March 2007

The Advanced Energy Initiative: Challenges, Progress, and Opportunities

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Presentation for *The Search for a Sustainable Energy Future: Challenges for Basic Research*, A Mini-Symposium sponsored by the Energy Working Group at Penn, March 9, 2007.

The Advanced Energy Initiative: Challenges, Progress, and Opportunities

Abstract
This talk will address hybrid vehicles and battery technology, ethanol as a fuel, and hydrogen fuel cells, the ability of these technologies to reduce oil dependence and the challenges for each approach, and the progress made. Stationary power generation, solar buildings, and portable power fuel cells will also be discussed. The presentation will be at a programmatic level and will touch on the applied research and technology development opportunities under the Advanced Energy Initiative.

Comments
Presentation for *The Search for a Sustainable Energy Future: Challenges for Basic Research*, A Mini-Symposium sponsored by the Energy Working Group at Penn, March 9, 2007.

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

THE ADVANCED ENERGY INITIATIVE

Challenges, Progress, and Opportunities

March 9, 2007

JoAnn Milliken
DOE Hydrogen Program

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Sentech, Inc.

PRESENTATION OUTLINE

THE PROBLEM — *Our Domestic Energy Situation*

- Oil Dependence
- Greenhouse Gas Emissions
- Air Pollution

SOLUTIONS — *Energy Initiatives*

- Energy Conservation and Efficiency
- Renewable Power Generation
- Alternative Fuels & Vehicles

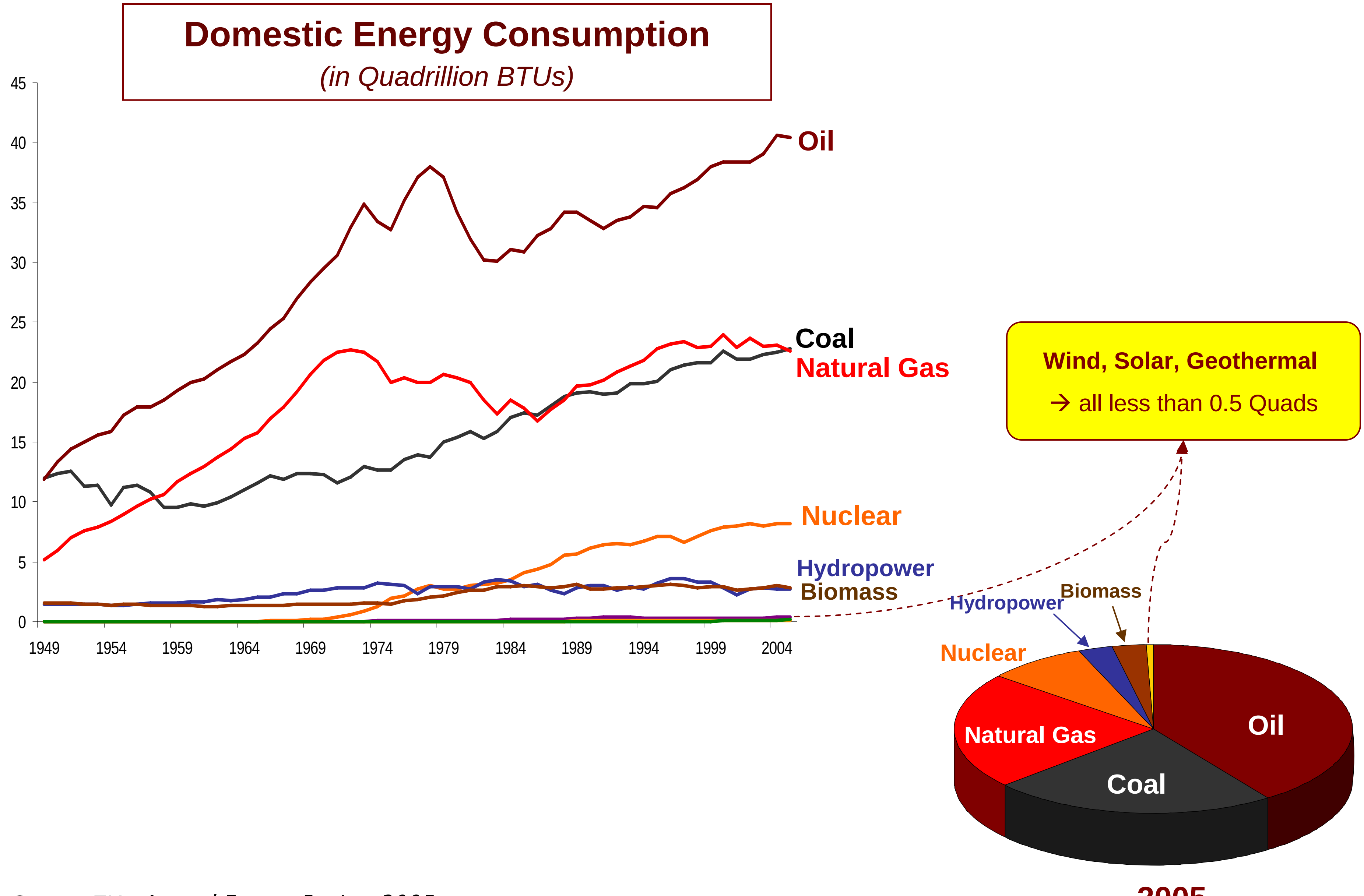
Research and Development

Progress and Opportunities

CONCLUSION — *The Way Forward*

- Well-to-Wheels Analysis
- Future Scenarios

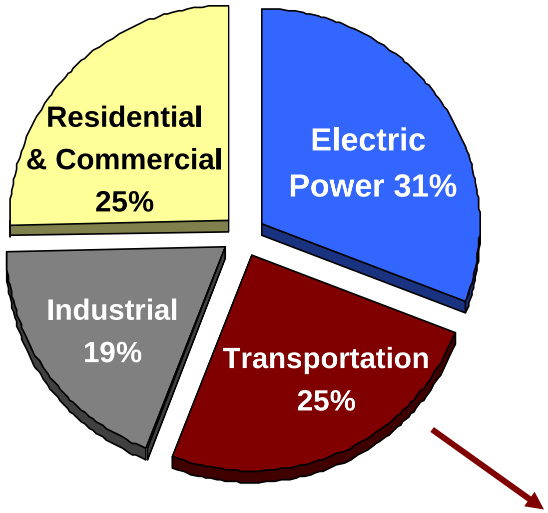
Domestic Energy: *Sources*



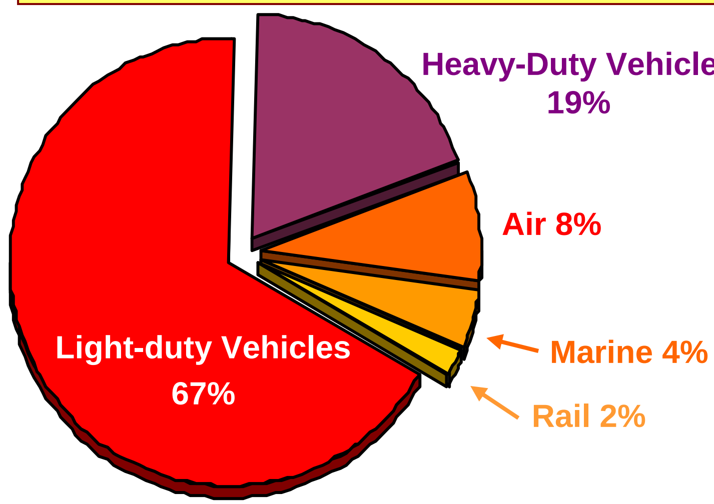
Source: EIA, *Annual Energy Review 2005.*

Domestic Energy: *Consumption*

Total Energy Consumed: U.S. - 2005



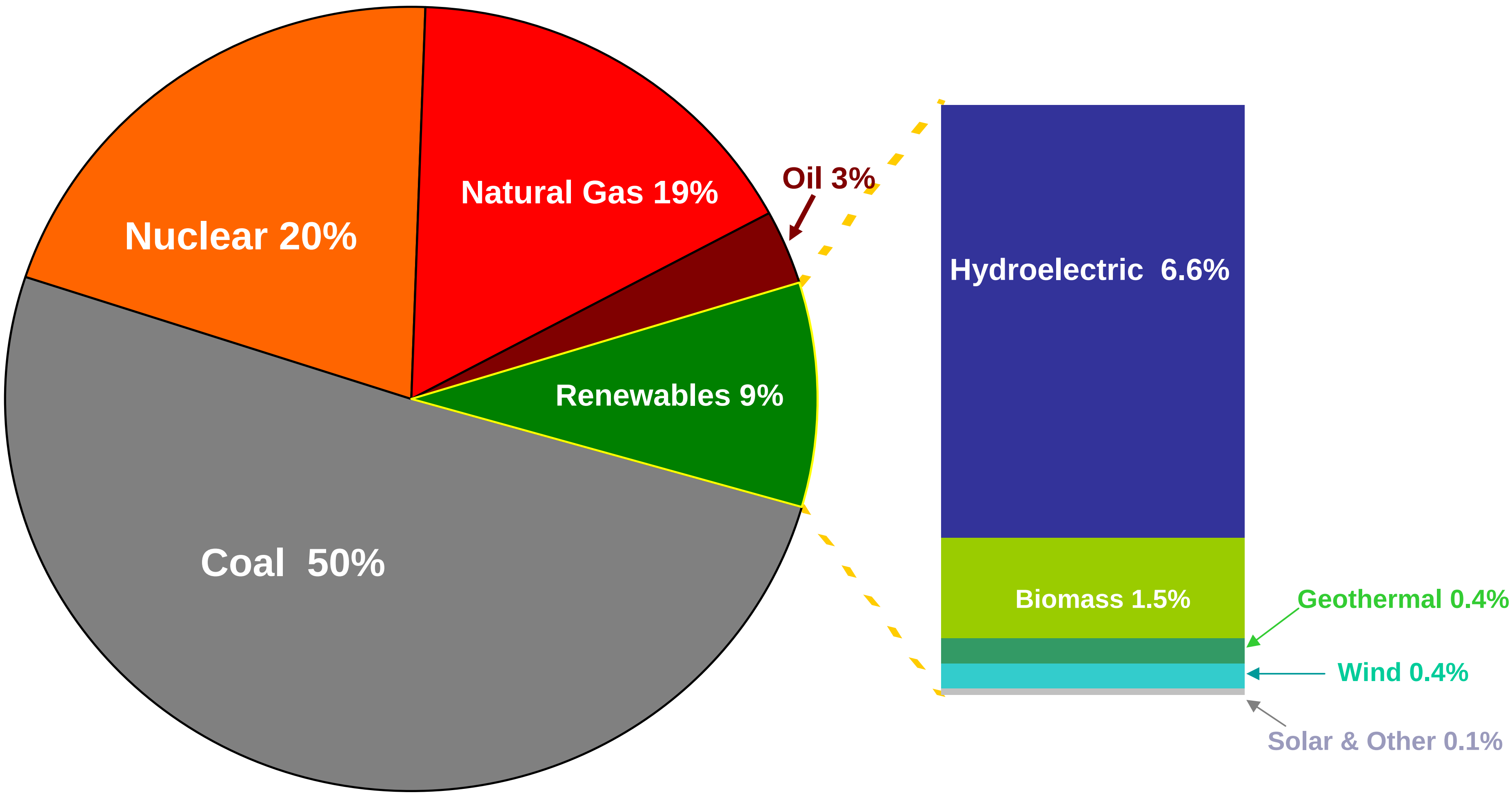
Transportation Energy Use – By Sector



Source: EIA, *Annual Energy Review 2005.*

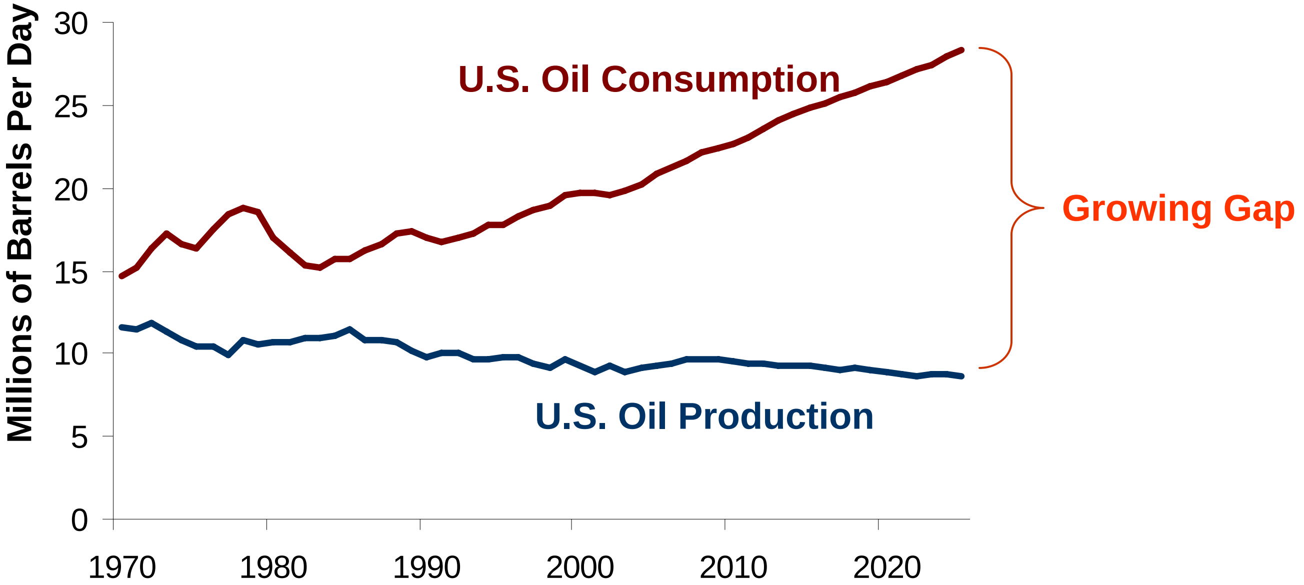
Domestic Electricity: *Sources*

U.S. Electricity Generation, by Energy Source, 2005

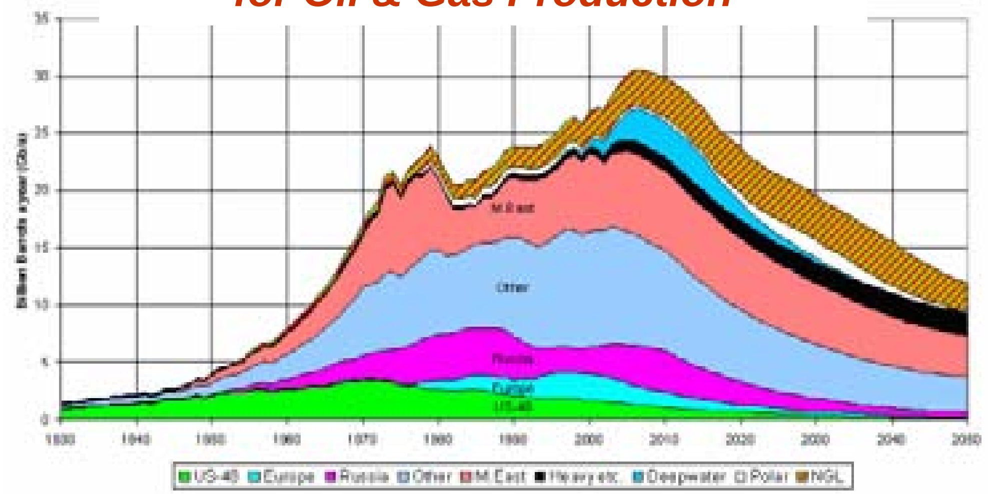


Source: EIA, *Annual Energy Review 2005.*

The OIL Issue

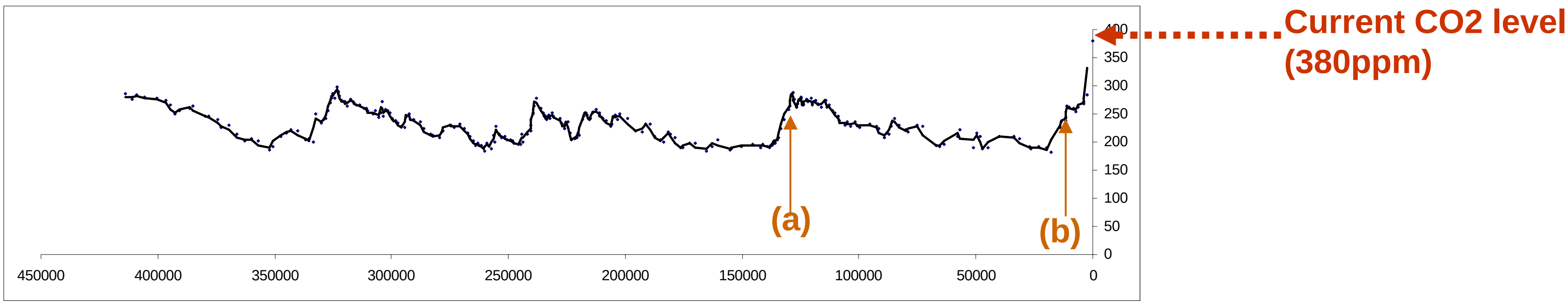


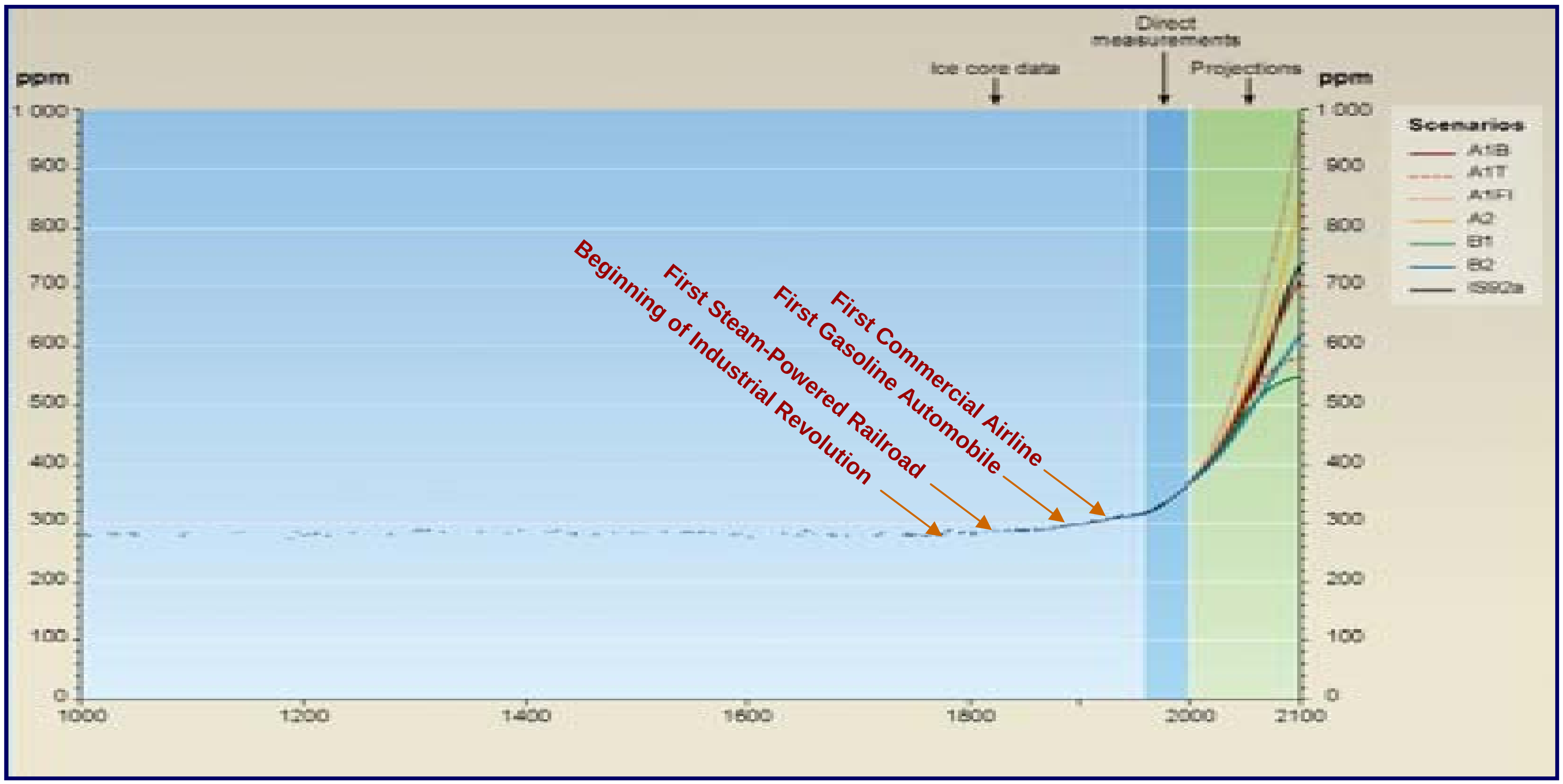
"Peak Oil" Scenario
for Oil & Gas Production



Sources: EIA, *Annual Energy Review 2005,*
and the Association for the Study of Peak Oil & Gas (UK)

Carbon Dioxide

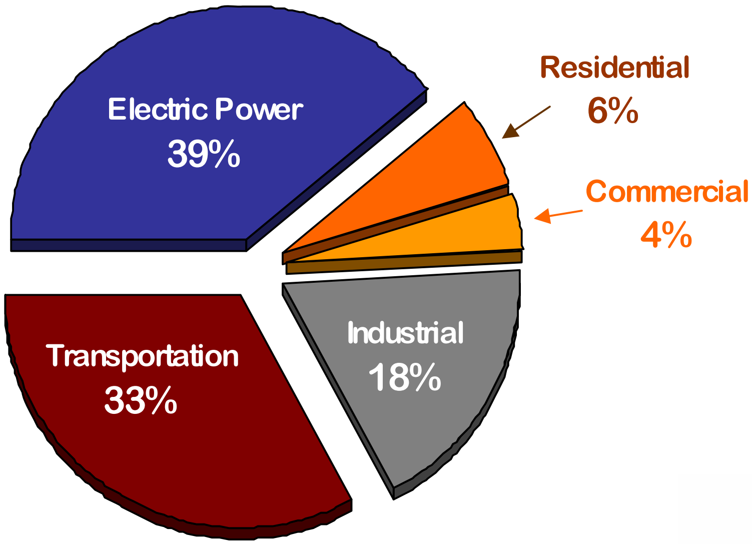




Sources: Vimeux, F., K.M. Cuffey, and Jouzel, J., 2002, "New insights into Southern Hemisphere temperature changes from Vostok ice cores using deuterium excess correction", *Earth and Planetary Science Letters*, **203**, 829-843.

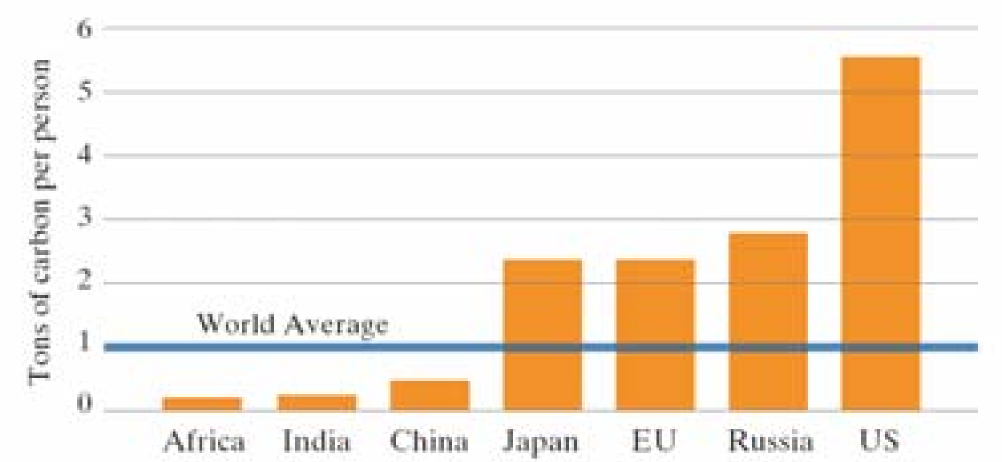
Carbon Dioxide: *Sources*

U.S. CO_2 Emissions by End-Use



Source: EIA, *Annual Energy Review, 2005.*

Annual Carbon Emissions Per Person



Source: World Resources Institute

THE PROBLEM

- Oil Dependence
- Greenhouse Gas Emissions
- Air Pollution

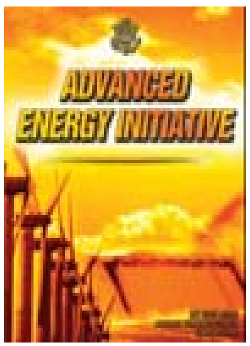
SOLUTIONS	*Energy Initiatives*
• Energy Conservation and Efficiency • Renewable Power Generation • Alternative Fuels & Vehicles	**Research and Development Progress and Opportunities**

Presidential Energy Initiatives

HYDROGEN FUEL INITIATIVE (January 2003)

- $1.2 billion for first five years (2004-08).
- Accelerates hydrogen and fuel cell technology development.
- Establishes partnerships with private sector.
- Goal: to make fuel cell vehicles practical and cost-effective by 2020.

ADVANCED ENERGY INITIATIVE (February 2006)



- 22% increase in funding for clean energy research.
- Accelerates R&D of near-term transportation options—biofuels and plug-in hybrids, as well as technologies for electricity generation.
- Reinforces Hydrogen Fuel Initiative.

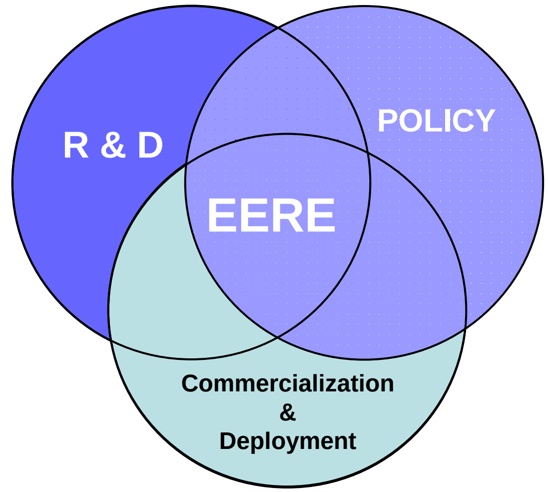
"20-in-10" INITIATIVE (January 2007)

- Accelerates R&D to produce 35 billion gallons of renewable and alternative fuels by 2017, and increases fuel economy standards, to displace 20% of annual gasoline use in 2017.
- Expands scope of Renewable Fuel Standard (RFS) to "Alternative Fuel Standard," including corn and cellulosic ethanol, biodiesel, methanol, butanol, hydrogen, and other alternative fuels.

DOE Energy Efficiency and Renewable Energy Program

Conducting Applied Research and Technology Development for Energy Solutions

Mission: Develop renewable energy sources and conversion technologies, as well as efficiency best practices, regulations and technologies that collectively strengthen our economy, environment and national security

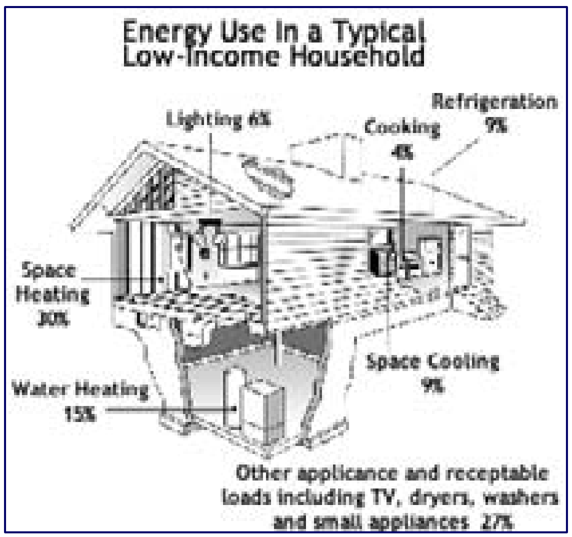


Energy Efficiency & Conservation	• Building Technologies • Industrial Technologies • Weatherization • Federal Energy Management
Renewable Power Generation	• Wind/Hydropower • Solar • Geothermal
Alternative Fuels & Vehicles	• Hybrid Electric Vehicles • Biofuels • Hydrogen & Fuel Cells

Energy Efficiency:

Weatherization & Intergovernmental

- Free weatherization services to low income citizens - permanently lowers their utility bills
- Accelerates adoption of clean energy technologies and practices by State and local governments, Tribes, and international partners



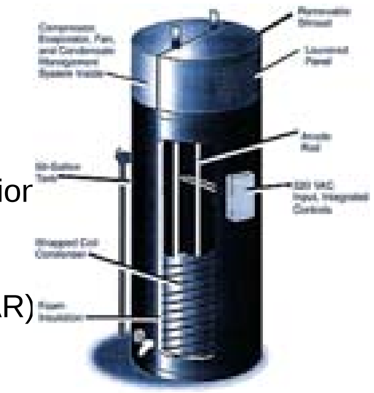
Tips on Saving Energy & Money at Home

http://www.p2pays.org/ref/19/18981.pdf

Building Technologies

Research Areas:

- Lighting
- Heating & Cooling
- Walls, Roofs, and Foundatior
- Windows and Doors
- Appliances (ENERGY STAR)



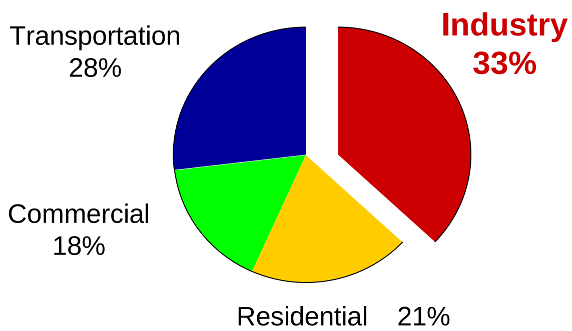
U.S. Market:

- 40% of all energy is consumed by buildings
- 2 million homes built annually; could be 20-30% more efficient at no extra cost
- Green building movement small, but growing

Energy Efficiency:

Industrial Technologies

2004 U.S. Energy Use: 100.3 Quads*
*Includes electricity losses



www.eere.energy.gov/industry/saveenergynow

Save Energy Now Results

- **52 trillion Btu per year** natural gas savings
- Reduced CO_2 emissions by **3.3 million tons per year**
- More than **$485 million per year** in energy cost savings

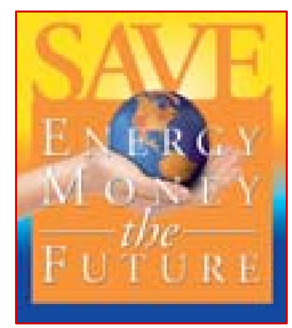
Federal Government as Role Model

Energy Savings Performance Contracting

- $1.9 billion in private-sector investment in energy efficiency projects at Federal facilities
- Saved 16 trillion Btu annually (equivalent to energy consumed by a city of about 450,000)
- Net savings of $1.5 billion to the government

Focus Areas

- New Construction/Retrofits
- Operations & Maintenance
- Utility Management

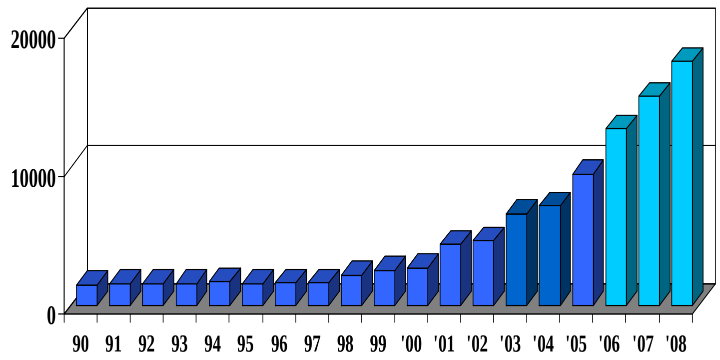


Energy Efficiency & Conservation	• Building Technologies • Industrial Technologies • Weatherization • Federal Energy Management
Renewable Power Generation	• Wind/Hydropower • Solar • Geothermal
Alternative Fuels & Vehicles	• Hybrid Electric Vehicles • Biofuels • Hydrogen & Fuel Cells

Renewable Power Generation: *Wind/Hydropower/Geothermal*

Wind

U.S. Market Growth – Cumulative Installed Wind Capacity (MW)



Progress

- Reduced cost gap by 50% for lower wind speed technology, enabling a 20X increase in available wind since 2002
- Approximately 11,000 MW land based, primarily utility-scale, in the U.S. Market is expanding at over 20% per year.
- Wind power currently provides enough electricity for almost 3 million households

Solar

- In the last 15 yrs, the global solar PV market grew 100-fold -- from < $100M (in annual sales) to > $11B.
- Cumulative U.S. domestic installed: 480 MW; 104 MW in 2005
- Outpaced by Europe ('05: 750 MW), and Japan ('05: 320 MW)
- Cost: ~$0.23/kWh for residential systems

Solar America Initiative

Market Transformation — activities that address marketplace barriers and offer the opportunity for market expansion.

Technology Pathway Partnerships — research and development on PV component and system designs, including low-cost approaches for manufacturing.

EERE

Energy Efficiency & Conservation	• Building Technologies • Industrial Technologies • Weatherization • Federal Energy Management
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Advanced Vehicle Technologies

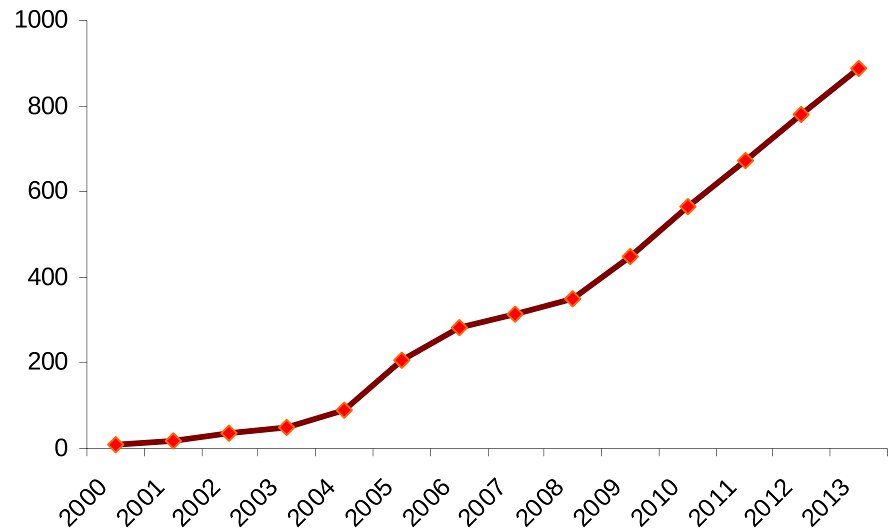
Energy efficient and environmentally friendly vehicle technologies can reduce emissions and the Nation's reliance on oil.

U.S. Market
- 230 million vehicles on the road
- 17 million new light-duty vehicles per year
- About 350,000 hybrid vehicles

Research Areas
- Plug-in hybrid vehicles:
  - ➢ Batteries for energy storage
  - ➢ Hybrid drive systems and testing
- Advanced combustion engines:
  - ➢ Very high efficiencies
  - ➢ Near zero emissions
- Materials research - lightweight, strong vehicle structures
- Market transformation through Clean Cities program and www.fueleconomy.gov

U.S. Sales of Hybrid Electric Vehicles

(actual & projected, in thousands)



Advanced Vehicle Technologies:
Research & Development

HYBRID ELECTRIC VEHICLES: Batteries

- **Lithium-ion batteries for power-assist HEVs are expected to enter the market in 2-4 years**
  - *Lack of lithium-ion manufacturing bases in the U.S. is a concern*
- **Remaining Technical Barriers**
  - *Battery cost is 2-3 times the target*
  - *Battery life of 15 years is challenging*
  - *Abuse tolerance and low temperature performance remain concerns*

Advanced Vehicle Technologies:

Research & Development

Plug-in Hybrid Electric Vehicles

Critical Obstacles

- **Battery Cost**
- **Battery Performance and Durability**
- **Power Electronics and Motor Performance**
- **Electric Utility Issues**

Approach

- **Battery Research:** reduce cost of battery through material and manufacturing improvements.
- **Power Electronics and Motor R&D**: Create a more robust electric drive system.
- **Utility Analysis**: Conduct more detailed utility interface and impact studies.

76hp gasoline engine, 67hp electric motor, 9.0kWh battery (30mi)

BIOFUELS

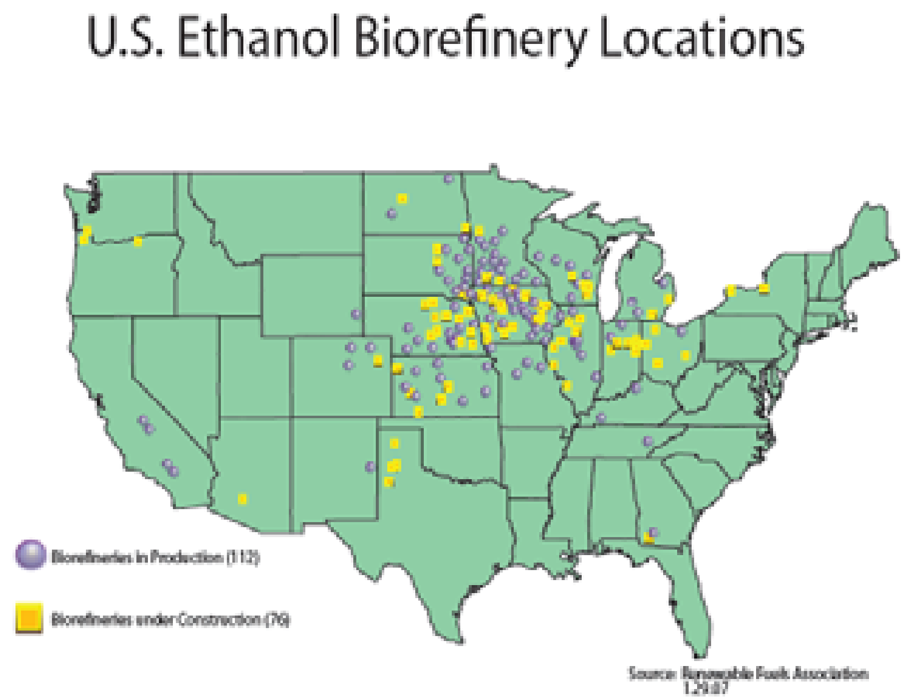
Advanced ethanol technologies, cellulosic feedstocks, and commercial bio-refineries could significantly reduce the Nation's reliance on oil.

U.S. Market

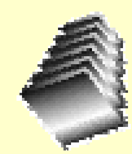
- 140 ethanol plants (up from 50 in 2000)
- 5.4 billion gallons ethanol in 2006 (up from 1.5 in 2000);1 billion gallons new capacity per year
- Nearly 1,200 stations offering E85
- First commercial cellulosic ethanol facilities are expected to open in 2007
- 6 million flexible fuel vehicles on the road

Current State of Cellulosic Technology

- 2005 minimum ethanol sales price of $2.26/gal reduced from $5.66 in 2001
  - 2012 target for cellulosic ethanol: $1.07/gal



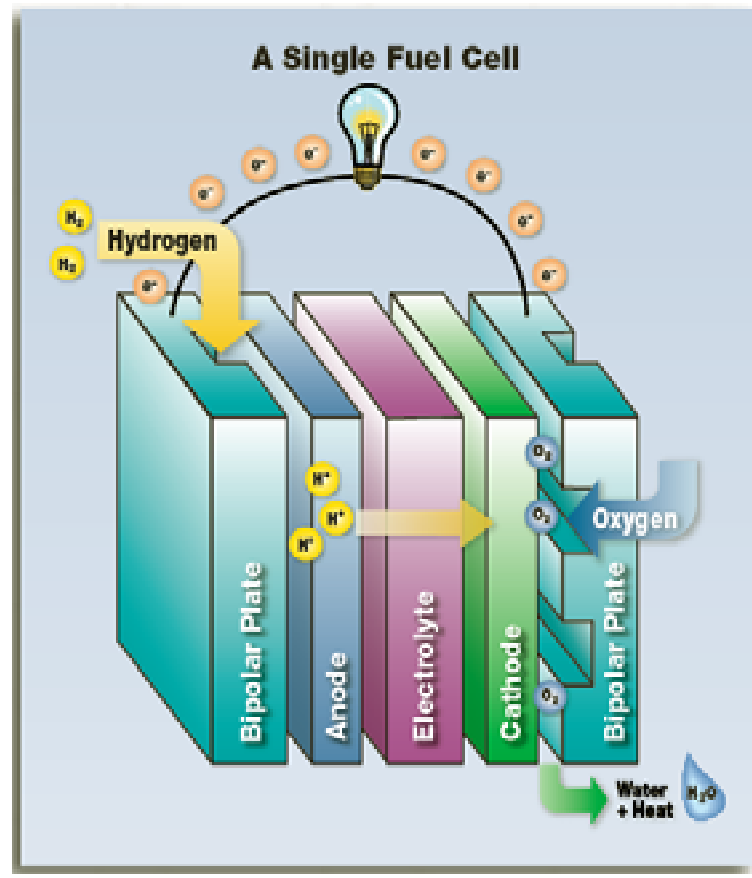
Energy Efficiency & Conservation	• **Buildings Technologies** • **Industrial Technologies** • **Weatherization** • **Federal Energy Management**
Renewable Power Generation	• **Wind/Hydropower** • **Solar** • **Geothermal**
Alternative Fuels & Vehicles	• **Hybrid Electric Vehicles** • **Biofuels** • ***Hydrogen & Fuel Cells***



HYDROGEN & FUEL CELLS: *Background*

Hydrogen and Fuel Cells offer energy and environmental benefits.

- **Transportation**:
  - Reduced dependence on oil through petroleum substitution in the light-duty fleet
  - Zero-emission vehicles
- **Stationary**:
  - Improved reliability in electric power generation, including storage of intermittent renewable energy
  - Reduced greenhouse gas emissions
- **Portable Power**:
  - Greater energy capacity (longer lifetime) for portable electronic devices

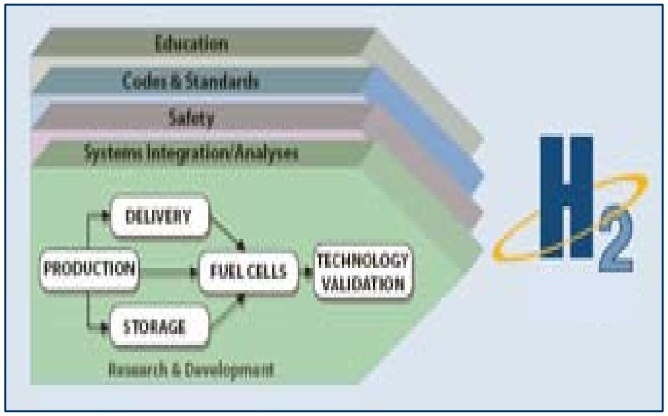


Fuel Cells use hydrogen, and oxygen from air, to generate electricity through an electrochemical reaction. The only by-products are water and heat. Single cells are stacked in series to produce the voltage needed to power cars, buses, homes, or portable electronic devices.

HYDROGEN & FUEL CELLS: ***The Hydrogen Program***

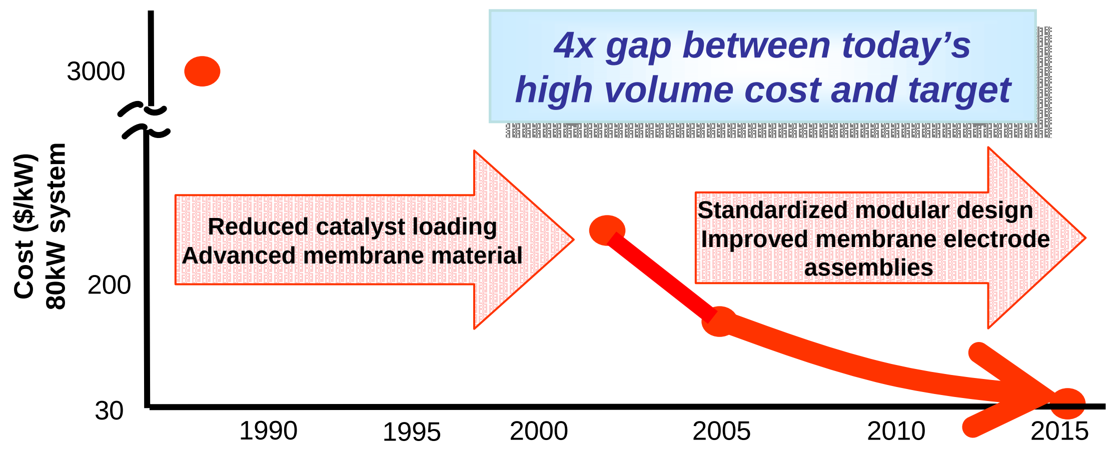
Research areas are focused on the challenges:

- **Technology Performance and Cost**
  - R&D to achieve cost and performance targets
    - *Hydrogen Production Cost (target: $2.00 - 3.00/kg)*
    - *Hydrogen Storage (target: >300-mile range)*
    - *Fuel Cell Cost and Durability (targets: $30 per kW, 5000 hours)*
  - Technology Validation through learning demonstrations
- **High Volume Manufacturing**
- **Hydrogen Delivery Infrastructure**
  - Compression, liquefaction, off-board storage
  - Pipeline materials
- **Safety, Codes and Standards**
- **Education**



HYDROGEN & FUEL CELLS: *Background*

Research and development activities for hydrogen production, storage, and fuel cell technologies are focused on reducing cost.



U.S. MARKET

- Stationary fuel cells are beginning to enter the market; portable power fuel cells are not far behind
- Fuel cells and hydrogen for the vehicle market are in active testing and validation

PROGRESS

- High-volume cost of fuel cells reduced
- New storage materials identified
- Learning demonstrations validating progress

RESEARCH & DEVELOPMENT AREAS

- Reducing the cost of hydrogen production and delivery technologies
- Increasing hydrogen storage capacities
- Reducing cost and improving durability of fuel cells
- Developing codes and standards and safety practices

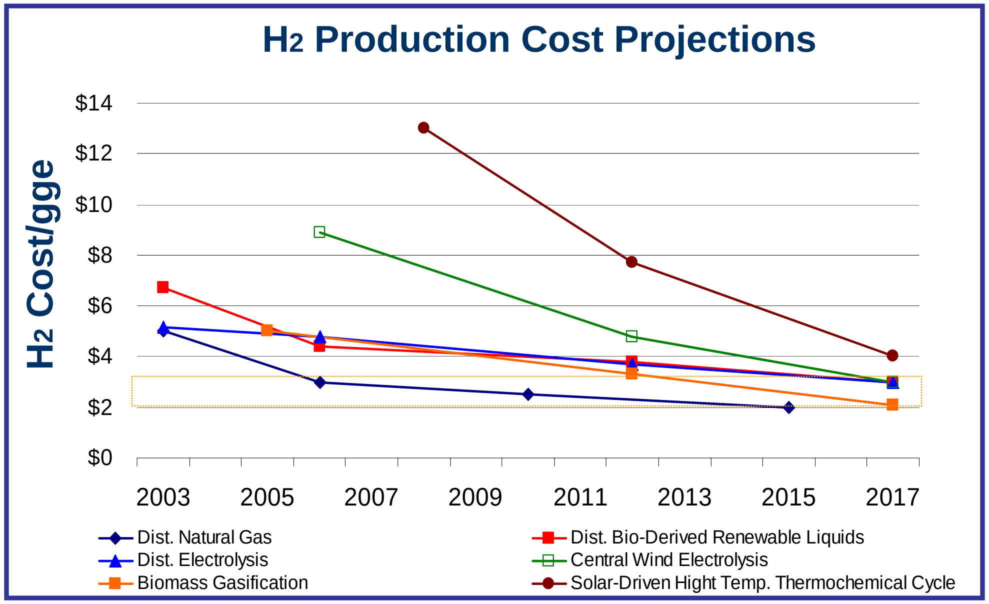
HYDROGEN & FUEL CELL R&D: ***Hydrogen Production***

Diverse, domestic production pathways will promote energy security.
Distributed production will enable an early, lower-cost infrastructure.

Near-term distributed hydrogen

(produced at station to enable low-cost delivery):

- *Natural gas reforming*
- *Renewable liquid reforming (alcohols, sugars)*
- *Electrolysis*



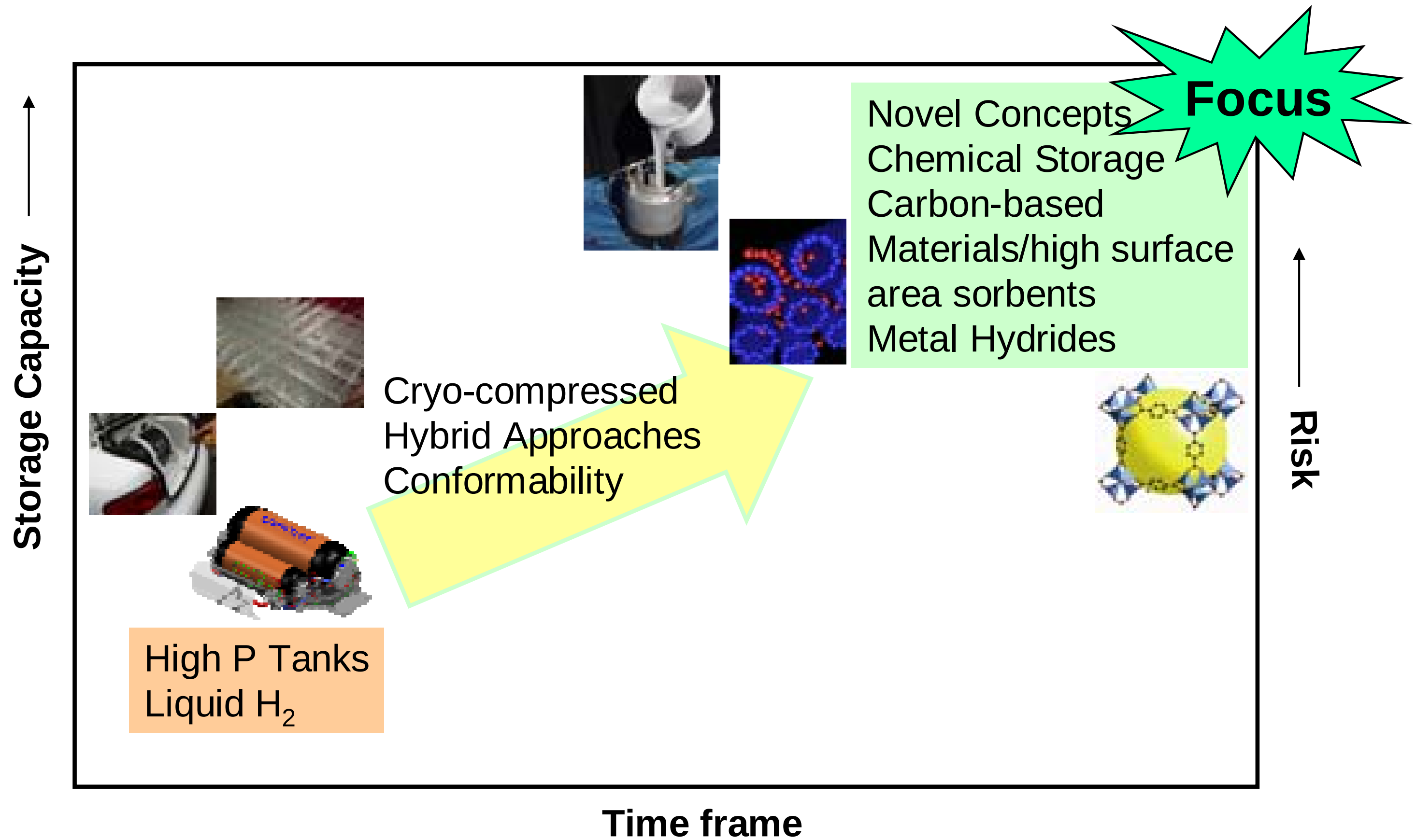
Longer-term centralized production

(large investment in delivery infrastructure needed):

- *Biomass gasification*
- *Coal with carbon sequestration*
- *Wind/solar driven electrolysis*
- *Solar/nuclear high-temperature thermochemical water splitting*
- *Photoelectrochemical*
- *Biological*

HYDROGEN & FUEL CELL R&D: ***Hydrogen Storage***

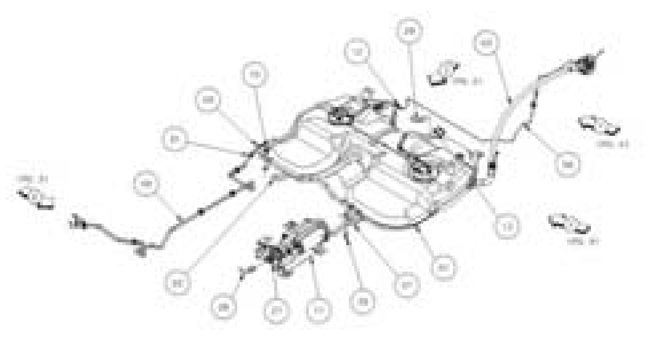
R&D Path



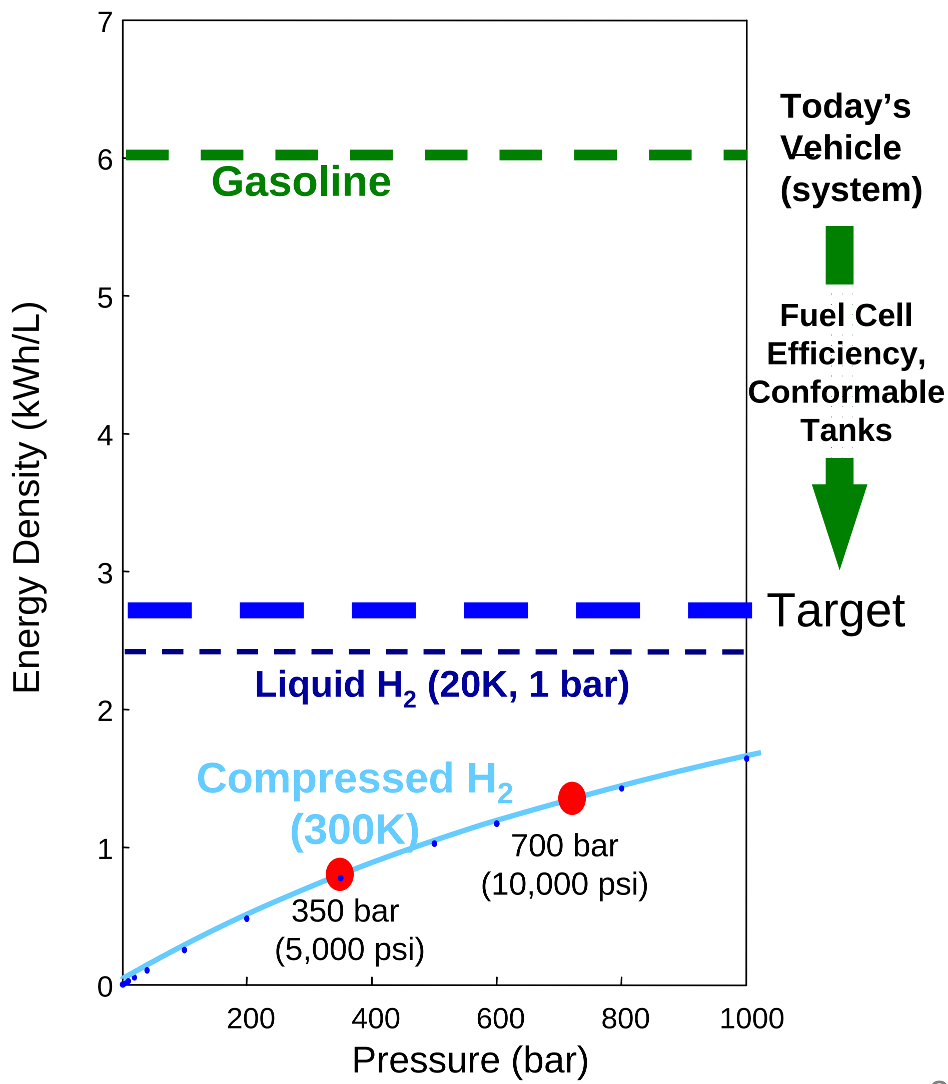
On-Board Hydrogen Storage Targets for > 300 Mile Range

Key System Targets

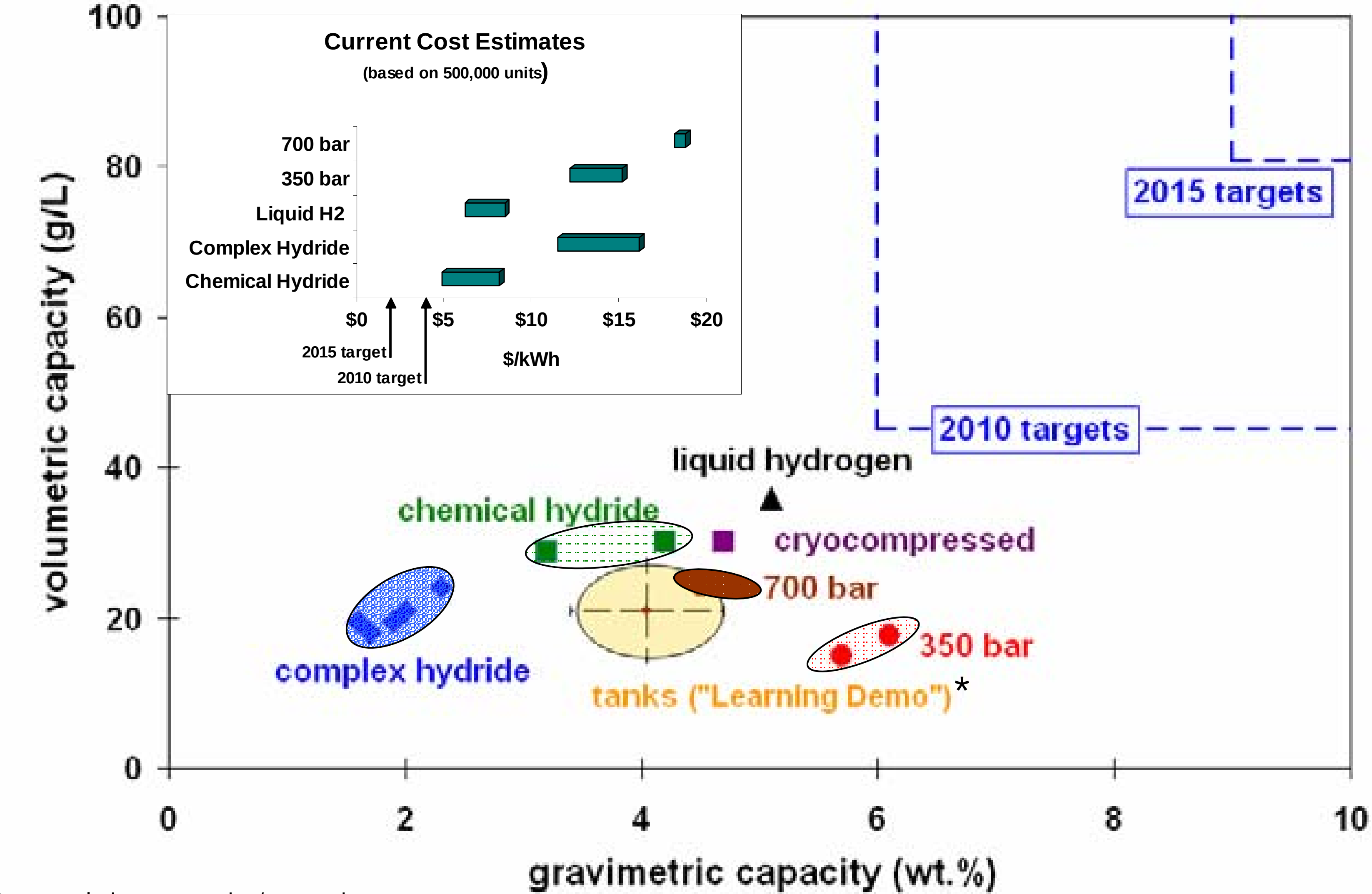
	2010	2015
Gravimetric capacity	**6 wt%** (2 kWh/kg)	**9 wt%** (3 kWh/kg)
Volumetric capacity	**45 g/L** (1.5 kWh/L)	**81 g/L** (2.7 kWh/L)
System Cost	**$4/kWh**	**$2/kWh**
Many more: www.hydrogen.energy.gov		



Gasoline Fuel System



Current Status vs. Targets



Costs exclude regeneration/processing.

Data based on R&D projections and independent analysis (FY05-FY06). To be periodically updated. * Learning Demo data shows range across 63 vehicles

HYDROGEN & FUEL CELL R&D: *Hydrogen Storage*

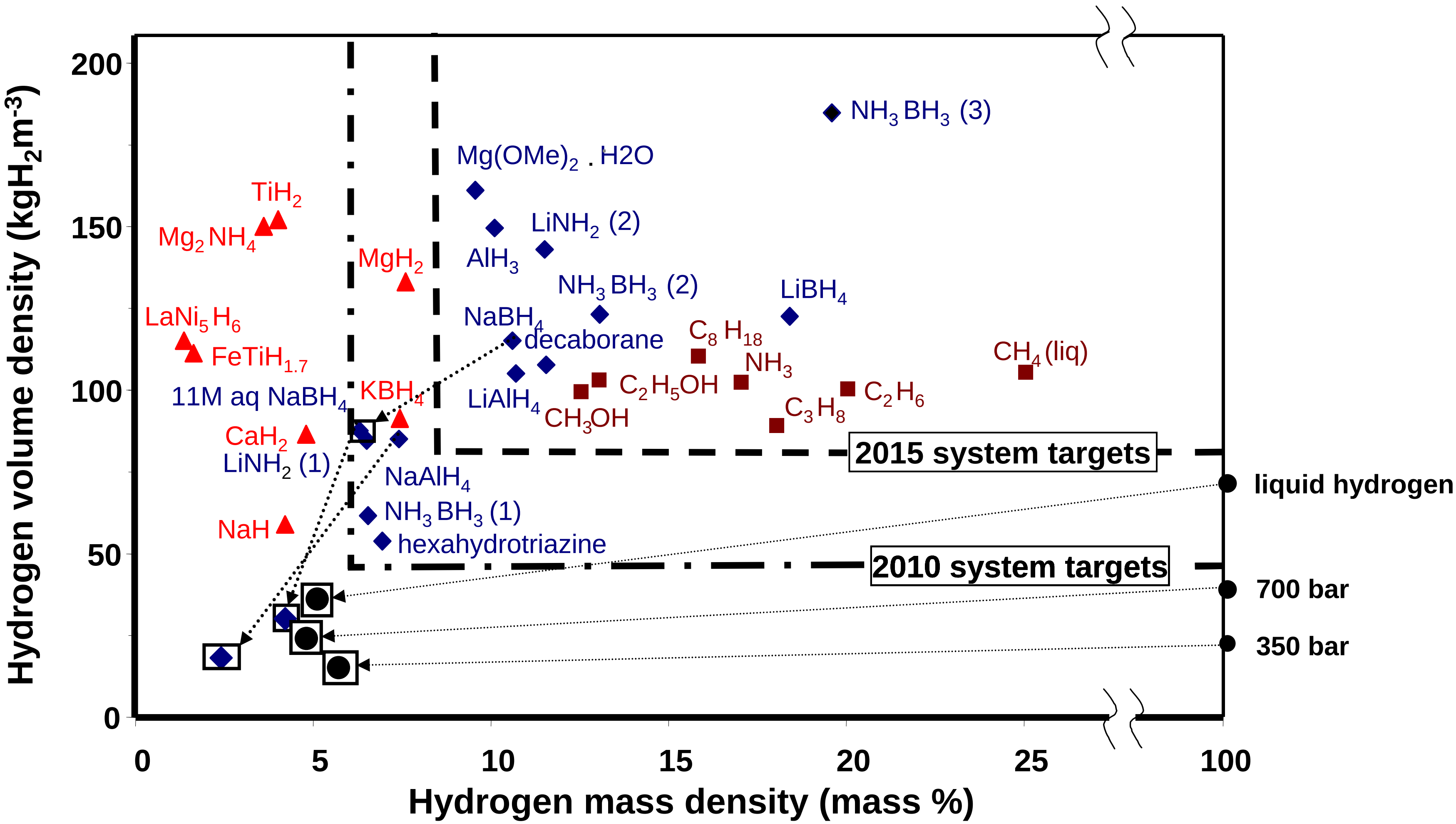
Materials with potential for higher storage capacities

	Metal Hydrides	Chemical H_2 Storage	Adsorbents/Carbon
2004	**Sodium alanate** *~3.5- 4 wt%, ~45 g/L* (~ 150 C)	**Ethylcarbazole** *~5.5 wt%, ~54 g/L* (<225 C)	**Hybrid Nanotubes** *~2-3 wt%, <30 to ~ 54 g/L* (77 K)
2005 to 2006	**Li Mg Amides** *~5.5wt%,~80 g/L* (>200 C) **Alane** *~7-10 wt%,~150 g/L* (<150 C) **Li borohydrides** *>9 wt%,~100 g/L* (~350 C) **Destabilized Binary hydrides** *~5-7wt%,~60-90 g/L* (250 C)	**4,7 Phenanthroline (organic liquids)** *~7 wt%, ~65 g/L* (<225 C) **Seeded Ammonia Borane** *~9 wt%,~90 g/L* (>120 C) **Ammonia Borane/Li amide** *~7 wt%, ~54 g/L* (~85 C)	**Metal/carbon hybrids, MetCars** *~6-8wt%*,~39 g/L** (*theory) **Bridged catalysts/IRMOF-8** *~1.8 wt.%,~10 g/L* (room temperature) **Metal-Organic Frameworks IRMOF-177** *~7 wt%,~30 g/L* (77K)

Reminder: Material capacities only, not system values. Still key issues with temperatures and operating conditions

HYDROGEN & FUEL CELL R&D: *Hydrogen Storage*

Material Capacities vs System Targets



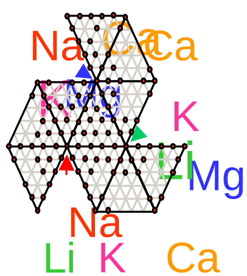
G. Thomas et al, DOE Annual Program Review
Adapted from Schlapbach et al for material capacities

HYDROGEN & FUEL CELL R&D: *Hydrogen Storage*

Metal Hydrides – Reversible On-board

Advantages
- Onboard refueling
- High volumetric densities

Key Challenges
- Lowering desorption temperatures
- Improving kinetic response
- Heat management during refill



Rapid Screening

More than 980 alkali/alkali earth alanates searched

(Na, Mg, Li)AlH_4
(Sachtler, UOP)

Chemical Storage – Regenerable Off-board

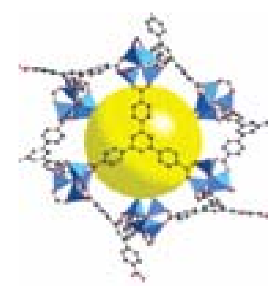
Advantages
- High capacities
- Some systems have demonstrated good kinetics, low temperature operation

Key Challenges
- Complexity (e.g., two-way infrastructure, onboard processor)
- Decreasing regeneration costs (& life cycle energy requirements)

Carbon Sorbents – Reversible On-board

Advantages
- Onboard refueling
- Generally good kinetics
- Thermal management may be minimal

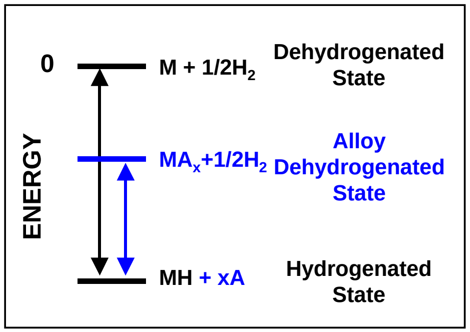
Key Challenges
- Improving volumetric capacities
- Increasing desorption temperatures



HYDROGEN & FUEL CELL R&D: ***Hydrogen Storage***

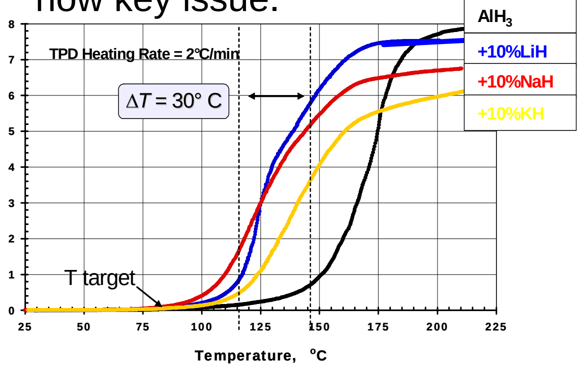
Progress – Metal Hydrides

- **Destabilized hydrides & nanoengineering**
  - >9 wt.% reversibility measured (e.g. $LiBH_4/MgX$)



Vajo & Olsen, et al., Brookhaven

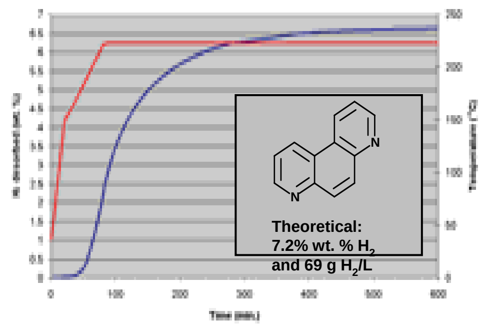
- Hydrogen release temperatures lowered for alanes. Regeneration now key issue.



Sandrock, Graetz, Reily & Wegrzyn. Brookhaven

Progress – Chemical Hydrides

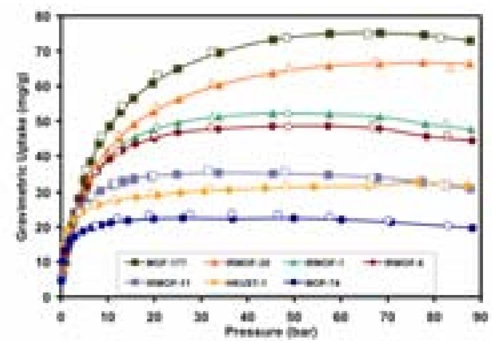
- **Demonstrated promising chemical hydrides-** Phenanthrolene at >7 wt. % capacity
- >100 catalysts screened



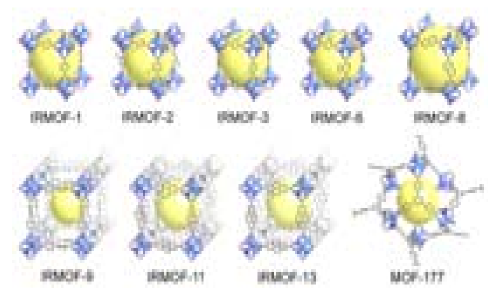
Cooper, Pez, et al, Air Products

Progress – Adsorbents

- **>7 wt.% at 77K shown on MOFs (> 30 g/L);** Several cycles reversibility shown

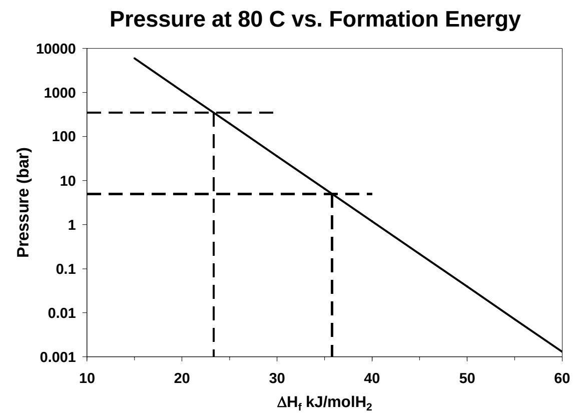


Yaghi UCLA & Matzger, U.MI

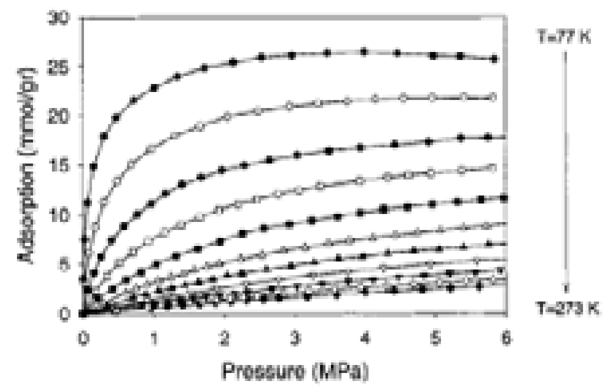


OTHER CHALLENGES: ***It's not just about capacity …***
… much research is focused on tailoring thermodynamics

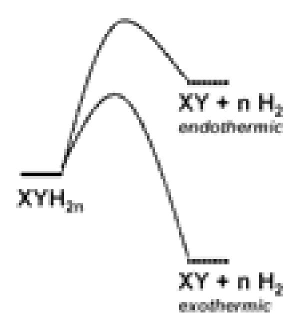
- Hydride heat of formation
  - pressure limits (~20-35 kJ/molH_2)
  - refueling (<20 kJ/molH_2)



- Surface heat of adsorption
  - operating temperature
  - release temperature



- Activation barrier for regeneration
  - energy efficiency
  - near thermo-neutral



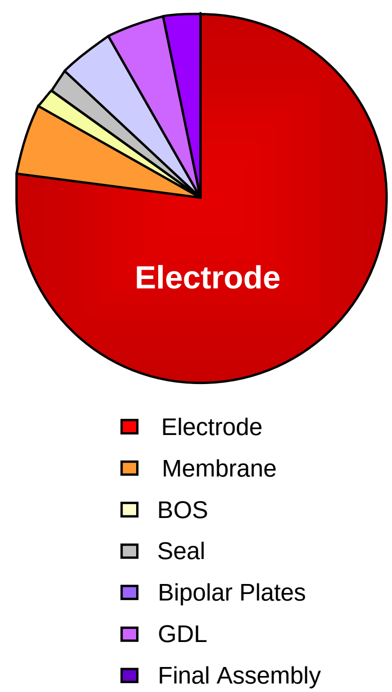
Major Research Area: *Catalysts*

Research Areas:

- *Need to reduce electrode cost*
  (currently about 80% of total stack cost)

- *Catalyst durability needs improvement*

Stack Cost



Four Strategies for Catalyst Research:

- **Strategy 1 – Lower PGM ("Platinum Group Metal")**
  Improve Pt catalyst utilization along with durability (Brookhaven, 3M)

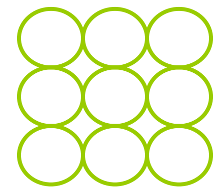
- **Strategy 2 – Pt alloys**
  Pt based alloys that maintain performance and durability compared to Pt and reduce cost (3M, UTC, Brookhaven)

- **Strategy 3 – Novel support structures**
  Explore non-carbon supports and alternative carbon structures (3M, PNNL, ANL)

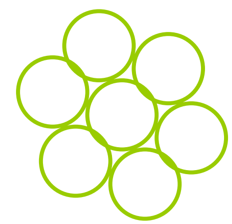
- **Strategy 4 – Non-Pt catalysts**
  Non-precious metal catalysts with reduced cost and comparable durability to Pt (3M, Los Alamos NL, ANL, Univ. of S. Carolina)

LBNL: Breakthrough Shows Potential Path to Lower Pt Loadings and Cost

Crystal Face		**Pt** ***μA/cm² @900mV*** ***(improvement)***	**Pt_3Ni** ***μA/cm² @900mV*** ***(improvement)***
	(110)	2200 ***(11x)***	5100 ***(>25x)***
	(100)	900 ***(4.5x)***	2200 ***(11x)***
	(111)	1900 ***(9.5x)***	18000 ***(90x)***
	Pt/C **reference**	200 ***(ref. case)***	



(100)
Increased Activity:
4.5x to 11x



(111)
Increased Activity:
9.5x to 90x

Identified potential improvements through control of Pt-alloy structure

FUELS & VEHICLES: ***Technology Validation***

Technologies are validated and progress evaluated through learning demonstrations




DOE Vehicle/Infrastructure Demonstration

- *69 fuel cell vehicles and 10 hydrogen stations*
- *Four teams in 50/50 cost-shared projects*
- *Verified Fuel cell systems with 53 – 58% efficiency (compared to 20 – 25% efficiency for internal combustion), vehicle range of 103 – 190 miles, and durability of 950 hours (~ 30,000 miles).*
- *Demonstrated ability to provide H_2 from natural gas for projected cost of $3/gge.*

DOT is demonstrating fuel cell buses and providing data to DOE for analysis.

Eight buses in California, Massachusetts, New York, South Carolina, and Washington, DC

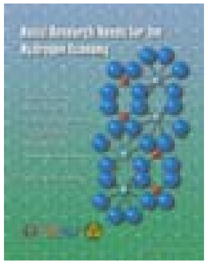
An Integrated Approach:

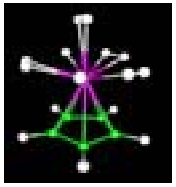
Synergy between Basic Science, Applied Research/Development, and Technology Validation/Demonstration

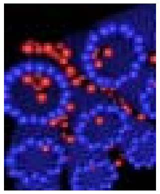
Basic Research

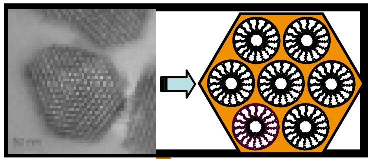
Develop and use theoretical models & fundamental experimentation to generate knowledge:

- *Fundamental property & transport phenomena*
- *Novel material structures, characterization*
- *Theory, modeling, understand reaction mechanisms*





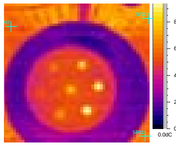


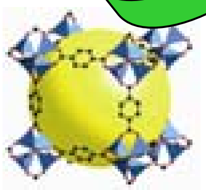


Applied Research & Development

Apply theory & experimentation to design & develop novel, high-performance materials to meet specific performance targets:

- *Develop new materials, leverage knowledge from basic research*
- *Optimize materials and testing to improve performance*
- *Design, develop and demonstrate materials, components and prototype systems to meet milestones*





Technology Validation & Demonstration

Test Systems under Real World Conditions

- *Demonstrate and validate performance against targets*
- *Gain knowledge (e.g. fueling time, driving range, durability, cost, etc.) and apply lessons learned to R&D*

THE PROBLEM

- Oil Dependence
- Greenhouse Gas Emissions
- Air Pollution

SOLUTIONS *Energy Initiatives*

Energy Conservation and Efficiency

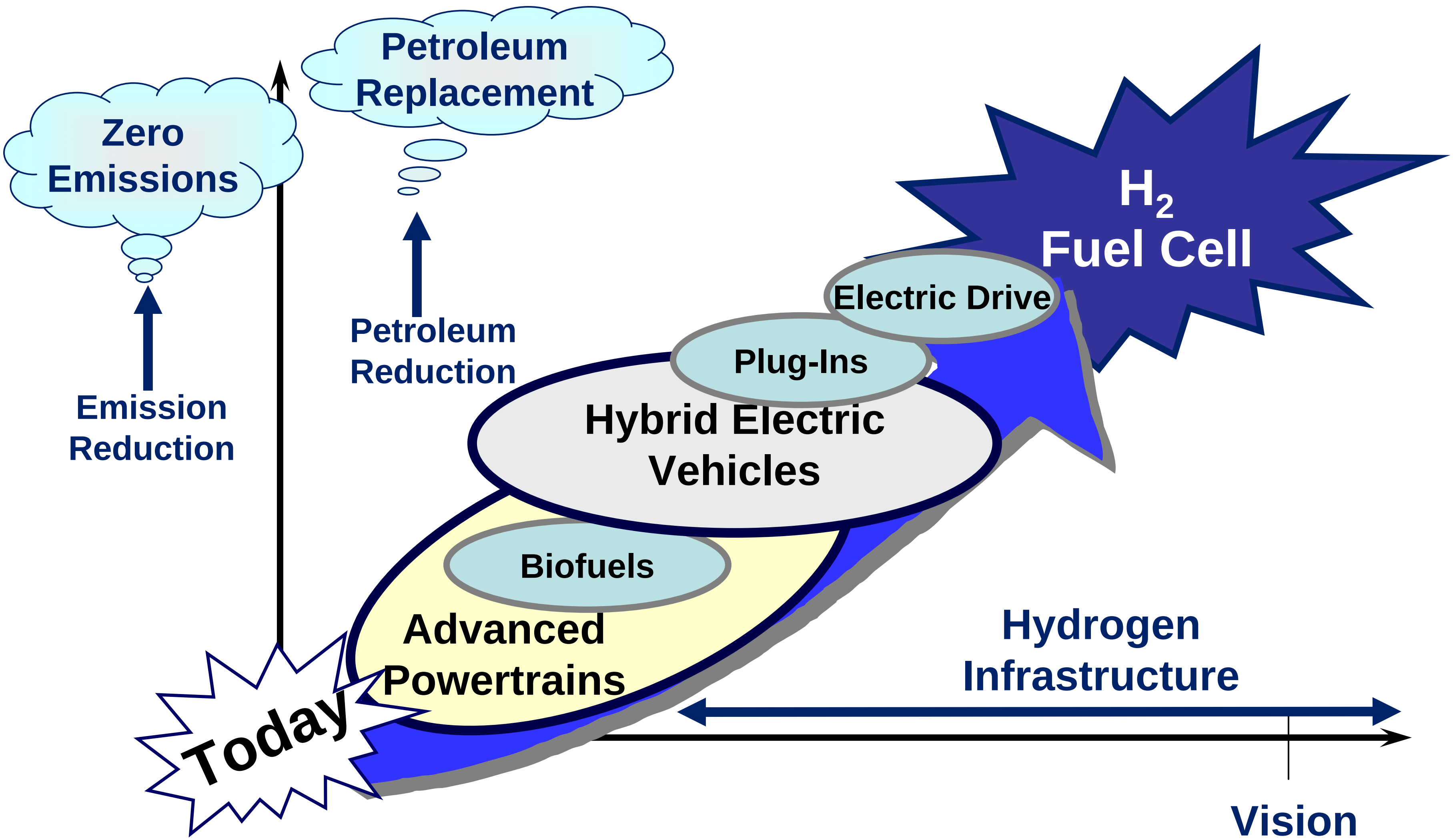
- Renewable Power Generation
- Alternative Fuels & Vehicles

Research and Development Progress and Opportunities

CONCLUSION *The Way Forward*

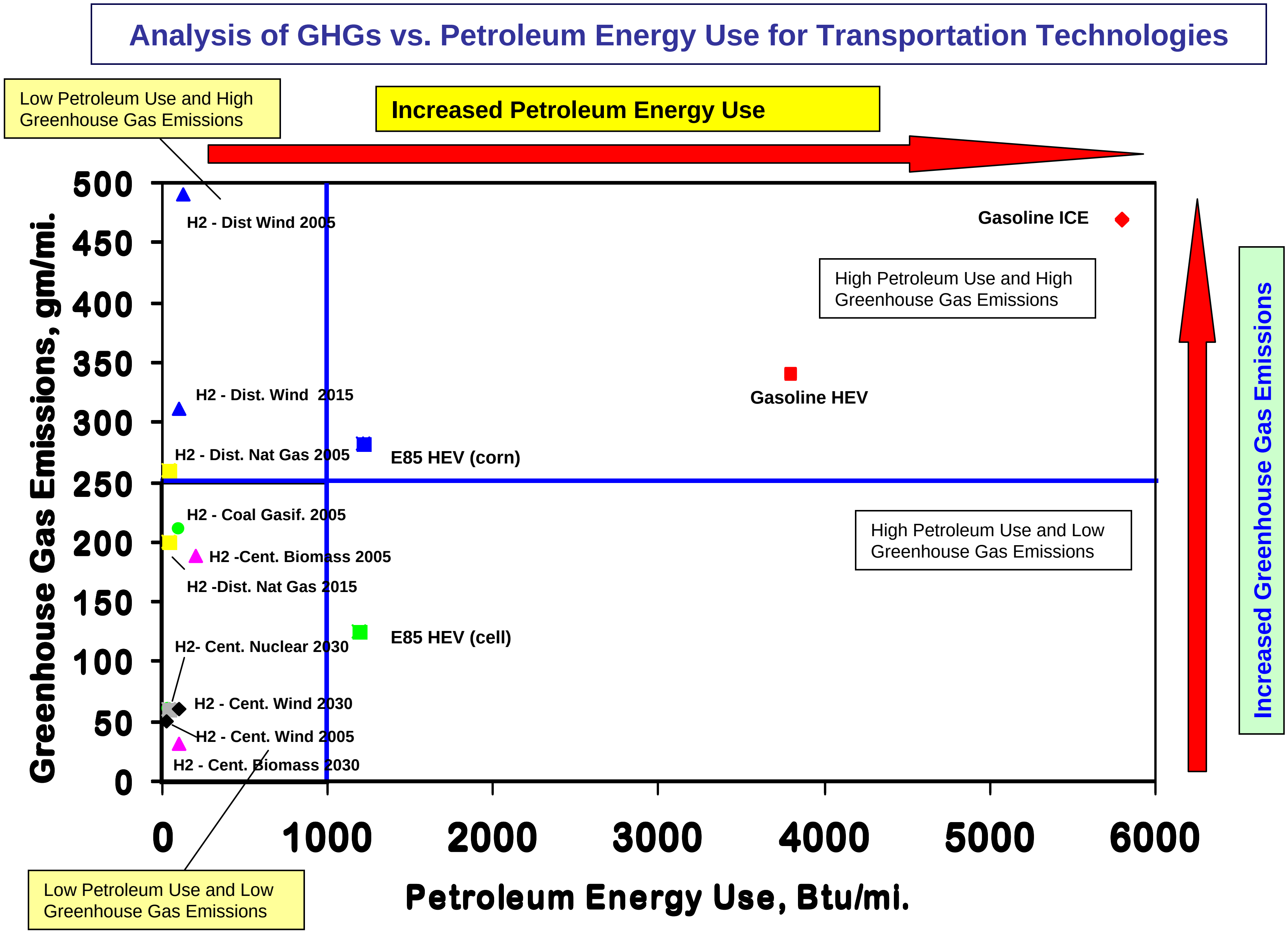
- **Well-to-Wheels Analysis**
- **Future Scenarios**

FUELS & VEHICLES: *The Path of Progress?*

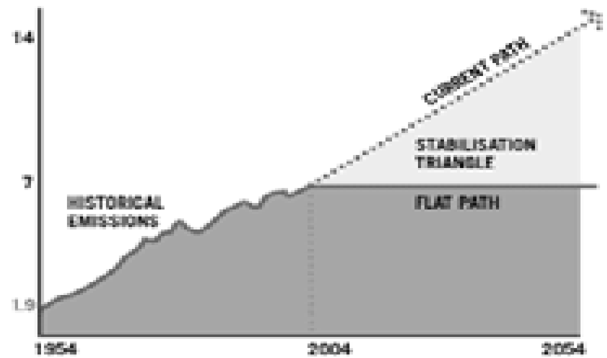


FUELS & VEHICLES: :

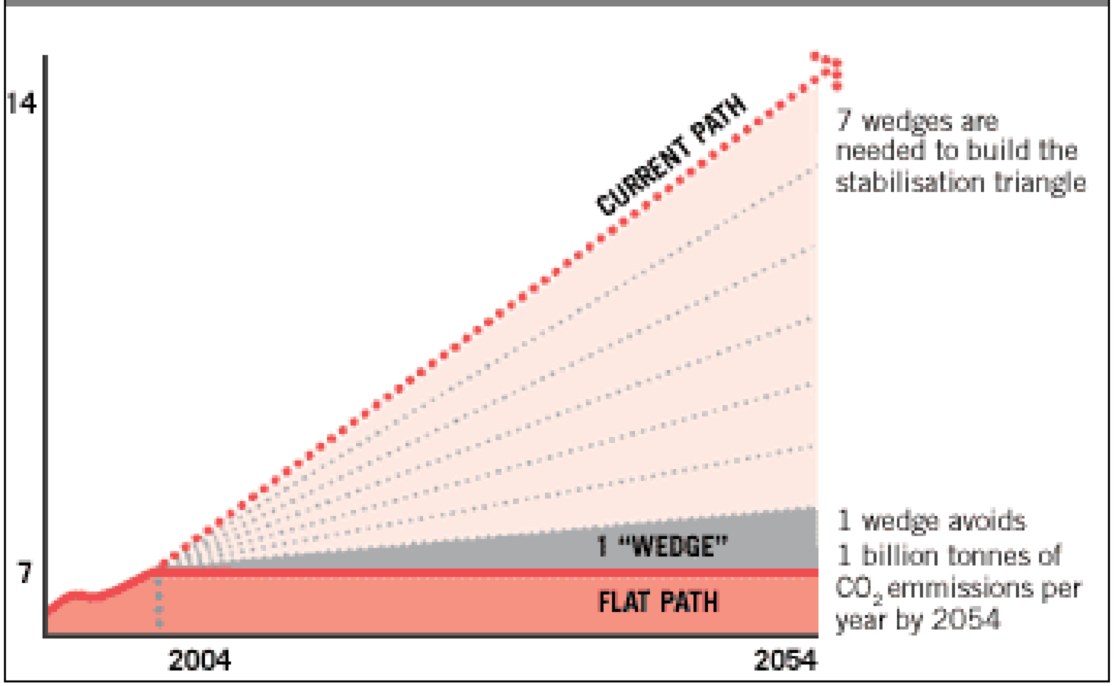
Well-to-Wheels Analysis

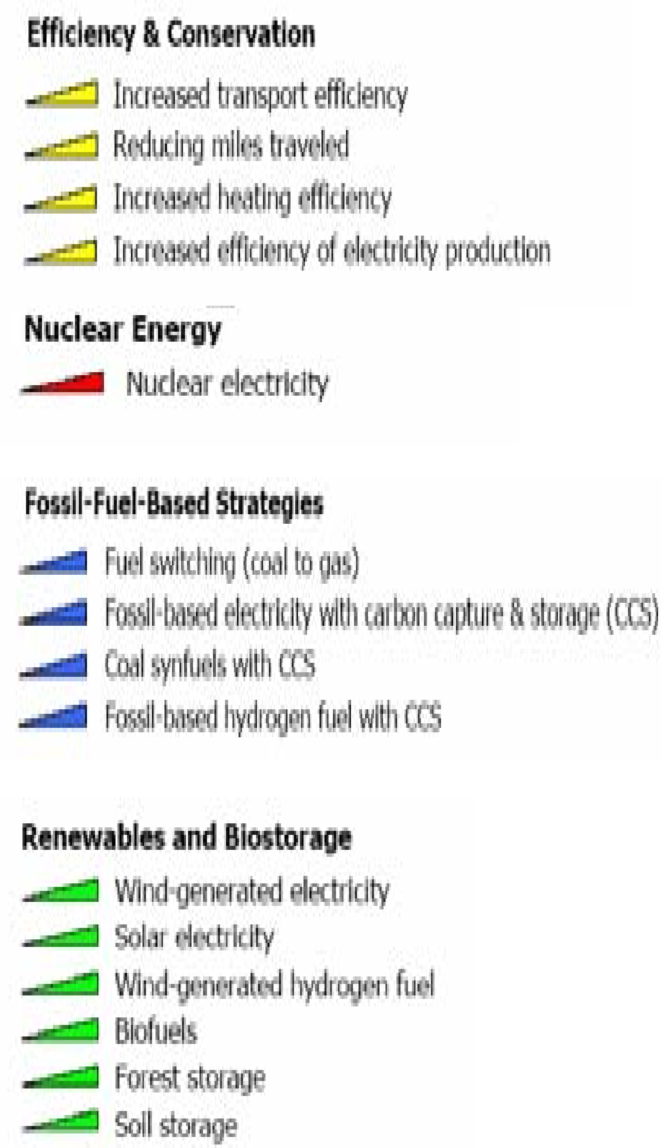


Future Scenarios:
Stabilizing CO_2--"The Wedge Approach"



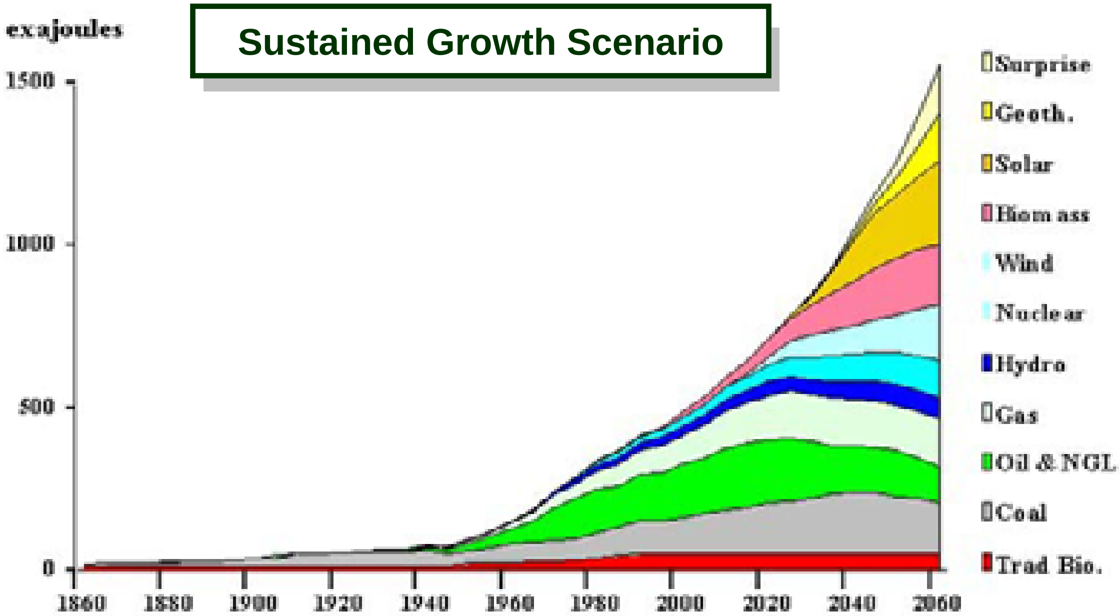
Stabilization Triangle - ***DETAIL***





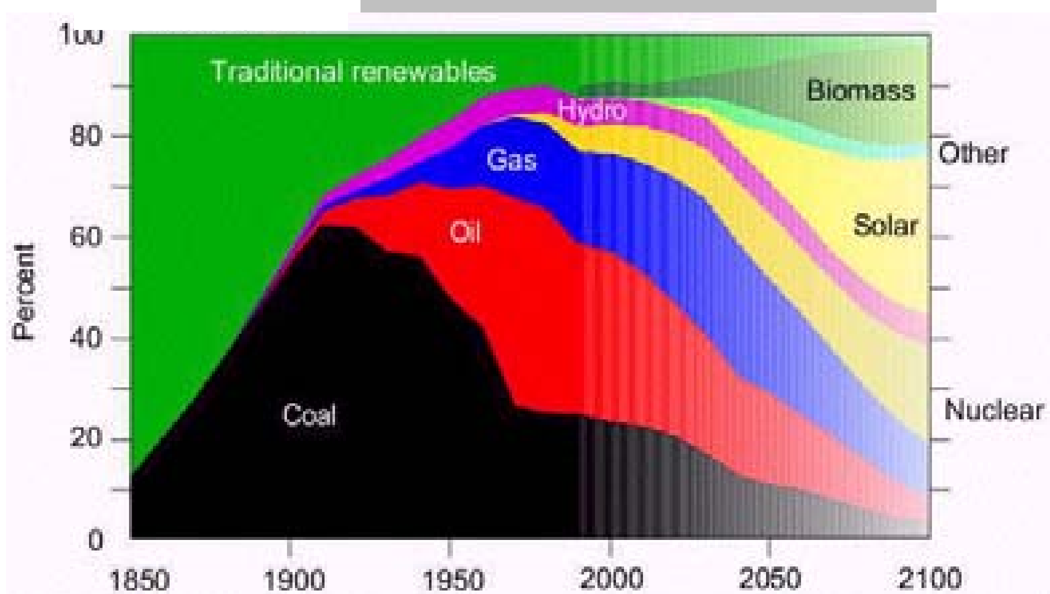
Future Scenarios: *Global Energy Supply*

Sustained Growth Scenario



Source: Shell International, Ltd.

Ecologically Driven Scenario



Source: World Energy Council

ADDITIONAL INFORMATION

follows …

U.S. Department of Energy

Office of Energy Efficiency and Renewable Energy

SUPPLEMENTAL INFO.: Budget

HYDROGEN FUEL INITIATIVE → Overall Budget

Activity	Funding ($ in thousands)				
	FY2004 Approp.	**FY2005** Approp.	**FY2006** Approp.	**FY2007** Request	**FY2008** Request
Hydrogen Fuel Initiative					
EERE Hydrogen (HFCIT)	144,881	166,772	153,451	195,801	213,000
Fossil Energy (FE)	4,879	16,518	21,036	23,611	12,450
Nuclear Energy (NE)	6,201	8,682	24,057	18,665	22,600
Science (SC)	0	29,183	32,500	50,000	59,500
DOE Hydrogen TOTAL	**155,961**	**221,155**	**231,044**	**288,077**	**307,550**
Department of Transportation	555	549	1,411	1,420	1,425
HFI TOTAL	**156,516**	**221,704**	**232,455**	**289,497**	**308,975**

SUPPLEMENTAL INFO.: Budget

EERE FY2008 Budget Request

ACTIVITY	FY2006 Approp. ($000)	FY2007 Request ($000)	FY2008 Request ($000)
Biomass and Biorefinery Systems	89,776	149,687	179,263
Building Technologies	68,190	77,329	84,456
Federal Energy Mg't. Program	18,974	16,906	16,791
Geothermal Technology	22,762	0	0
Hydrogen Technology	153,451	195,801	213,000
Hydropower	495	0	0
Industrial Technologies	56,856	45,563	45,998
Solar Energy	81,791	148,372	148,304
Vehicle Technologies	178,351	166,024	176,138
Weatherization & Intergov. Activities	316,866	225,031	204,904
Wind Energy	38,333	43,819	40,069
Facilities & Infrastructure	26,052	5,935	6,982
Program Support	13,321	10,930	13,281
Program Direction	101,868	91,024	105,013
TOTAL EERE	**1,173,843***	**1,176,421**	**1,236,199**

*Congressionally directed activities = $159 million

SUPPLEMENTAL INFO.: Budget

HFCIT BUDGET → Program Budget

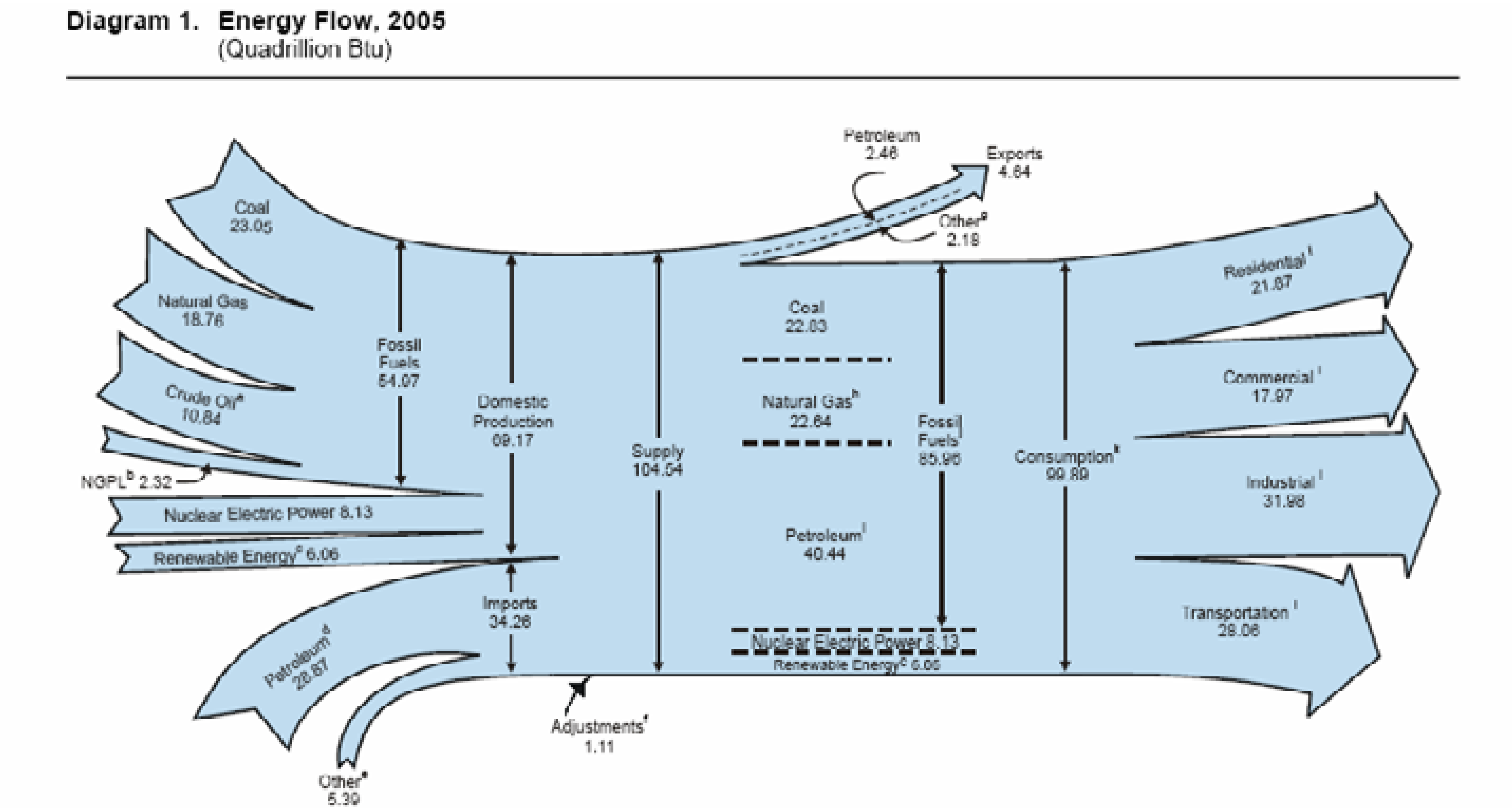
Activity	Funding ($ in thousands)				
	FY 2004 Approp.	FY 2005 Approp.	FY 2006 Approp.	FY 2007 Request	FY 2008 Request
Hydrogen Production & Delivery	10,083	13,303	8,391	36,844	40,000
Hydrogen Storage R&D	13,628	22,418	26,040	34,620	43,900
Fuel Cell Stack Component R&D	24,551	31,702	30,710	38,082	44,000
Technology Validation	15,648	26,098	33,301	39,566	30,000
Transportation Fuel Cell Systems	7,317	7,300	1,050	7,518	8,000
Distributed Energy Fuel Cell Sys.	7,249	6,753	939	7,419	7,700
Fuel Processor R&D	14,442	9,469	637	4,056	3,000
Safety, Codes and Standards	5,755	5,801	4,595	13,848	16,000
Education	2,417	0	481	1,978	3,900
Systems Analysis	1,429	3,157	4,787	9,892	11,500
Manufacturing R&D	0	0	0	1,978	5,000
Technical/Program Mgt. Support	395	535	0	0	0
Congressionally Directed Act.	41,967	40,236	42,520	0	0
TOTAL	**144,881**	**166,772**	**153,451**	**195,801**	**213,000**

Total HFCIT Budget Over 5 Years (FY2004 - FY2008): **$873.9 million**

Sample Solicitations

TITLE	DUE DATE	ESTIMATED TOTAL FUNDING
Broad Agency Announcement: R&D for Novel Materials for Solid Hydrogen Storage (N00164-07-R-6967) ***http://www.crane.navy.mil/acquisition/Synop/07r6967.htm***	March 22, 2007	TBD
Solar America Initiative (SAI) Market Transformation: Solar America Showcases (DE-PS36-07GO97008) ***http://e-center.doe.gov***	March 30, 2007	$2.7 million *(award ceiling; total funding not available)*
R&D of Fuel Cell Technology for the Hydrogen Economy (DE-PS36-06GO96017) ***http://e-center.doe.gov***	April 7, 2007	$100 million
R&D for Hydrogen Production & Delivery Technology (DE-PS36-07GO97009) ***http://e-center.doe.gov***	March 27, 2007	$19.3 million
Lessons Learned from Stationary Power Generation (DE-PS36-07GO97010) ***http://e-center.doe.gov***	April 18, 2007	$ 0.5 million
Hydrogen and Fuel Cells Analysis: Environmental Impacts (DE-PS36-07GO97011) ***http://e-center.doe.gov***	April 18, 2007	$ 0.6 million

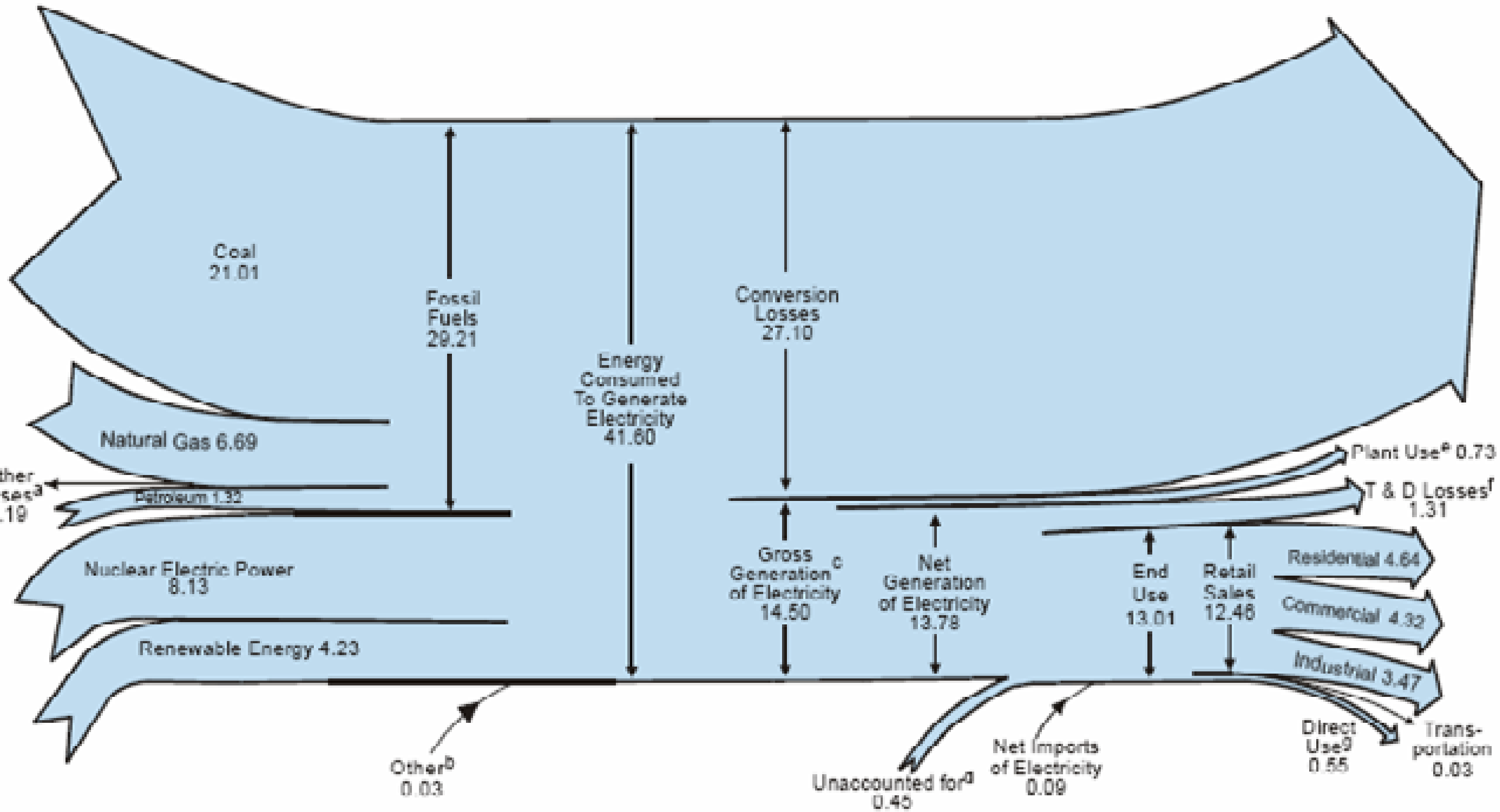
Domestic Energy: *THE BIG PICTURE*



Source: EIA, *Annual Energy Review 2005.*

Domestic Electricity: *THE BIG PICTURE*

Diagram 5. Electricity Flow, 2005
(Quadrillion Btu)



Source: EIA, *Annual Energy Review 2005.*

Advanced Vehicle Technologies:
Research & Development

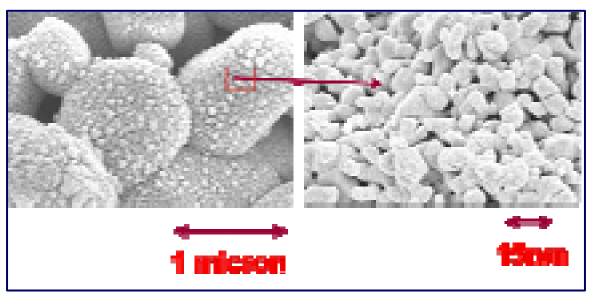
HYBRID ELECTRIC VEHICLES: Batteries

Progress

- 40% cost-reduction in Li-ion HEV 40 kW battery system, while maintaining performance
- Developed nano-phase iron-phosphate cathode material:
  - high rates of charge/discharge
  - good cycle life
  - more abuse tolerant than other chemistries
  - material being used in 36V power tools
- Advanced, low-cost 25 kW HEV battery system: 50% increase in power density demonstrated
- Development of the NiMH battery technology for electric and hybrid electric vehicles

ANL develops abuse tolerant lithium titanate (LTO) anode material capable of high charge/discharge rates

- Small primary particles (10 to 20 nm) are agglomerated into larger (1 to 2 mm) secondary particles.
  - The larger agglomerates can be more easily processed into electrodes and provide higher electrode density
  - Coupled with Mn spinel the resulting cells provide up to 50C charge and discharge capability (compared to 10-20C for other materials)

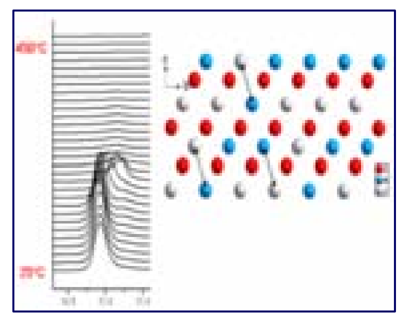


Exploratory Research

Need to address chemical instabilities that impede the development of advanced batteries.

- Focus areas:

1. Advanced cell chemistry,
2. Non-carbonaceous anodes,
3. New electrolytes,
4. Novel cathode materials,
5. Advanced diagnostics and analytical methods,
6. Phenomenological modeling.



BIOFUELS: ***Research & Development***

Future efforts will address obstacles to both biochemical and thermochemical routes to biofuels, support demonstrations, and resolve infrastructure issues.

Barriers	Solutions
High cost of enzymatic conversion	R&D to improve effectiveness and reduce cost of enzymatic conversion
Inadequate technology for producing ethanol from sugars derived from cellulosic biomass	R&D on advanced micro-organisms for fermentation of sugars
Limitations of thermochemical conversion processes	Re-establish thermochemical conversion as a second path to success

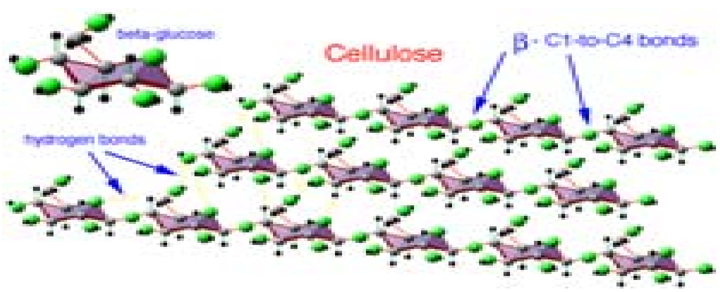
Collaborative research, development, and demonstration is focused on removing barriers to large-scale production of cellulosic biofuels.

Collaborative R&D

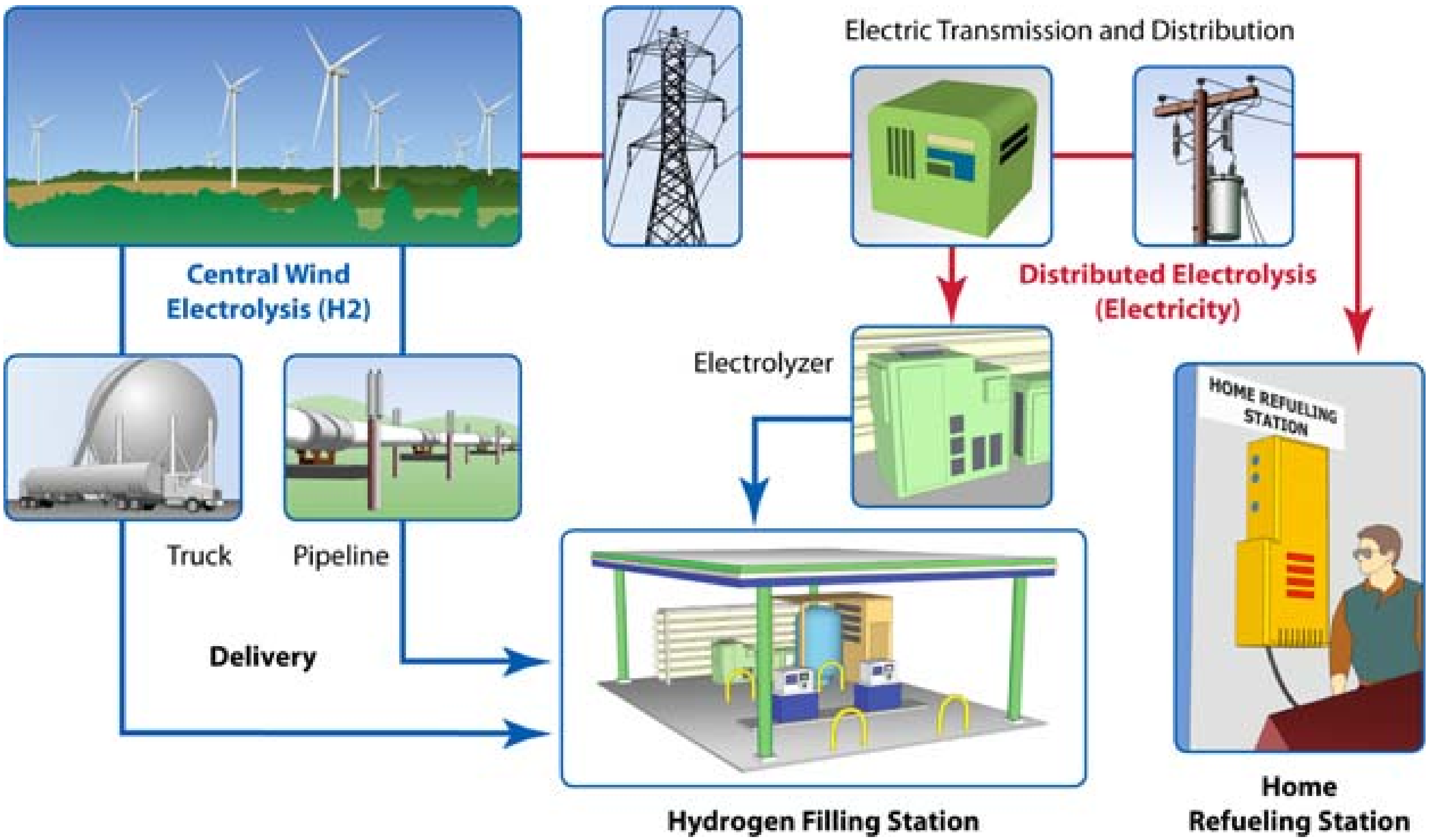
- **Feedstocks:** integration of feedstocks with conversion processes
- **Conversion Technologies:** biochemical and thermochemical
- **Integrated Biorefineries:** systems integration, demonstrations, infrastructure development

Integrated Biorefineries

- **Systems Integration:** feedstocks, conversion, biopower, infrastructure
- **Demonstration:** pilot scale, commercial scale

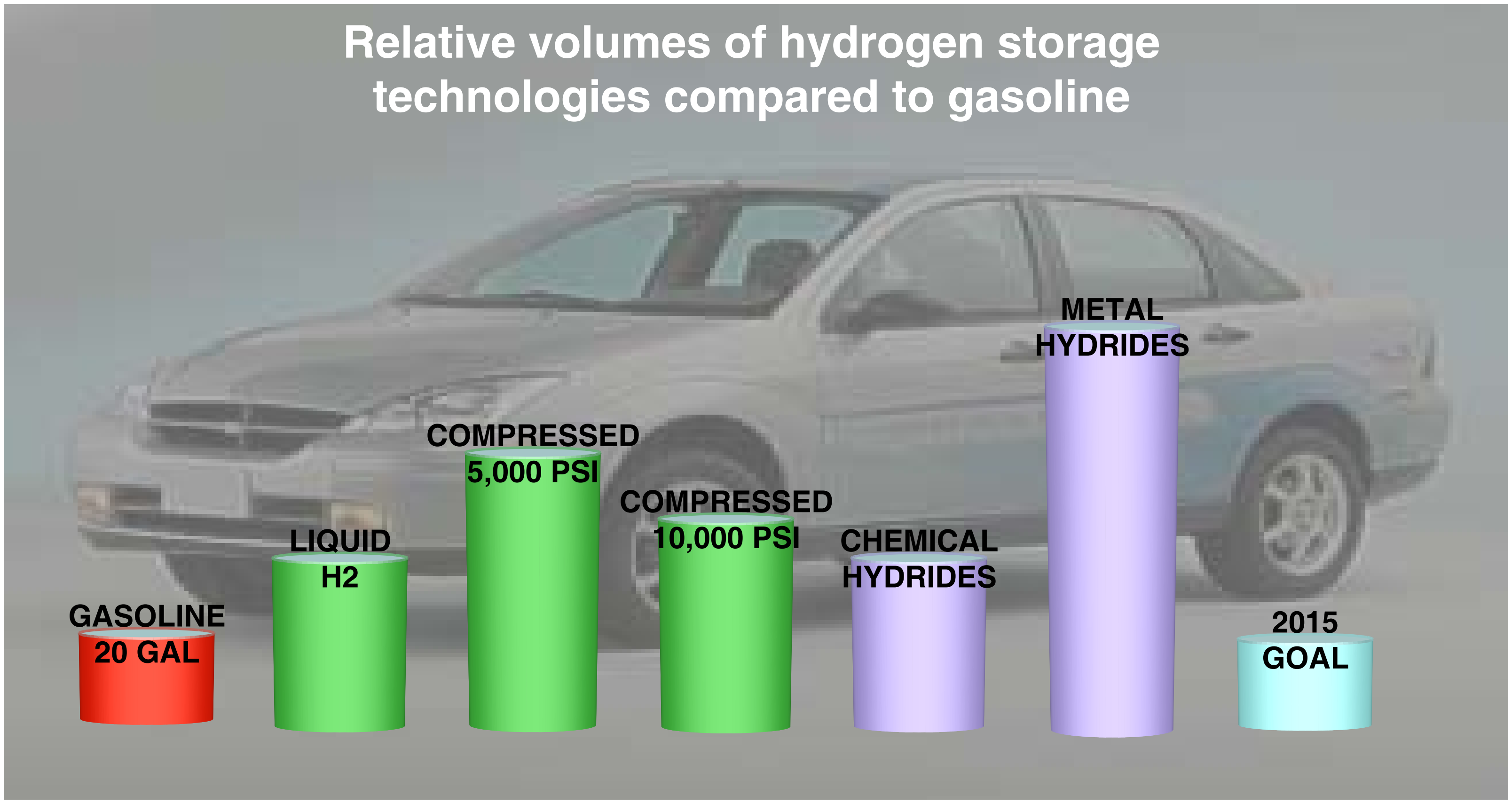


Wind2H2 Project: *Hydrogen Could Provide Energy Storage for Intermittent Renewables*



SUPPLEMENTAL INFO.: *H_2 Storage*

Compact on-board hydrogen storage is a critical barrier to fuel cell vehicle commercialization, and also needed for off-board and delivery applications.



REACHED THEORETICAL LIMIT   NOT REACHED THEORETICAL LIMIT

Research is on-going to make metal and chemical hydride systems more compact.

SUPPLEMENTAL INFO.: *Fuel Cells*

There are five types of fuel cells:

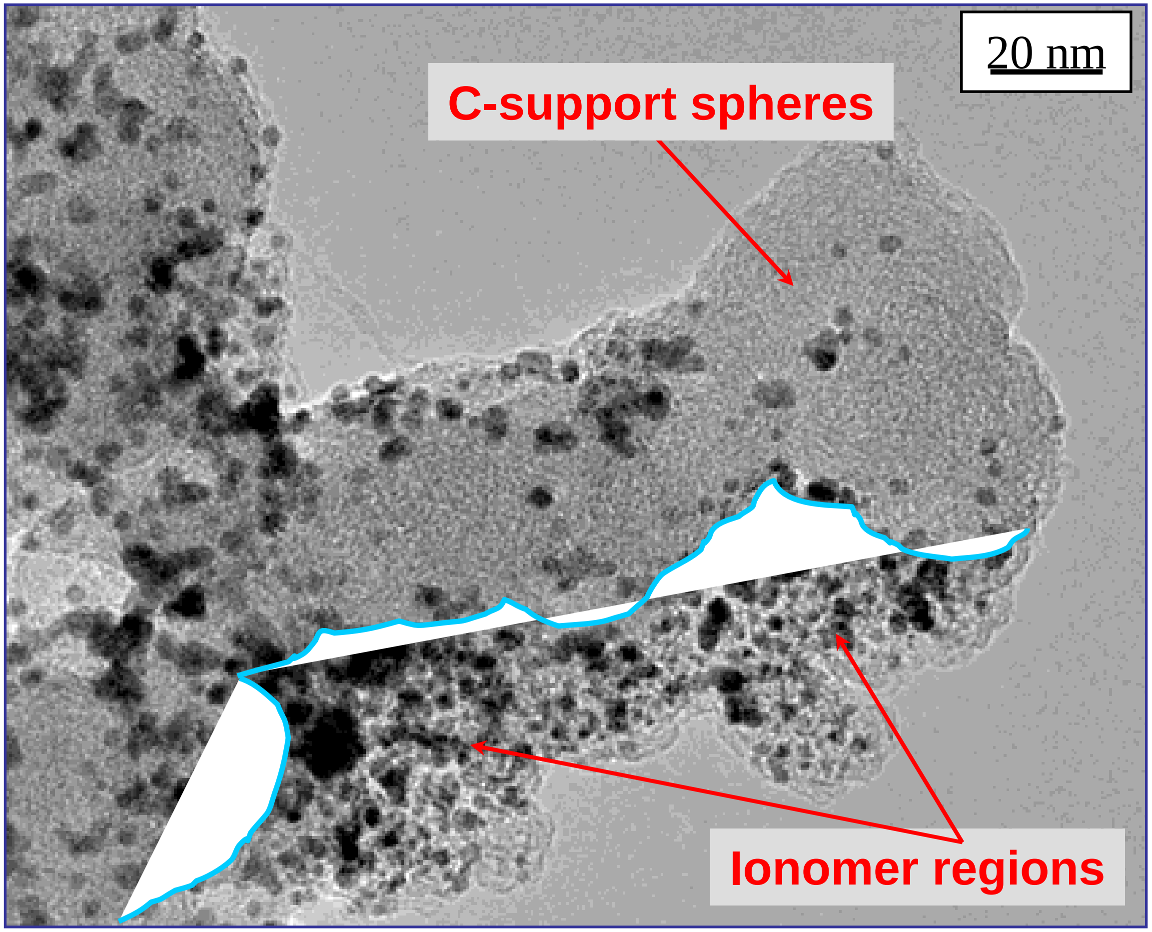
- **Polymer Electrolyte Membrane (PEMFC,** also known as “proton exchange membrane”)
  - *Pros:* Low temperature operation, quick start, and high power density
  - *Cons:* Expensive catalysts
  - *Applications:* Transportation and portable power
- **Phosphoric Acid Fuel Cell (PAFC)**
  - *Pros:* Low temperature operation and high efficiency
  - *Cons:* Low current and power density
  - *Applications:* Distributed generation
- **Alkaline Fuel Cell (AFC)**
  - *Pros:* Low temperature operation and high efficiency
  - *Cons:* Expensive impurity removal
  - *Applications:* Military and space
- **Solid Oxide Fuel Cell (SOFC)**
  - *Pros:* High efficiency, multiple fuel feedstocks, usable waste heat, and cheap
  - catalysts
  - *Cons:* Slow start-up and corrosion issues
  - *Applications:* Auxiliary Power Units (APUs) and distributed generation
- **Molten Carbonate Fuel Cell (MCFC)**
  - *Pros:* High efficiency, multiple fuel feedstocks, and usable waste heat
  - *Cons:* Slow start-up and corrosion issues
  - *Applications:* Electric utility

Understanding Fuel Cell Degradation

The ionomer…

(1) … tends to "clump" around and between the C-support rather than homogeneously coating the spheres

(2) … "picks up" much of the Pt during ink preparation and redistributes it, resulting in a very high Pt concentration in the ionomer regions.

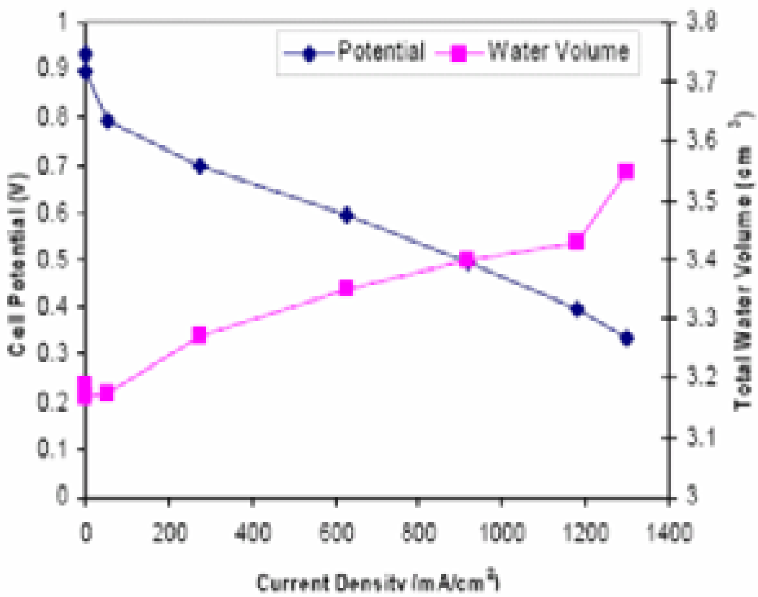


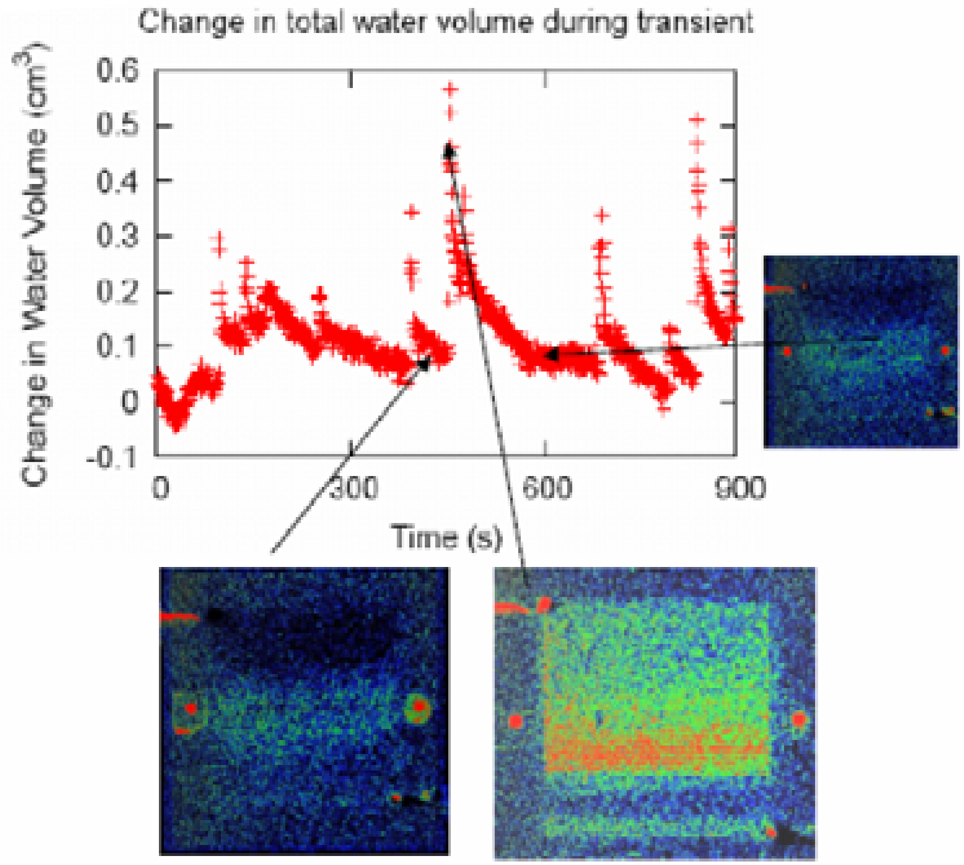
Identified catalyst layer component distribution after processing and aging.
Results allow for improvements in processing and materials development

Neutron Imaging of Water Transfer in a Working Fuel Cell

Real-time visualization of water in fuel cell components during transients

- Measured transient water content during a step from OCV to 1.5 A cm^{-2}
- Combined with current density and cell potential can plot out the polarization curve and visualize the mass transport simultaneously.





In collaboration with M.A. Hickner and M.P. Siegel from Sandia National Laboratory