U.S. Transportation Research Trends

Alternate Fuels, Vehicle Electrification and Searching for the Silver Bullet

The Greening of Transportation 2:

Sustainability via Alternative Fuels

The Transportation Center

Northwestern University

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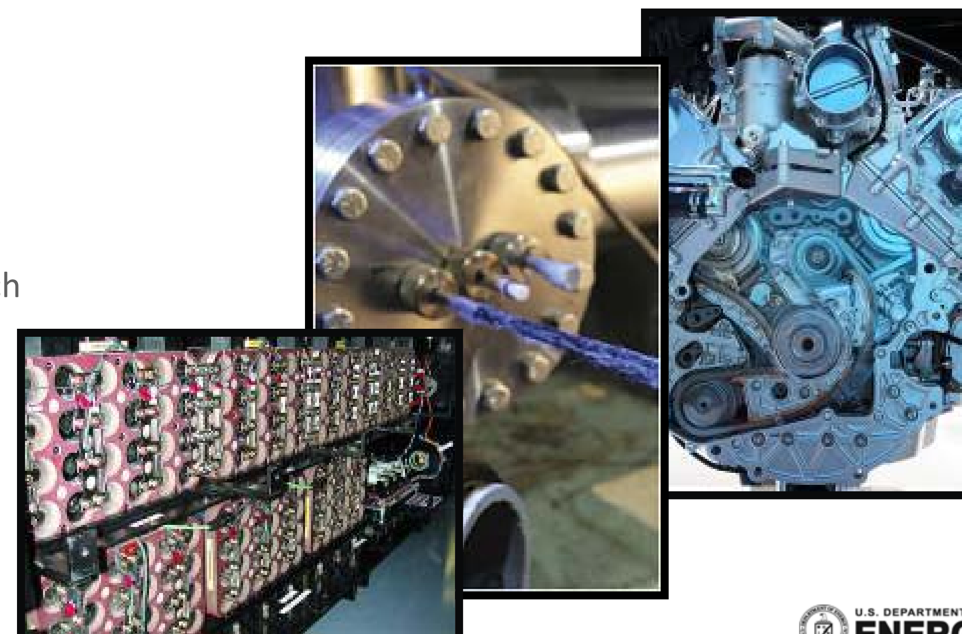
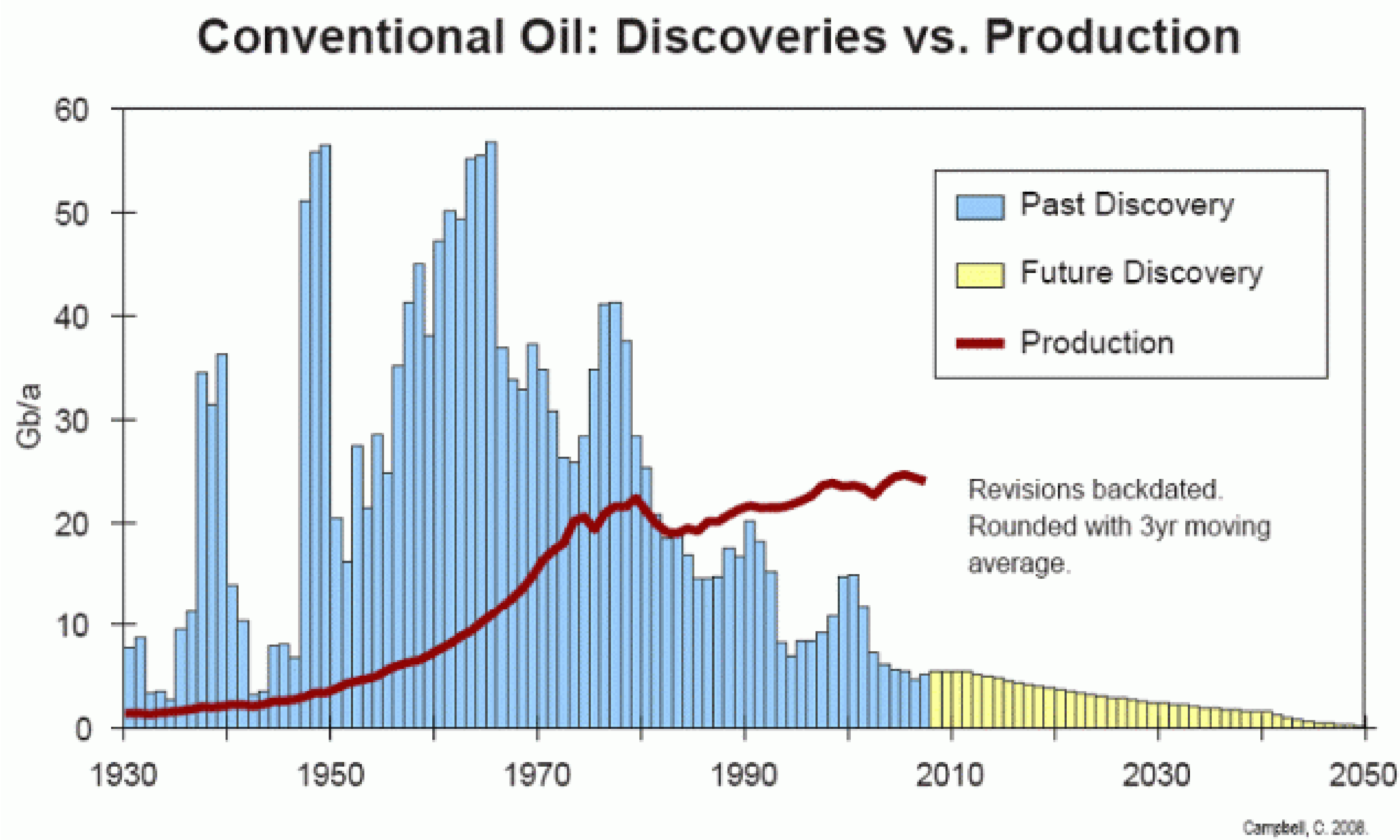
05 October, 2010

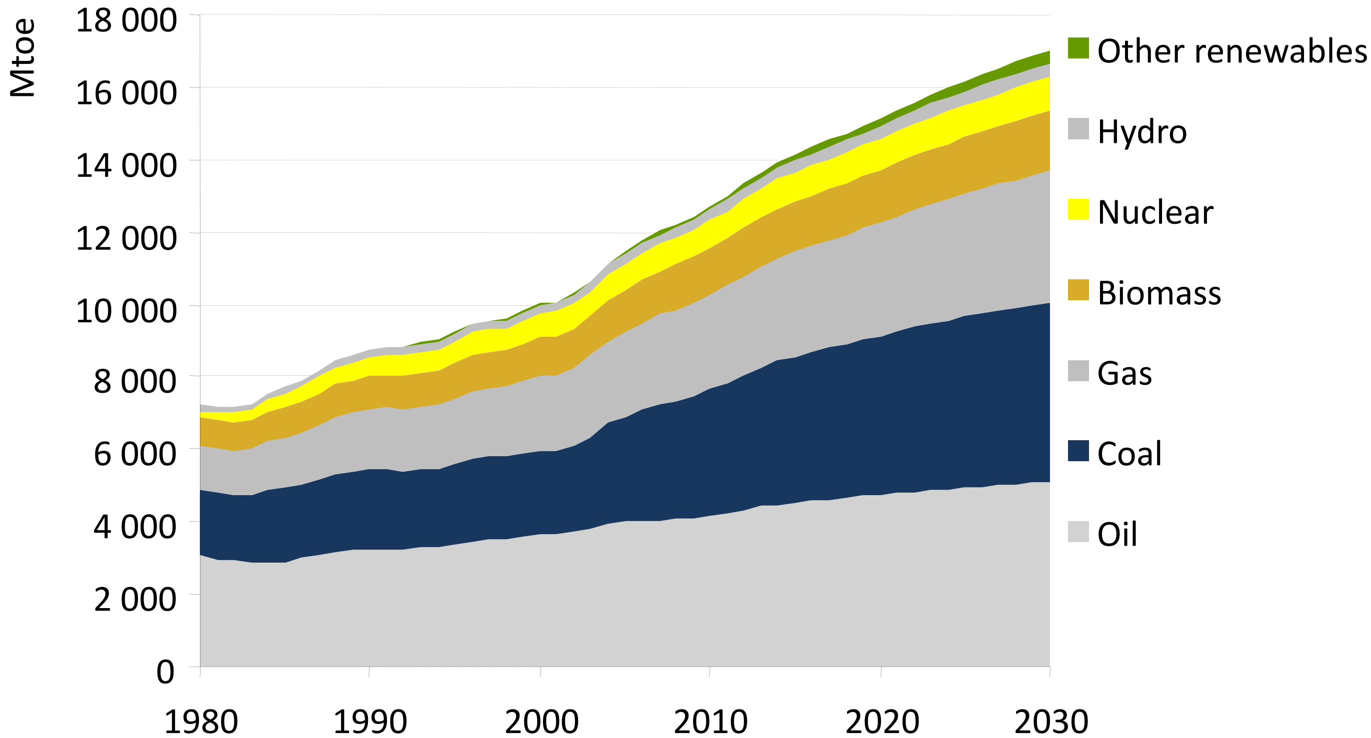


We have Probably Picked all the Low Hanging Fruit (and it doesn't grow back)



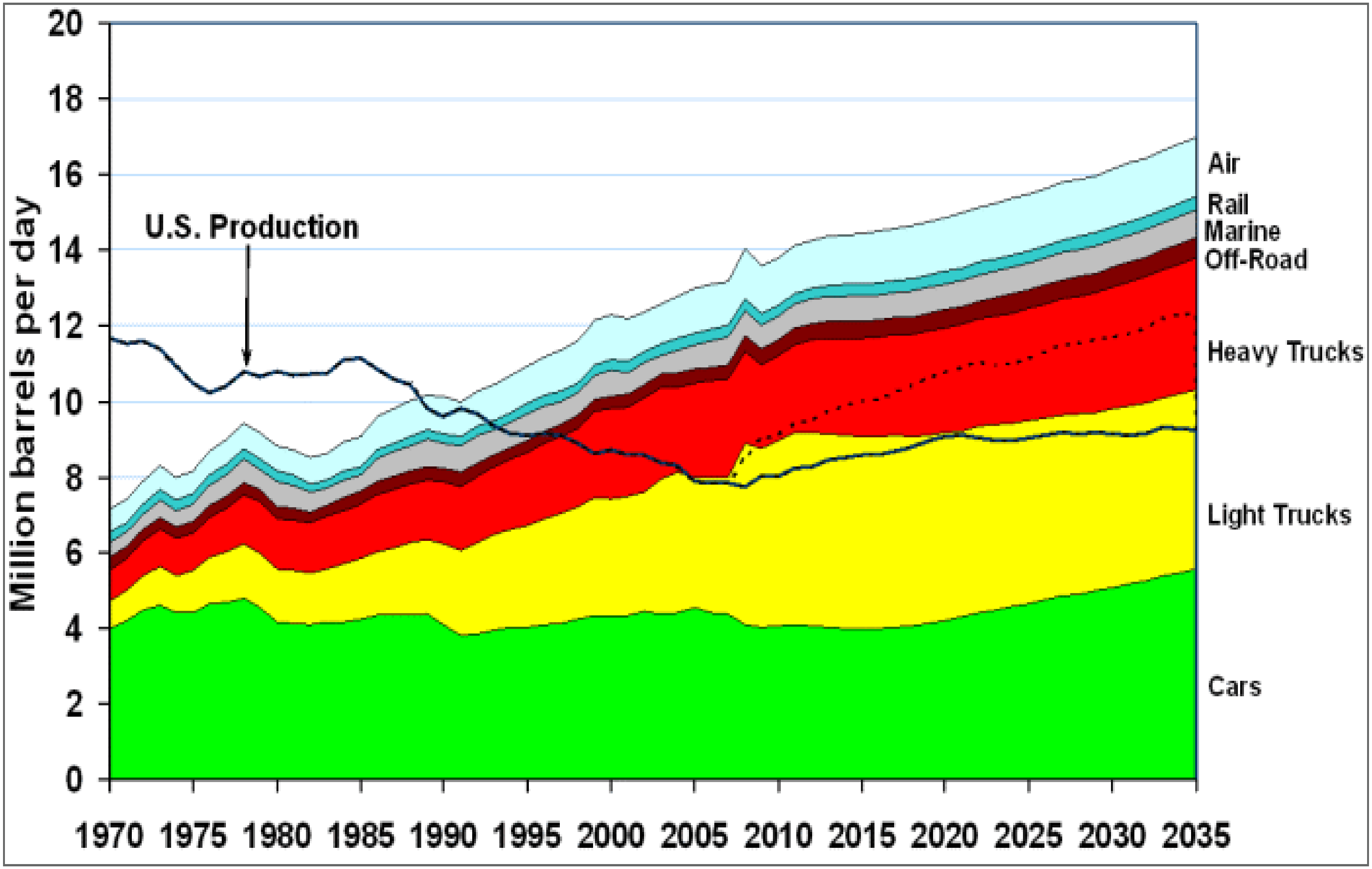
International Energy Agency's World Energy Outlook 2008

World primary energy demand in the Reference Scenario:

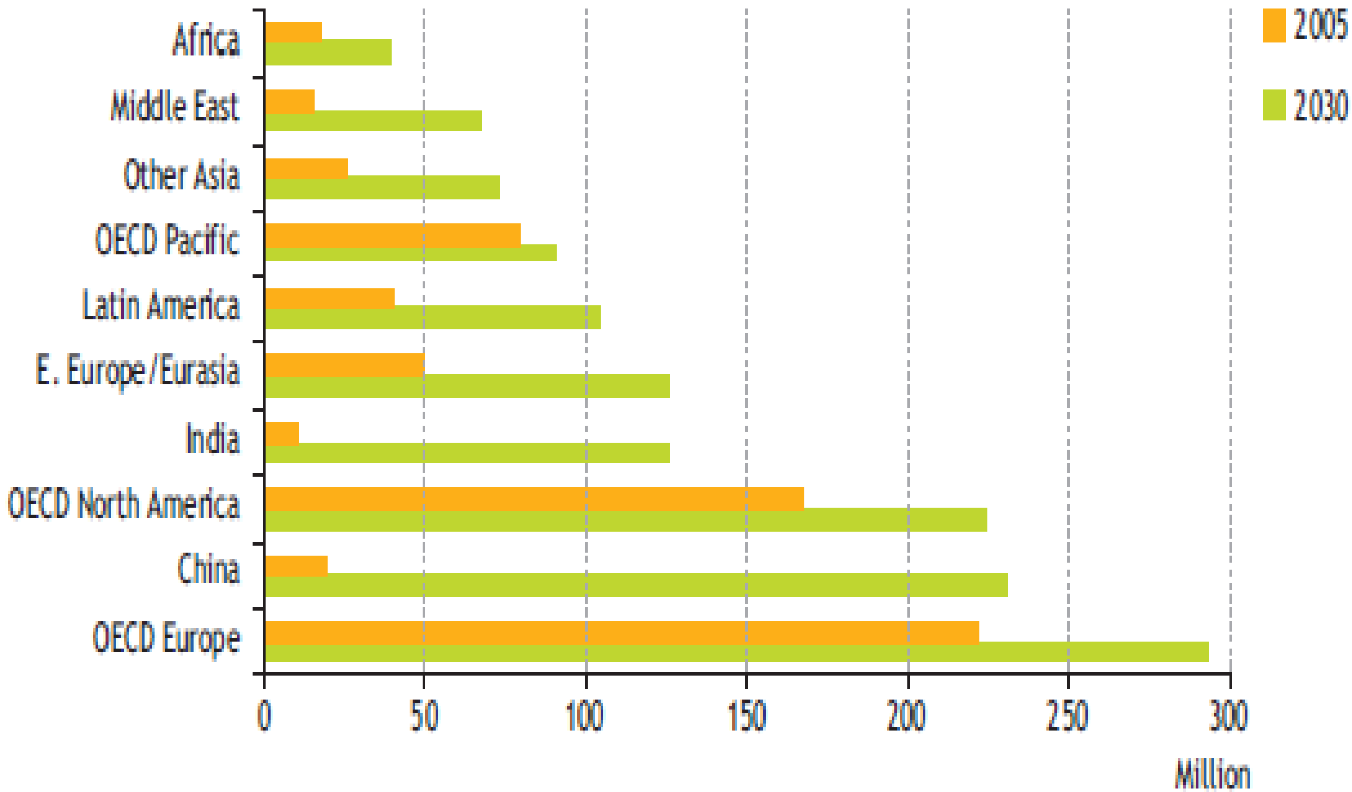


World energy demand expands by 45% between now and 2030 – an average rate of increase of 1.6% per year – with coal accounting for more than a third of the overall rise

February 8, 2010- Transportation Petroleum Gap



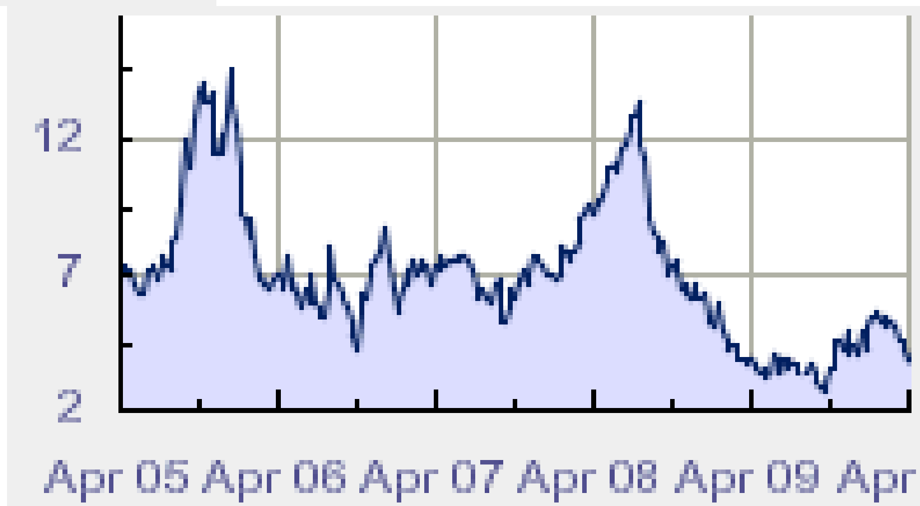
Worldwide Motor Vehicle Stocks Projected in International Energy Agency's World Energy Outlook 2008



Oil Prices are Rising Again

Drops in price are "research killers"

And Natural Gas appears to be heading down

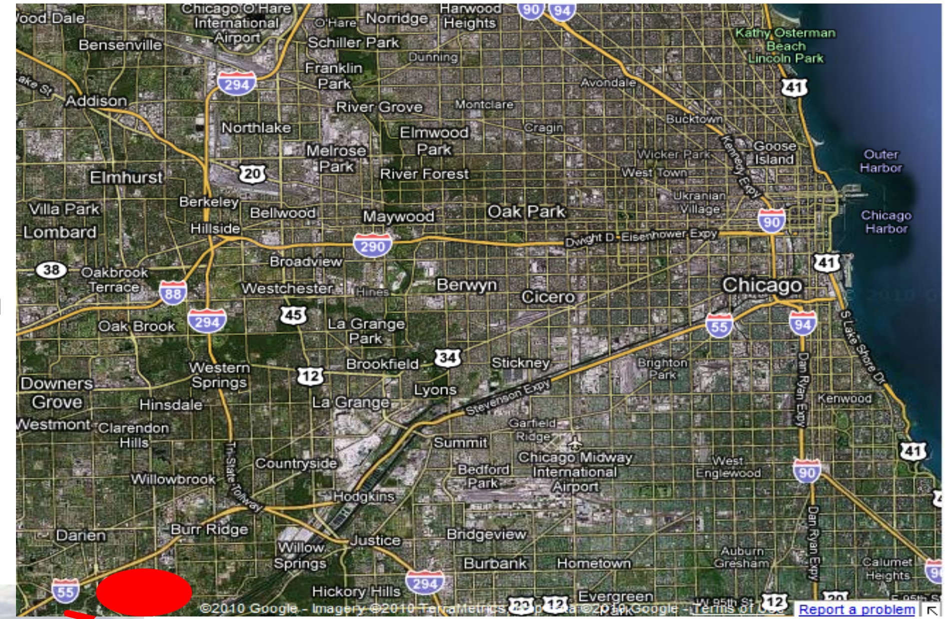


A Quick History of "Oil Killers"

Fuel of Choice	Year of Birth
Synthetic Fuels – from Shale	– 1980
Methanol	– 1990
Electricity (BEV)	– 1995
Hydrogen	– 2000
Ethanol	– 2008
Electricity again (PHEV)	– 2010

Argonne Is One of U.S. Department of Energy's Largest National Laboratories

- Basic science, applied technology and engineering research and development
- System Assessment Section, Energy System Division
- Assessment of transportation fuels and advanced vehicle technologies



Argonne National Laboratory

Among the National Labs, Argonne Has the Lead R&D Role in Several Automotive Fields

- **Hybrid vehicle systems, incl PHEVs**
  - Modeling
  - Benchmarking and evaluation
  - Component integration
- **Engine emissions control**
  - In-cylinder combustion
  - Bio-fuels
  - Laser-ignition for natural gas engines
- **Batteries**
- **Fuel cells**
- **Vehicle recycling**
- **Applied materials research**
  - Tribology
  - Nanofluids
- **High-performance computing**
- **Analysis and System Assessments**

4-wheel drive dynamometer for hybrid vehicle evaluation

Hydrogen Engine Test Stand

MATT HIL
Mobile Automotive Technology Testbed Hardware-In-the-Loop

Argonne's Systems Assessment Group

- Life-cycle analysis with the GREET model
- Economics of fuel production and distribution infrastructure
- Evaluation of alternative-fuel vehicle demonstration for DOE's Clean Cities Program
- Marketability and commercialization of advanced vehicle technologies
- Present key projects
  - Non-petroleum fuels
  - Biofuels
  - Hydrogen
  - Hybrid electric vehicles and plug-in hybrid electric vehicles
  - Battery-powered electric vehicles
  - Fuel-cell vehicles

Examples of Argonne Vehicle Testing in FY10

- 2010 Toyota Prius (Gen III)*
- 2010 Ford Fusion Hybrid
- Mercedes Benz S400h
- 2010 Honda Insight
- Mini-E (BEV)
- Tesla Roadster (BEV)
- NDA Protected Testing

* Also In-depth component research

Prime Areas of Research

- Electric Systems
- Advanced Combustion
- Alternate Fuels

Electric Systems

Petroleum Displacement through Fuel Substitution and Improved Efficiency

Administration Goal: 1 Million PHEVs by 2015

Types of Vehicles and Benefits

HEV →

PHEV →

EV →

Toyota Prius

- 1 kWh battery
- Power Rating: 80kW
- System Cost: $3000

50 MPG

Chevy Volt

- 16 kWh battery
- Power Rating: 170kW
- System Cost: est. $16,000

100 MPGe

Nissan Leaf

- ≥ 40 kWh battery
- Power Rating: ≥ 110kW
- System Cost: est.$36,000

All Electric

Status and Targets

2009 Status

Status: $8000-$12,000 for a PHEV 40-mile range battery

Status: Current cost of the electric traction system is $40/kW

Targets

2014 PHEV: Battery that has a 40-mile all-electric range and cost $3,400

2015 PEEM: Cost for electric traction system no greater than $12/kW peak by 2015

Projections for 2020 Market Shares indicate that Electric Vehicle share will Grow

Roland Berger: Powertrain 2020

	U.S.	Europe	Japan	China
HEV	13%	7%	9%	6%
PHEV	9%	15%	11%	9%
EV	4%	5%	4%	6%

http://www.rolandberger.com/media/pdf/Roland_Berger_Li-Ion_batteries_20100222.pdf

Electric Vehicles have limited Range
Range Anxiety is addressed via Several Approaches

- Battery Swaps
- Fast Charging
- Really Big Batteries
- Research on better Batteries

In Perspective:

•A major electric vehicle company produced 700 vehicles last year.

•In 1985 - Sterling Height Assembly Plant made 700 vehicles in half a day.

Battery Swaps – Back of the Envelope

- Need standardized or interchangeable batteries
- Need sufficient vehicles to justify the infrastructure
- Need a cost model that can work

Current EV Battery Pack is listed as costing $12,000 for replacement

(Which we all believe to be wildly optimistic)

$12000 x 5% annual return on investment = $600

3 year battery life means amortizing cost is $4000

Annual Return for each pack must surpass $4600 per year

For battery swapping profit, must drive 1300 miles per day per battery pack!

Conclusion: The EV Battery is twenty times too expensive for the swap model.

Fast Charging – Back of the Envelope
To make the economics work will require Subsidies

- Need to handle Thermal Loads and power distribution
- Massive investment in infrastructure required – similar to hydrogen
- Fast Charging will not be the first resort, because there will be other options, so the gasoline forecourt model will not hold.

Cost of level three charger is $15K – $60K

Value of electricity is about $5 per car

- EDF estimate: $15,000 charger is estimated to return a profit of $60 per year
- Scottish power estimates that a break even cost for electricity is 60 cents/ kW-h (making fast charge electric vehicles more expensive per mile than gasoline.)

Advanced Combustion Engine R&D

Increasing engine efficiency is one of the most cost-effective approaches to increasing fuel economy

Benefits All Vehicle Classes

Light-Duty

Cars
- Power Rating: 100-300hp

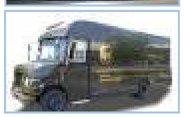

Trucks
- Power Rating: 200-400hp

25-40% Improvement

Heavy-Duty

Class 2b-8
- Power Rating: 250-600hp





Up to 50% Improvement

Targets

2015 Passenger Vehicle: Improve gasoline vehicle fuel economy by 25% and diesel vehicle fuel economy by 40%; compared to 2009 baseline

2015 Commercial Engine: Improve commercial engine efficiency by more than 20%; compared to 2009 baseline

2015 HEV & PHEV Improvements:
Could provide >70 MPG HEV

"Support improved mileage performance of internal combustion engines…" – Secretary of Energy Steven Chu

Advanced & Alternative Fuels

Direct Displacement of Petroleum and Enabling Advanced Engine Technology

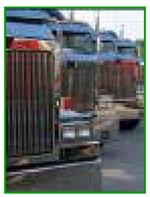
Ethanol "Blend Wall" is approximately 11-15 billion gallons per year with E10

Technologies and Benefits

LD Fuels

- 7B gallons displaced in 2008
- Renewable and synthetic fuels, such as E85 and F-T
- Little consumer sacrifice and currently available
- Opportunity for greater optimization with some blends

HD Fuels



- 250M gallons displaced in 2008
- Biodiesel & 3rd Generation Renewable Fuels
- Easier deployment with larger fleets`

Targets and Status

2009 Status	*Targets*
2009: Intermediate blends testing in support of E15 waiver on-track to finish 2010. **2009:** Approximately 10.5 billion gallons of renewables used	**2011 Target:** Have definitive answer on viability of E15 and B20 **2022 Target:** Attainment of RFS II mandate – 36 B gallons/year including expanded E85 use

R&D Focus

i-blends:
overcome blend wall, displace oil & meet RFS mandates

- Emissions results looks similar to E0. Catalyst temperature increase seen.
- $38M project includes emissions, durability, driveability, and materials compatibility for vehicles, small engines, and infrastructure

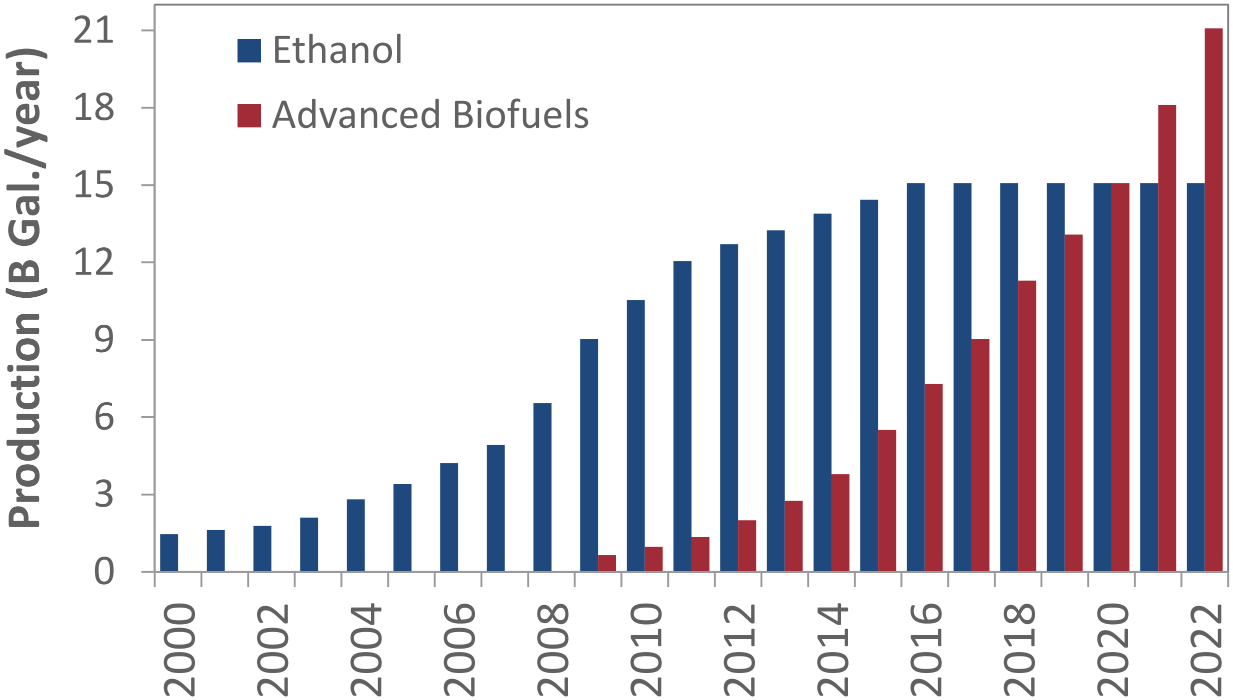
E85 Optimized FFV Engines – Increase use of E85 by decreasing the fuel economy penalty of ethanol

- Eliminate half of energy content penalty by taking advantage of higher octane
- Utilizing turbo-charging, variable valve timing, direct injection, and compression ratio increase to achieve 15% increase in fuel efficiency with E85

Biodiesel - Increase acceptance for legacy equipment.

- Determining effect of B20 on emissions and after-treatment systems → 12% / 48% reduction -in PM for B20/B100.

Background & Motivation



Adapted from: **Renewable Fuels Standard** *(Federal Register,* **75**(58))

U.S. Renewable Fuel Standard requires and increase of ethanol and advanced biofuels to 36 billion gallons by 2022.

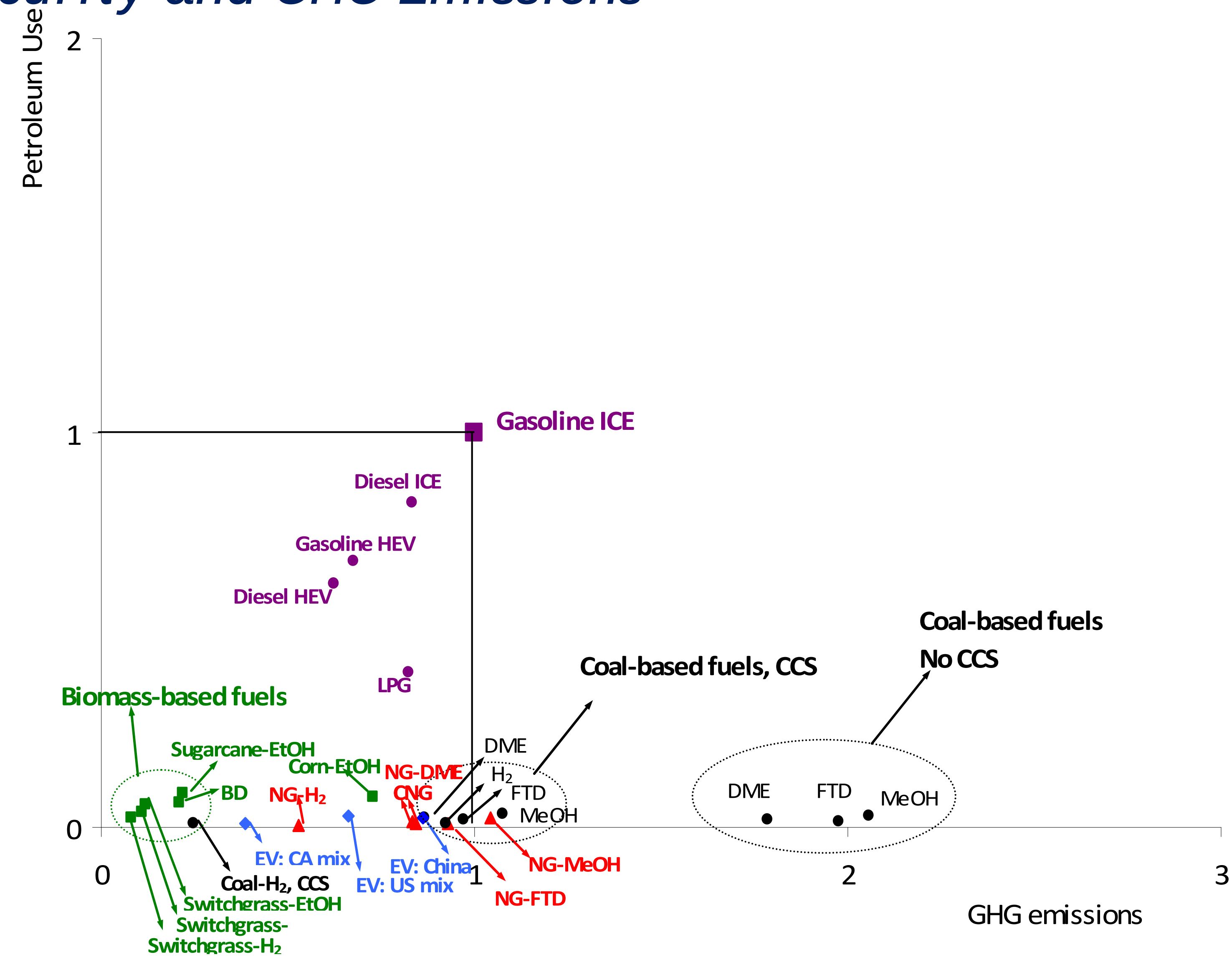
→ ***Iso*-Butanol**

More Than 100 Fuel Production Pathways from Various Energy Feedstocks

Petroleum Conventional Oil Sands	Gasoline Diesel Liquefied Petroleum Gas Naphtha Residual Oil Jet Fuel
Natural Gas North American Non-North American	Compressed Natural Gas Liquefied Natural Gas Liquefied Petroleum Gas Hydrogen Methanol Dimethyl Ether Fischer-Tropsch Diesel Fischer-Tropsch Naphtha Fischer-Tropsch Jet Fuel
Corn	Ethanol Butanol
Sugarcane	Ethanol
Soybeans	Biodiesel Renewable Diesel Renewable Jet Fuel
Coke Oven Gas Petroleum Coke Nuclear Energy	Hydrogen
Coal	Hydrogen Methanol Dimethyl Ether Fischer-Tropsch Diesel Fischer-Tropsch Jet Fuel
Renewable Natural Gas Landfill Gas	Compressed Natural Gas Liquefied Natural Gas Hydrogen Methanol Dimethyl Ether Fischer-Tropsch Diesel Fischer-Tropsch Naphtha Fischer-Tropsch Jet Fuel
Cellulosic Biomass Switchgrass Fast Growing Trees Crop Residues Forest Residues	Ethanol Hydrogen Methanol Dimethyl Ether Fischer-Tropsch Diesel Fischer-Tropsch Jet Fuel
Residual Oil Coal Natural Gas Biomass Other Renewables	Electricity

The yellow boxes contain the names of the feedstocks and the red boxes contain the names of the fuels that can be produced from each of those feedstocks.

Coal-Based Fuels Pose a Trade-Off Between Energy Security and GHG Emissions



From Wang and Huo: Frontiers of Energy and Power Engineering in China, 3(2): 212-225

Many Potential Biofuel Production Pathways

- **Sugar Crops for <u>EtOH</u>**
  - <u>Sugar cane</u>
  - Sugar beet
  - Sweet sorghum

- **Starch Crops for <u>EtOH</u>**
  - <u>Corn</u>
  - Wheat
  - Cassava
  - Sweet potato

- **<u>Landfill Gas</u>**
  - <u>CNG/LNG</u>
  - <u>Fischer-Tropsch diesel</u>
  - <u>Hydrogen</u>
  - <u>Methanol</u>
  - <u>DME</u>
  - Fischer-Tropsch jet fuel

- **Oils for <u>Biodiesel/Renewable Diesel</u>/Renewable Jet Fuel**
  - <u>Soybeans</u>
  - Rapeseed
  - Palm oil
  - Jatropha
  - Waste cooking oil
  - Animal fat

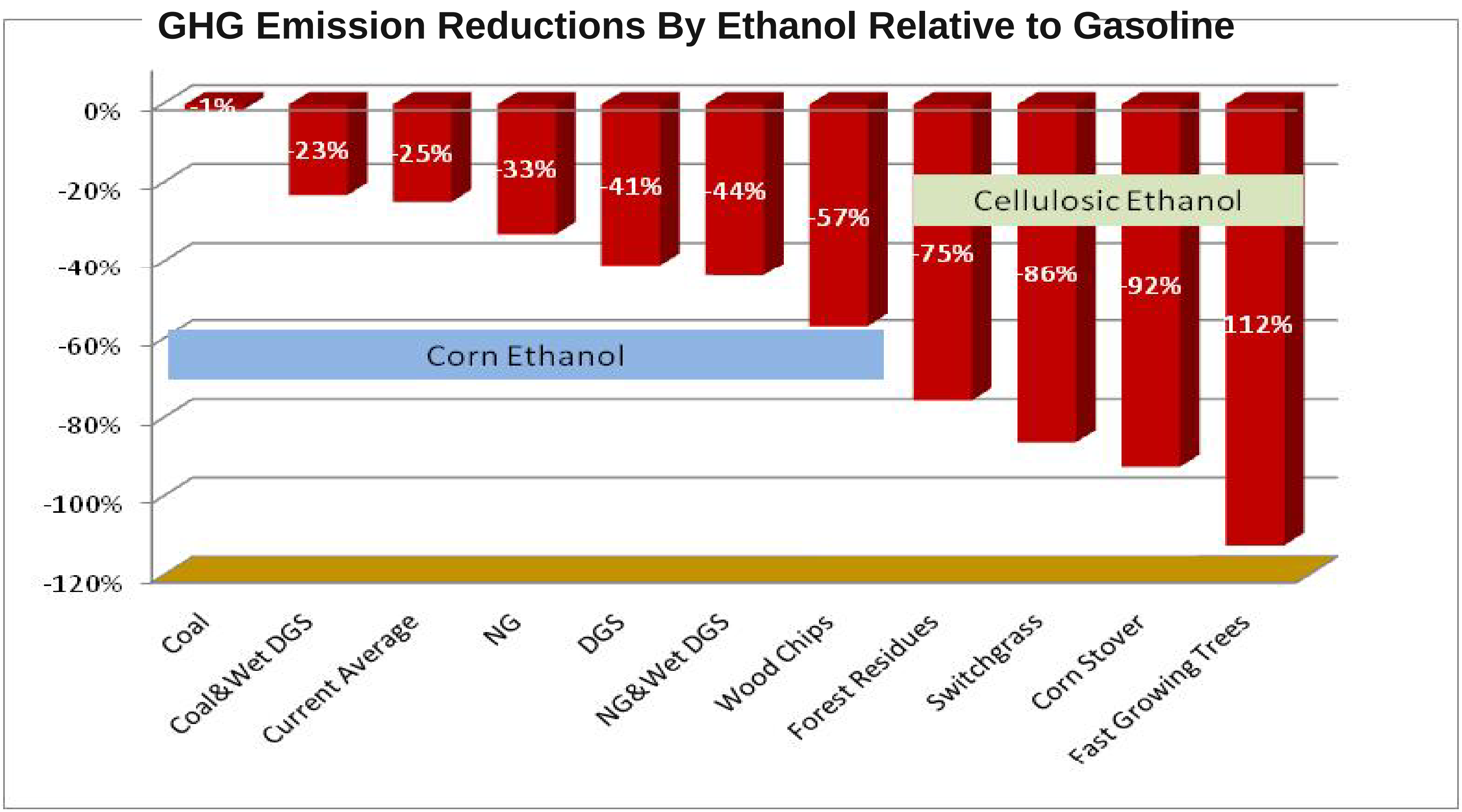
- **Cellulosic Biomass for <u>EtOH</u>**
  - <u>Corn stover</u>, rice straw, wheat straw
  - <u>Forest residues</u>
  - Municipal solid waste
  - <u>Dedicated energy crops</u>
  - Black liquor

- **<u>Butanol</u>**
  - <u>Corn</u>
  - Sugar beet

- **Algae**
  - Biodiesel
  - Renewable diesel

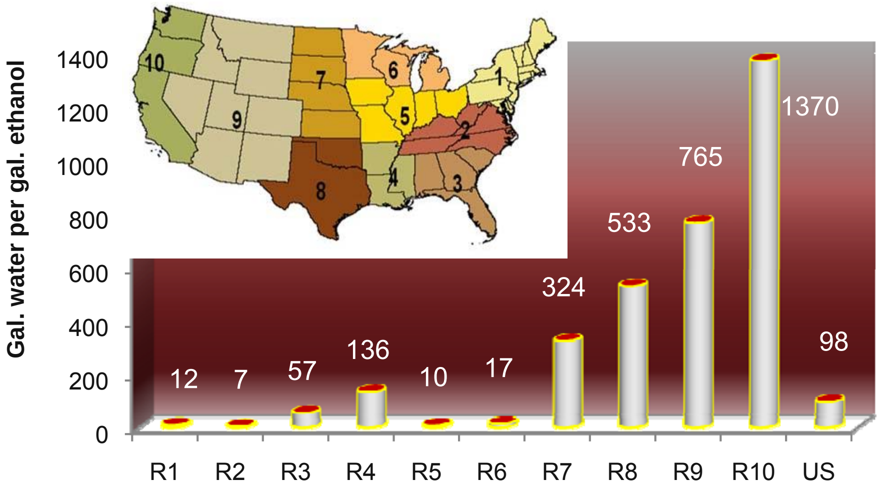
- **<u>Cellulosic Biomass</u> via Gasification**
  - <u>Fischer-Tropsch diesel</u>
  - <u>Hydrogen</u>
  - <u>Methanol</u>
  - <u>DME</u>
  - Fischer-Tropsch jet fuel

GHG Emissions of Corn Ethanol Vary Considerably Among Process Fuels in Plants; Cellulosic Ethanol Consistently Achieve Large Reductions



GHG effects of potential land use changes are not fully included in these results.

Resource Management Must Be Addressed at Regional Level



- Significant regional variations in irrigation water consumption for corn
- Water consumption factor for non-irrigated cellulosic biofuel is comparable to that of petroleum gasoline.
- Published in *Journal of Environmental Management*
- Results provided key references for GAO's biofuel report to Congress *(Sept. 2009)* and Congressional testimony by GAO on Energy and Water (*July 2009*)

Competing water use from multiple sectors and projects

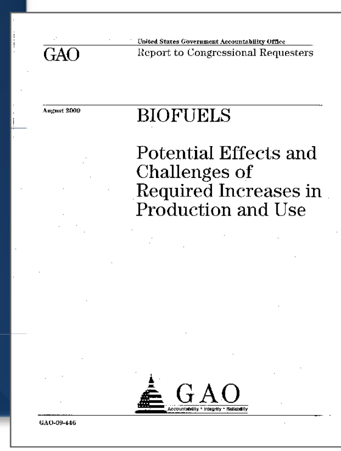
- Power
- Biofuel
- Agricultural
- Urban development
- Others

Water quality impact associated with biofuel production

- Regional environmental loading to waterways
- Nutrient accumulation in surface and ground water

Compounding effect on water body could be devastating

- Hypoxic zone expansion
- Aquatic ecosystem degradation


GAO
United States Government Accountability Office
Report to Congressional Requesters

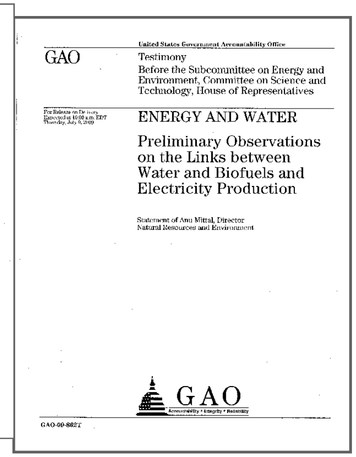
August 2009

BIOFUELS

Potential Effects and Challenges of Required Increases in Production and Use

GAO

GAO-09-446


GAO
United States Government Accountability Office
Testimony
Before the Subcommittee on Energy and Environment, Committee on Science and Technology, House of Representatives

ENERGY AND WATER

Preliminary Observations on the Links between Water and Biofuels and Electricity Production

GAO

How Much Water Is Consumed To Drive A Passenger Car For A Mile?

	Corn Ethanol			Cellulosic Ethanol			Petroleum Gasoline
Regions	USDA 5	USDA 6	USDA 7	Native habitat			PADD II, III, V
Production process		Dry milling		Thermochemical	Biochemical		Vary
Share of fuel production	*52%*	*14%*	*30%*				*81%*
Share of feedstock production	*52%*	*16%*	*20%*				*90%*
gal water/gal gas. eq.	*15*	*26*	*492*	*3*	*9**	*15*	*3 - 7*
gal water/mile travelled	***0.6***	***1.1***	***21.0***	***0.1***	***0.4***	***0.6***	***0.1 – 0.3***

*** Advanced biochemical process**

Natural Gas?

- Natural gas reserves are growing at unprecedented levels
- Projections are for natural gas prices to stay low
- On the flip side, natural gas is valuable for just about everything
- And studies indicate that natural gas is more efficiently spent making electricity for plug-in hybrids.
- How long will Fracking be legal?

Conclusion: There are no silver bullets, but many bronze bullets

- Economics rule! – It better make cost sense
- No single fuel/system will replace oil
  - Ethanol
  - Iso Butanol
  - PHEVs
  - Diesel-cycle Engines
- Long Term
  - Lithium air batteries
  - Algae-based fuel

STUDY FINDS SILVER BULLETS LARGELY INEFFECTIVE AGAINST WEREWOLVES

July 28 2009

Berlin, Germany – A new study though has indicated that the silver bullet theory may be nothing more than a myth and that Werewolves may in fact be much harder to dispose of than previously thought.

Mankind has long held onto a connection with the animal. From the Anubis of Egypt to the dragons of China to the American Bald Eagle, the animal world has long held a great fascination for human beings. Because of that connection animals quite often integrate themselves into popular culture and become personified.
There is perhaps no better of example of that than the Werewolf, a fusion of the human and one of the most vicious of animals is tale that has been told throughout human culture across the world.

Integrated Development of Transportation Fuels and Engines

Approach: a system-level, iterative feedback loop – new feedstocks, processing, combustion science, modeling, real-world testing, optimization, and life-cycle analysis.