caterpillar

DOE / NREL Role – Procurement, Program Management and Technical Support (chassis dyno testing, on-road testing, duty cycle analysis)

(all but one of these projects has ended in FY07)

AH²PS

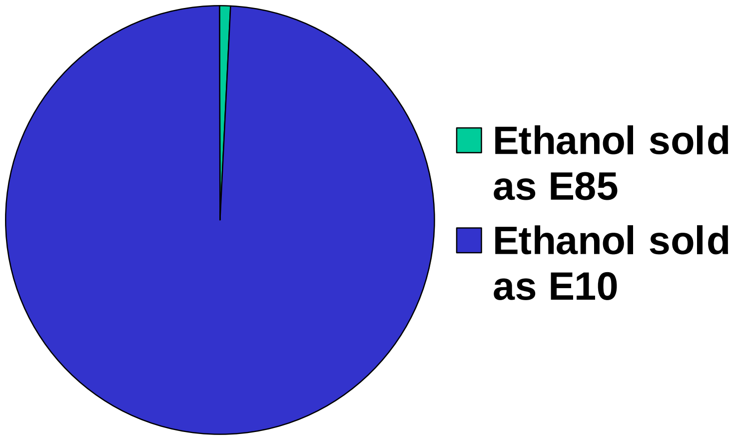
E85 Remains Important

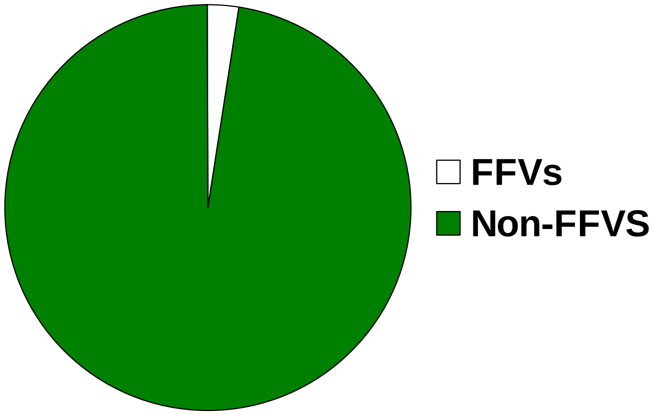
- We continue to support the expansion of the use of E85… *by focusing its deployment in areas in which it makes the most sense!*
  - Concentrated development of distribution/fueling infrastructure near production
  - High-traffic corridors
- Cooperative agreements and national laboratory projects focus on reducing or eliminating the fuel economy penalty associated with using E85
  - Awarded 7 E85 Engine Optimization Contracts
- Clean Cities consumer education and technical advice for retail fueling station operators and fleet managers

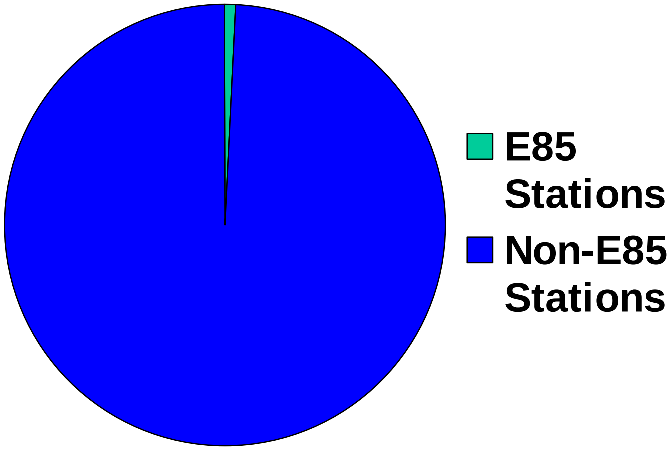
20 in 10/EISA Goals Cannot be Met Solely Through Expansion of E10 Gasoline

- Ethanol markets are not able today to absorb the ethanol volumes specified by the Energy Independence & Security Act (36B gallons)
  - Today, blended gasoline used in standard vehicles (non-FFVs) is limited to 10 percent ethanol (E10).
  - More than 99 percent of the ethanol produced today is used in E10 blends; a tiny fraction is used to produce E85 for FFVs.
  - E10 markets are likely to saturate by 2012, 2013, possibly sooner, as production capacity approaches 14B gallons (~10% of all gasoline sold).
- There are two paths to increase ethanol markets beyond 14B gallons:
  - Path A: Saturate E10 markets – and significantly expand E85 markets at an accelerated pace
  - Path B: Certify “intermediate blends” of gasoline to use up to 15 or 20% ethanol (E15, E20) and let market forces drive ethanol supply distribution
- DOE is investigating the impact of Path B on the existing “legacy” fleet of vehicles and non-road equipment

Nation has limited E85 Infrastructure







E85 Route to Solution:

For example, in order for E85 market to absorb 25 billion gallons of ethanol per year by 2017 we estimate that the US would need :

- 10 billion gallons per year of E85, 250X more than today.
- 100 million FFVs vs 6 million FFVs today.
- 60,000 E85 stations vs 1,200 today.

DOE is Testing Intermediate Blends in Legacy Equipment

- The purpose of the testing is to determine what effects intermediate blends may have on existing vehicles and equipment
- This testing could aid EPA in their regulatory role regarding RFS2
- Published testing results will help EPA in considering potential future requests for “sub-sim” waivers

Other Fuels

- There is more to life than ethanol
- VTP conducts fuels-related R&D in a variety of areas:
  - Other renewable fuels – synthetic biofuels, biodiesel, higher alcohols, etc.
  - Other alternative fuels – gas-to-liquids, coal-to-liquids, hydrogen for ICEs, etc.
  - Impact of fuel composition on combustion characteristics
  - Fundamental studies of chemical kinetics of combustion and modeling of fuels

Clean Cities *A voluntary, locally based government/industry partnership*

Mission: To advance the energy, economic, and environmental security of the U.S. by supporting local decisions to adopt practices that contribute to the reduction of petroleum consumption in the transportation sector.

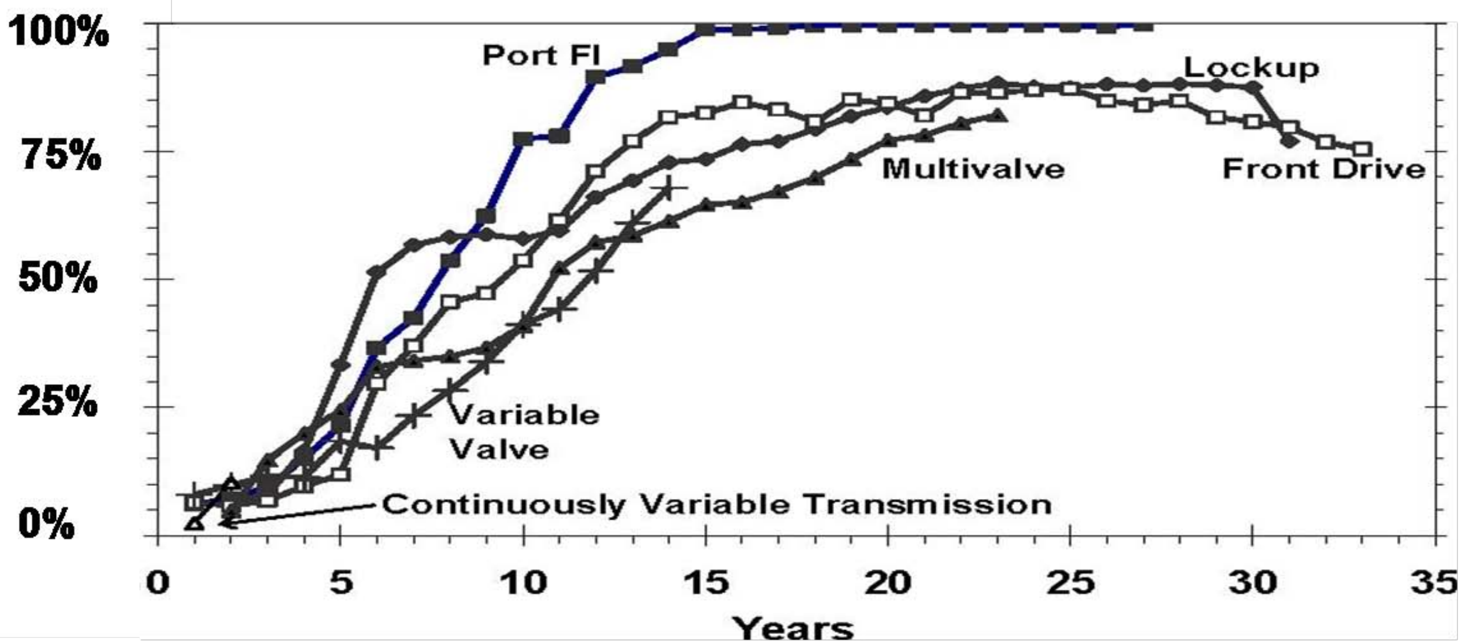
TECHNOLOGIES

- **AFVs**
- **Fuel Economy**
- **Idle Reduction**
- **Fuel Blends**
- **HEVs**

Faster Market Penetration

Through early R&D investments

It takes about 15 years for a technology to reach maximum penetration in new vehicle sales and another 15 years for the technology to be ubiquitous.



Policy and incentives can accelerate market penetration.

Light-Duty Automotive Technology and Fuel Economy Trends: 1975 Through 2006, EPA420-R-011, July 2006, p.

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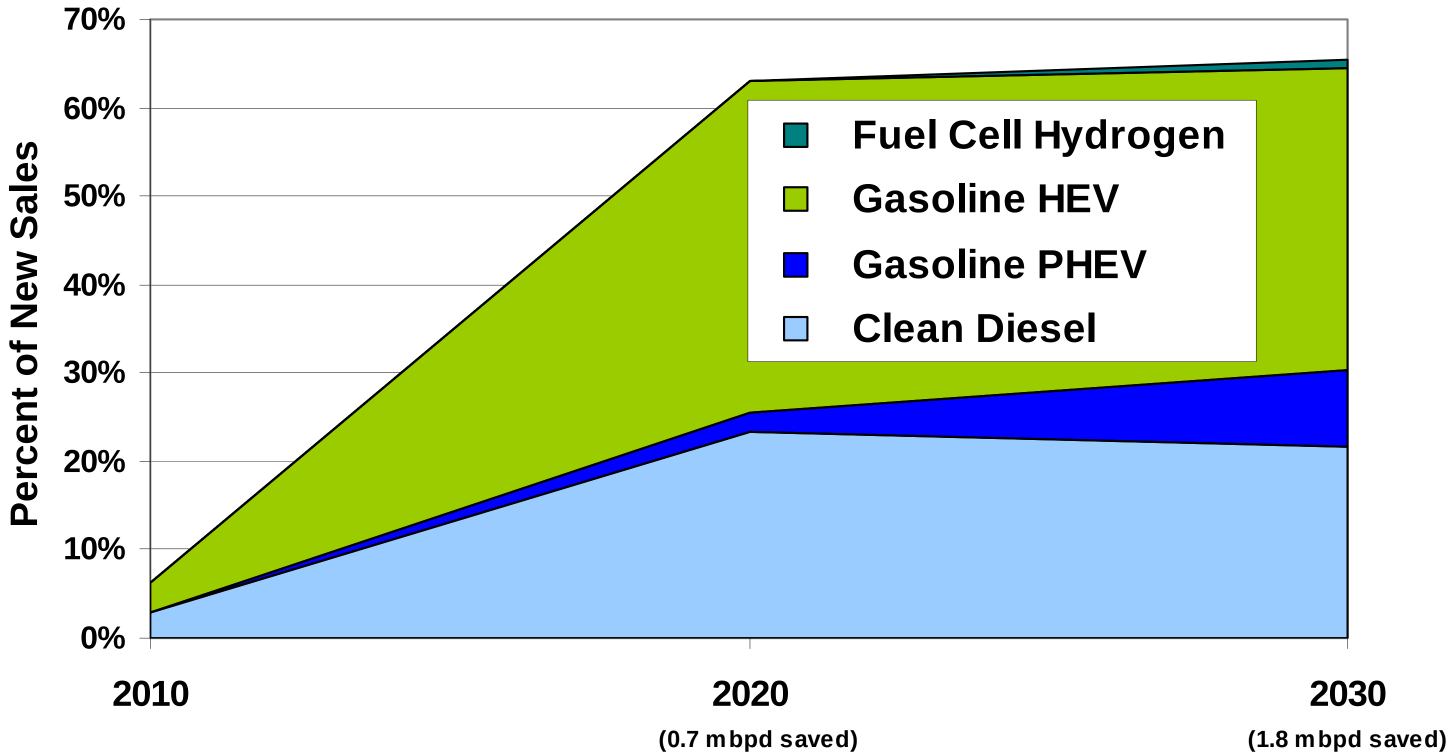
Projected Advanced Technology Market Shares for Light Vehicles



- An advanced technology vehicle (clean diesel, hybrid) getting fifty percent better fuel economy is expected to achieve greater market penetration if it has lower incremental cost and fuel prices are high.
- Additional PHEV benefits include:
  - Even greater oil savings
  - Oil consumption displaced by domestic electricity
  - Lower greenhouse gas emissions (regardless of electricity fuel source)
  - Improved operational efficiency of electric utilities

Major Technology Success Stories

Deployed Technologies	Technology Partners	Policy Implications	Market Impact
Low Sulfur Diesel Fuel	NREL	Informed EPA of sulfur effects from fuel research	40B gallons of low sulfur diesel fuel used annually
Nickel Metal Hydride Batteries	Cobasys	Royalty payments to Treasury	Every US Hybrid Vehicle sold has IP from this battery research
Quick Plastic Forming of Aluminum	GM PNNL ORNL	Higher Energy Efficiency	Chevrolet Malibu MAXX 2004, Cadillac and GM Vehicles
Light Duty Diesel Engine	Cummins ORNL SNL	Higher Energy Efficiency for Light Vehicles	Agreement with DaimlerChrysler for 2009 volume production

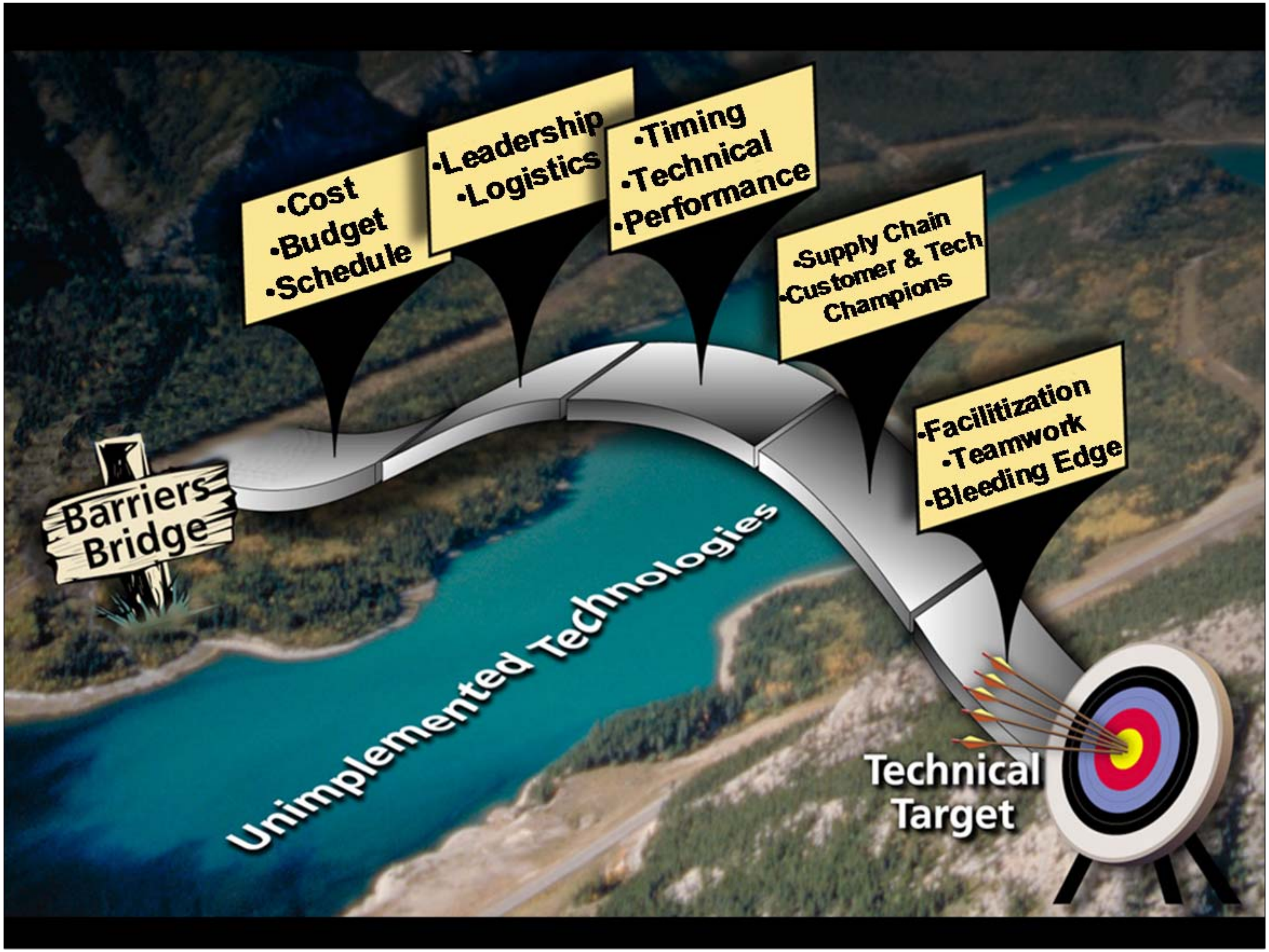
Key Lessons Learned (or Re-learned)

- Cost is a complex variable
  - The competition (metal) isn't sitting still
  - Decisions should be based on sustainable supply prices
  - Product pricing constraints are very important
- Hitting the cost and technical targets is necessary, but not sufficient, to achieve commercial success
  - Supply chain is especially important. Here are a few supply chain problems that we have experienced:
    - Supplier quality
    - Supplier financial distress
    - Inability to change suppliers due to proprietary nature of a key product feature
    - Product availability not assured
    - Price instability

What can we do to overcome barriers?

- Tax incentives
- Lower prices for advanced technology
- Better marketing schemes
- Consumer action

Pathway to Technology Commercialization



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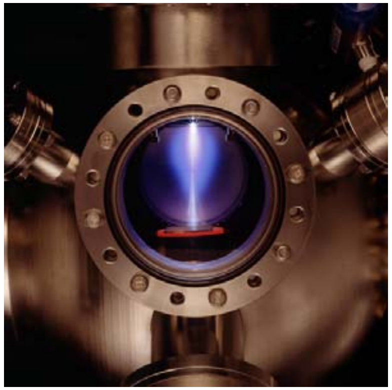

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