

Sustainable Energy Options For Transportation

Courtesy of The Robert Bosch Corporation



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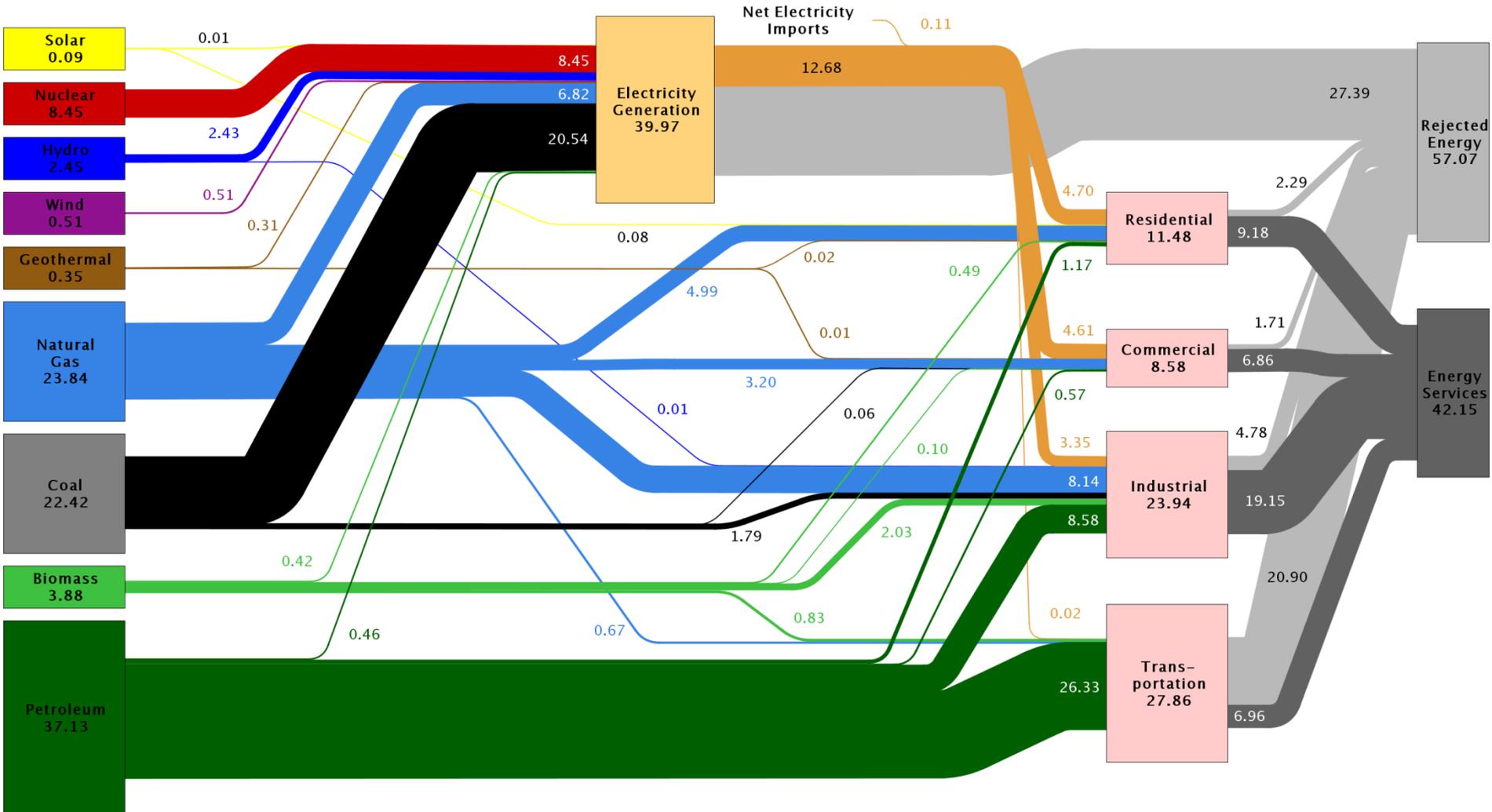
Kansas State Energy Conference

October 12-13 2010

Wichita, Kansas

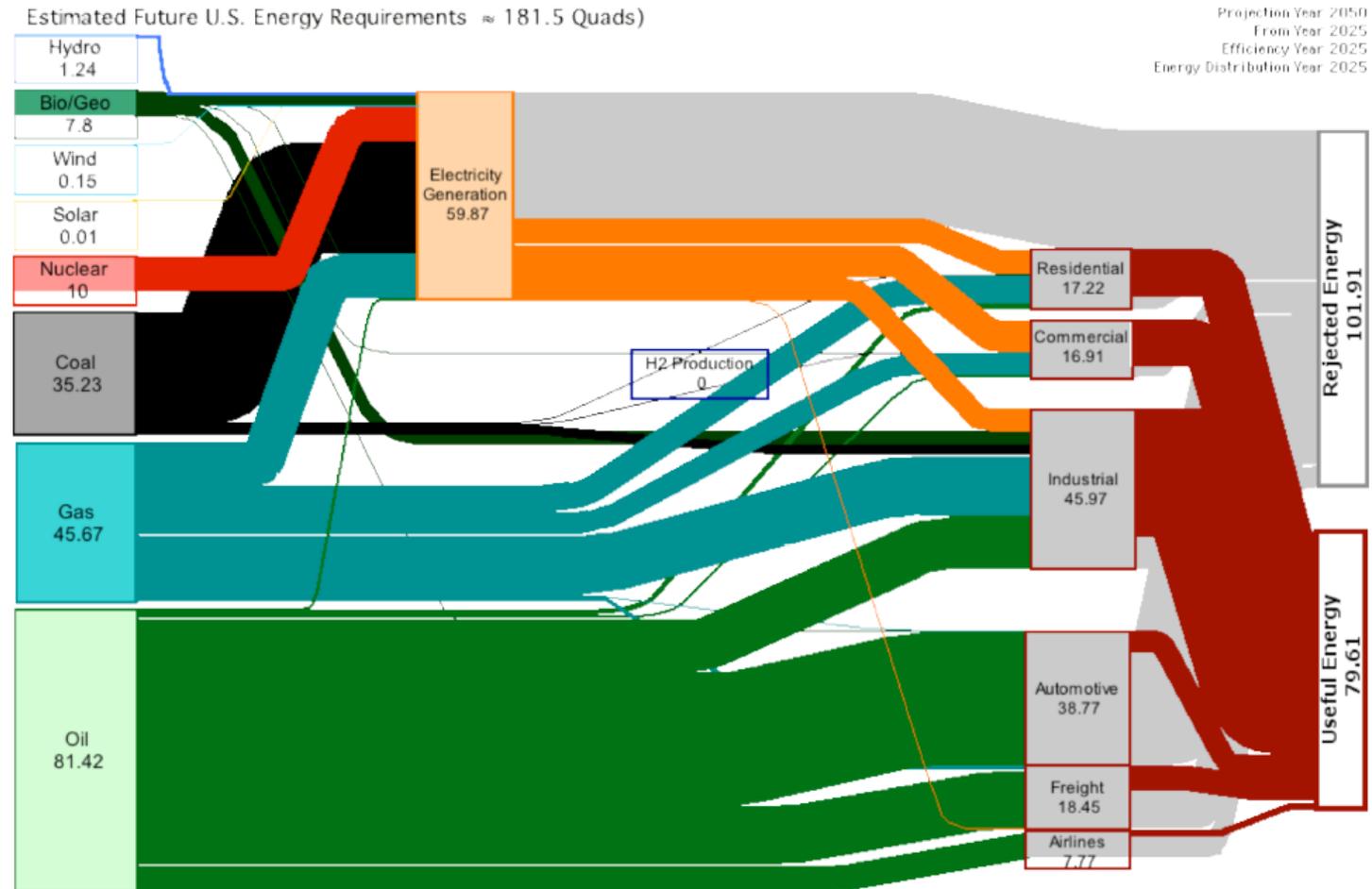
Energy Schematic of the United States

Estimated U.S. Energy Use in 2008: ~99.2 Quads



Source: LLNL 2009. Data is based on DOE/EIA-0384(2008), June 2009. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports flows for non-thermal resources (i.e., hydro, wind and solar) in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 80% for the residential, commercial and industrial sectors, and as 25% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

Energy Schematic of the United States circa 2050 (BAU)

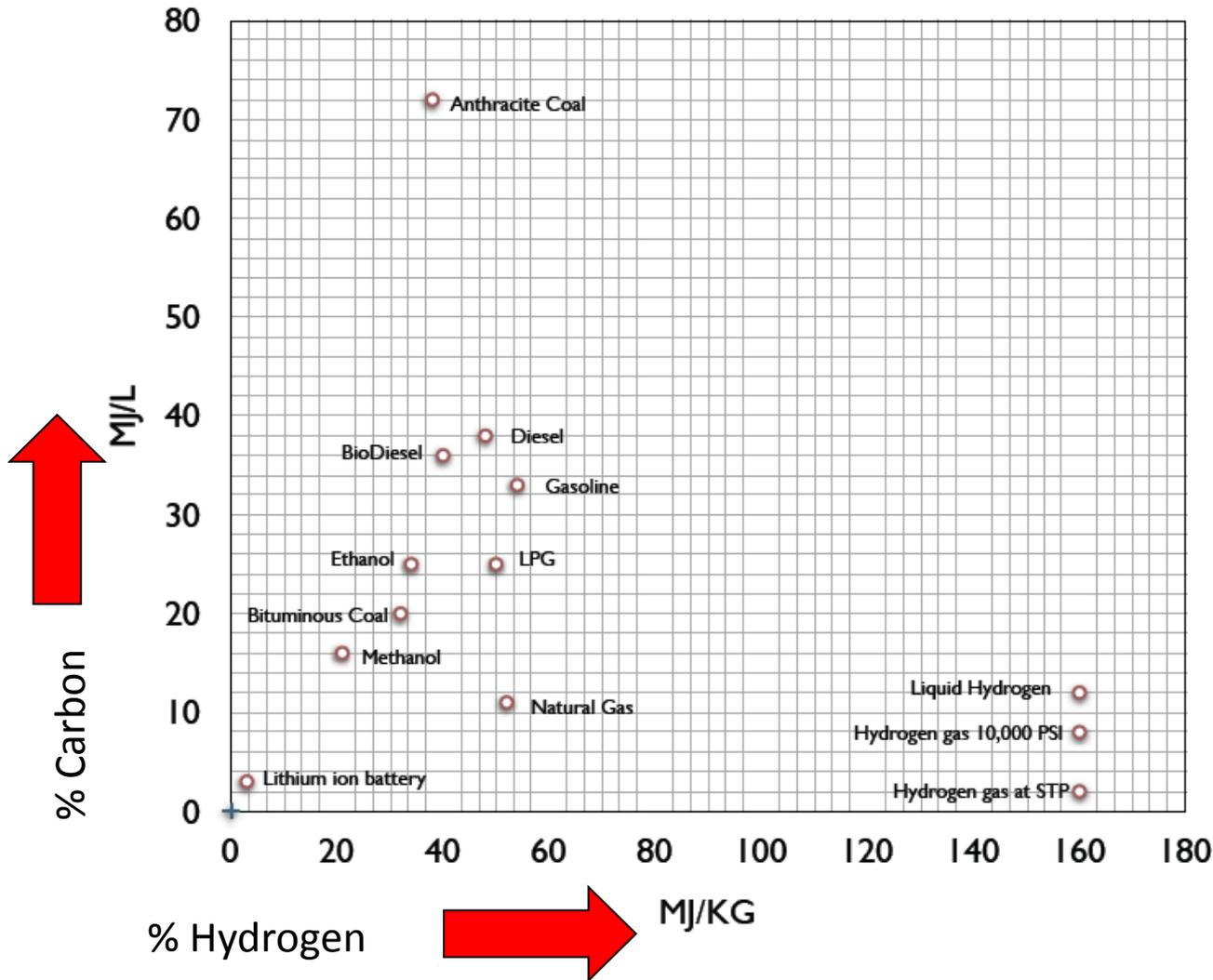


Scenario 3. Linear extrapolation of *Annual Energy Outlook* projections for 2020-2025 out to 2050. A driving age population of 318 million, averaging 19,500 miles driven per year in 20 mpg vehicles, requires 39 Quads of petroleum or 18 million bbl/day.

What is Energy Density?

- Fuels are compounds that contain carbon atoms and hydrogen atoms. Renewable fuels likely also contain Oxygen. Their energy is stored in the molecular bonds
- The carbon to hydrogen ratio is related to how much energy the fuel contains by WEIGHT compared to how much fuel the energy contains by VOLUME.
- The higher the percentage of Hydrogen in the fuel, the better it's density by Weight.
- The higher the percentage of Carbon in the fuel, the better it's density by Volume

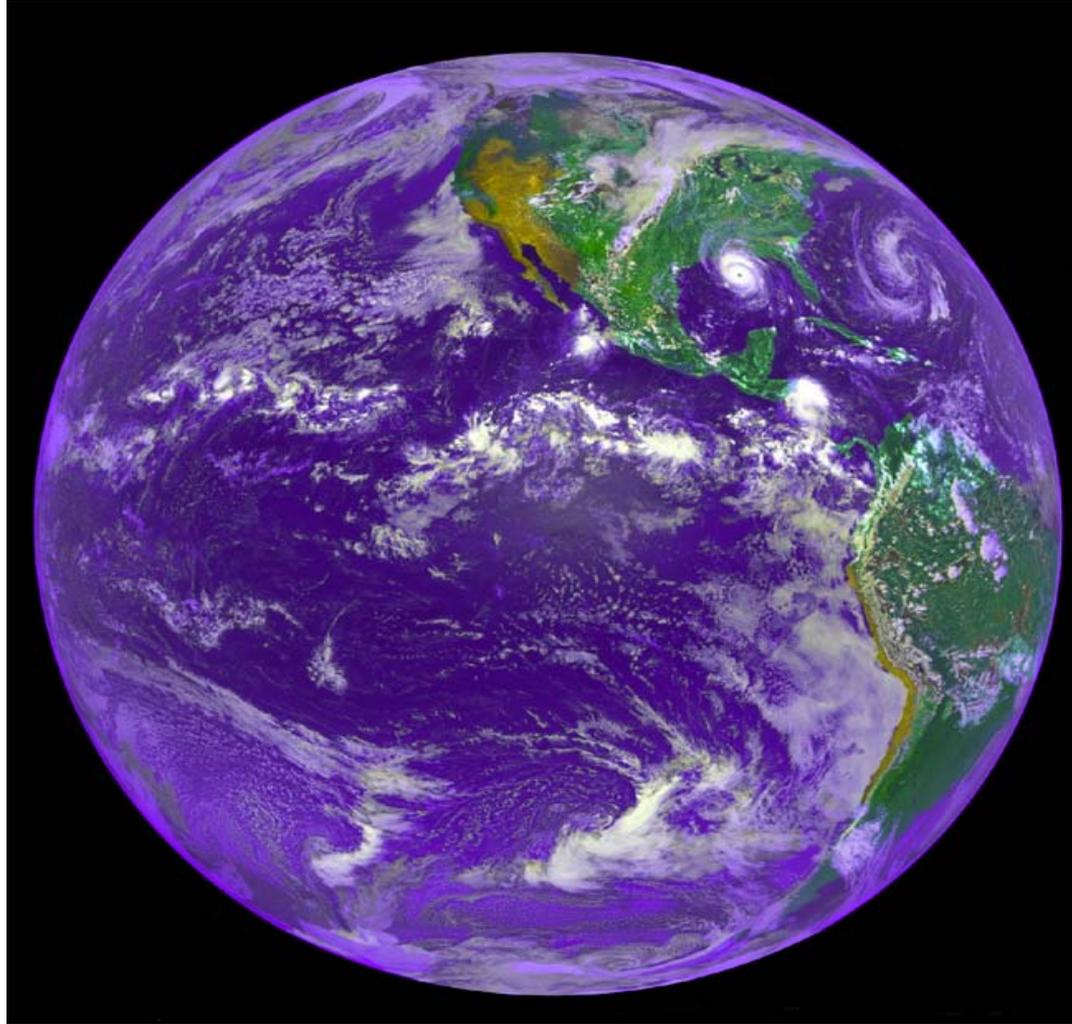
Energy Densities & Fuel Choices



The joule is the energy exerted by the force of one newton acting to move an object through a distance of one metre or the work required to continuously produce one watt of power for one second or one *watt second*.

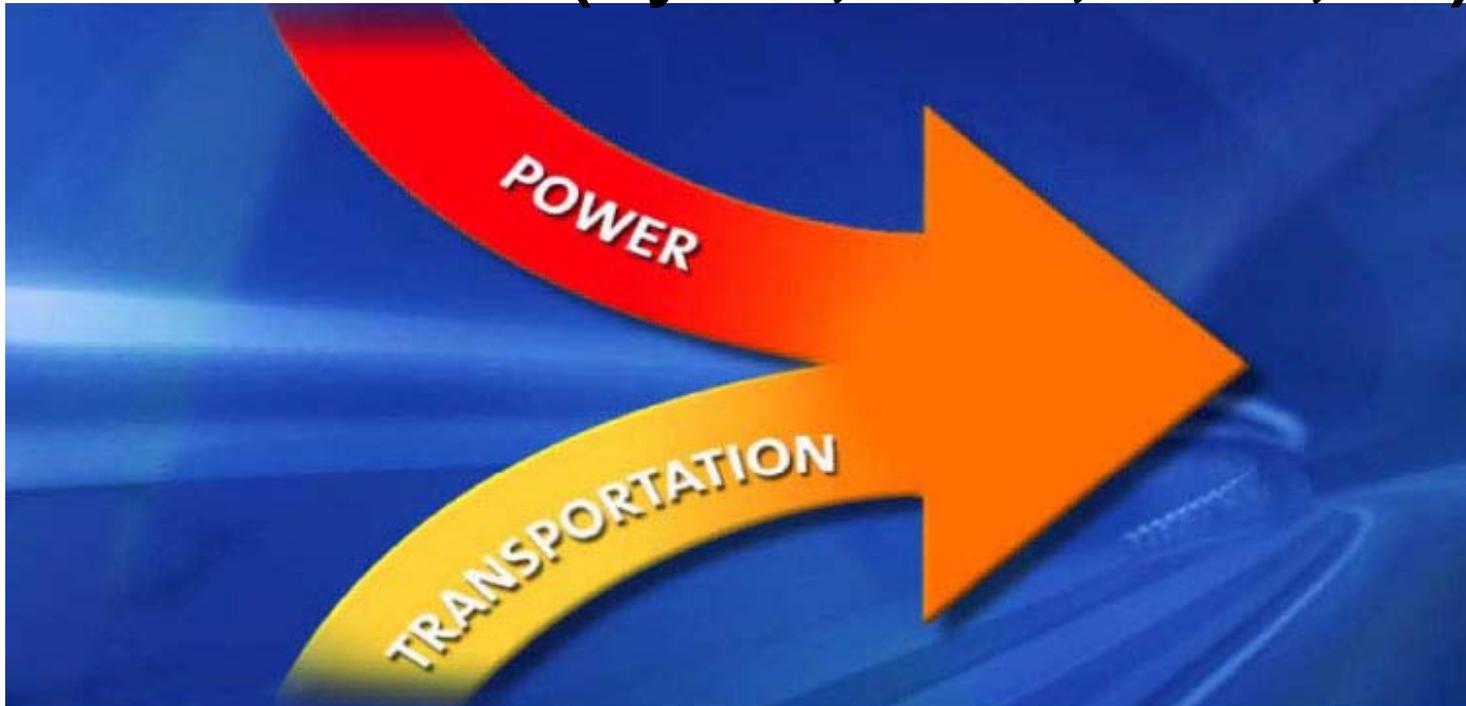
The megajoule (MJ) is equal to one million joules, or approximately the kinetic energy of a one-ton vehicle moving at 100 MPH

Where Do We Go From Here?



The Future Of Transportation:

Electric Drive!! (Hybrid, PHEV, EREV, EV)



**More and More, Transportation
will be “Electron” Based**

What is a hybrid?

- **Noun**
- **Hybrid**
- **Offspring** resulting from **cross-breeding different entities**, e.g. different species
- Something of mixed **origin** or **composition**

From Wikipedia, the Free Encyclopedia



What Is a Hybrid?

- In a motor vehicle this means the utilization of two or more forms of motive power.
- Today this means the use of an internal combustion engine *and* electric motor(s).
- Today's hybrid light duty vehicles are gasoline powered, but diesel, CNG & H₂ hybrids are here too!



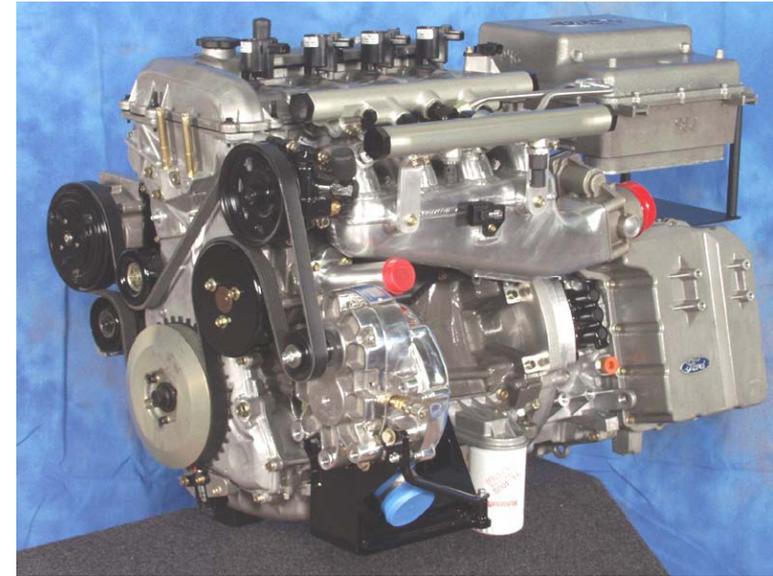
Why Hybrids & Electric Drive??

- Electric drive is more efficient than internal combustion (ICE)
- Hybrids offer three primary efficiency gains over conventional vehicles:
 - Regenerative Braking;
 - Idle Stop & Electric Launch;
 - Smaller Engine (can be sized for average, rather than peak load).
- **potential of hybridization**
 - start / stop - function: ~ 5 %
 - recuperation (electric braking): ~ 5 %
 - electric driving: ~ 5 %
- **additional potentials:**
 - downsizing / supercharging: ~ 6 %
 - gearbox technology: ~ 4 %
- **overall results:**
 - optimization of fuel efficiency: ~ 25 %
 - fuel consumption ~ 3.8 l / 100 km
62 mpg

What is a hybrid?



UPS Diesel MD Diesel hybrid



Hydrogen fueled ICE/Hybrid



Quantum Technologies Fuel Cell hybrid

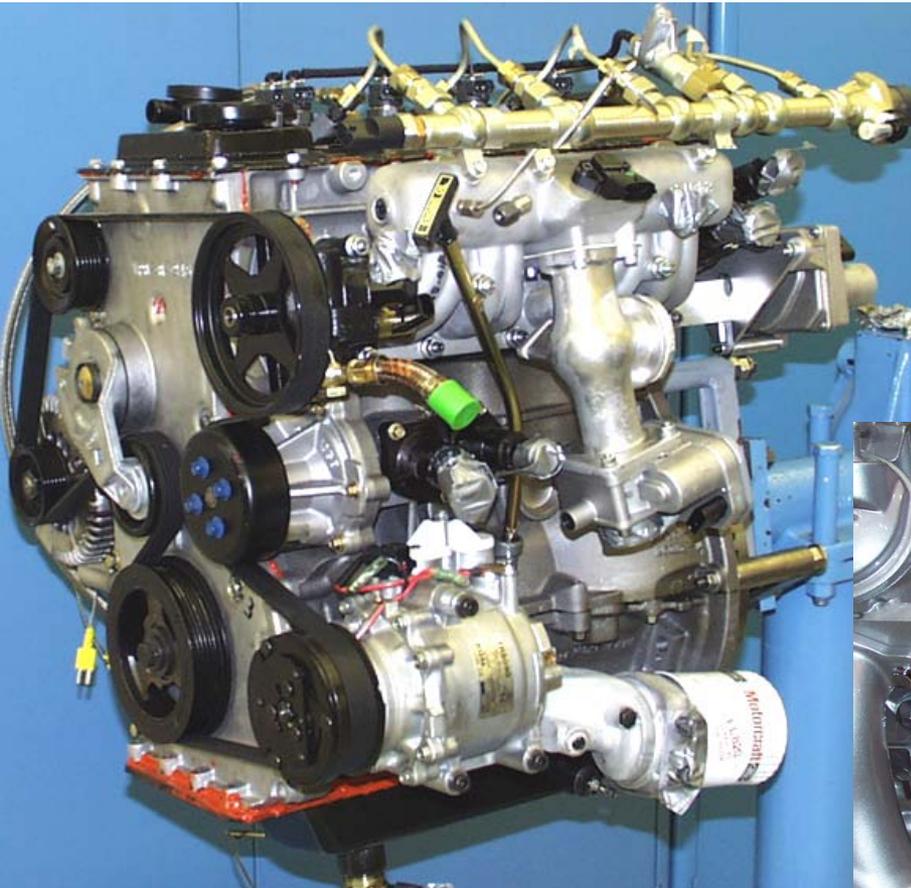


Ford Escape hybrid

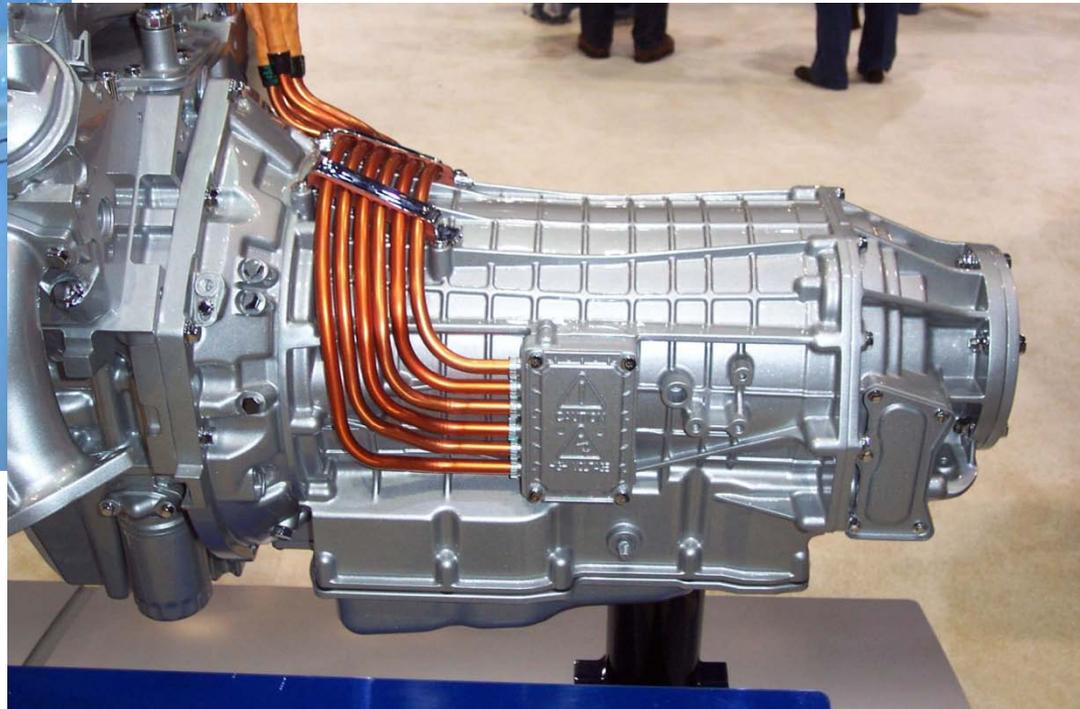
Variations on a Theme

Diesel Hybrids, already popular in medium duty are coming to light and heavy duty vehicles as well

Ford Motor Co. is Committed to H₂ ICE's as a bridge to H₂ Fuel Cells!



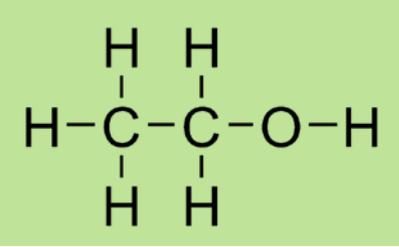
Clean Diesel LD Hybrid



GM/Daimler/BMW dual mode hybrid drive

EPACT Technologies for Transportation

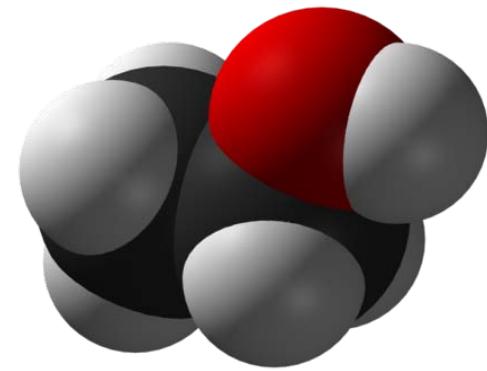
- The Energy Policy Act of 1992 defined alternative fuels & advanced technologies.
- The EPAct alternative fuels:
 - Methane (Either as CNG or LNG)
 - Propane (LPG)
 - GTL fuels (Fischer-Tropsch & P type)
 - Bio-Diesel
 - Ethanol
 - Methanol
 - E-85 (Flex Fuel)
 - Electricity
 - Hydrogen



What is Ethanol ?

- Ethanol is produced by fermenting plant sugars
 - Typically derived from corn and other grain products
- Usually mixed with gasoline when used in transportation
 - E10
 - E15
 - E85
- Any conventional vehicle can operate on E10 ethanol fuel.
 - E10 has been used for decades
 - Vehicles that can use E85 are called ***flexible fuel vehicles***

What is Ethanol ?



- Is denatured to prevent drinking
- Mixes easily with water and gasoline, bio degradable
- Carbon neutral
- Reduces hydrocarbon and carbon monoxide emissions, no sulfur
- Contains 35% oxygen by weight. This oxygenation is why it is a popular additive for EPA mandated gasoline reformulation
- High octane rating. Used as an octane booster
- Energy density 63% of diesel-wt.
59% of diesel-gal.

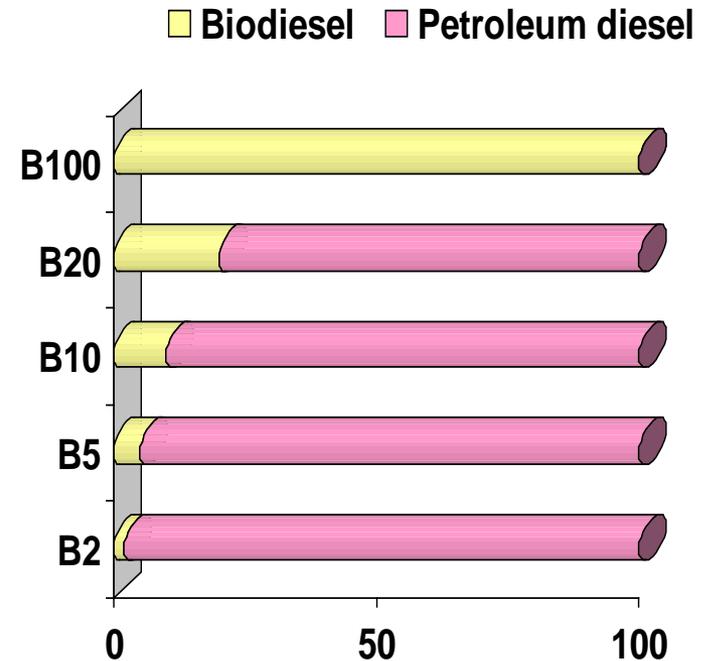
What is Biodiesel?



As defined by the IRS:
Biodiesel is mono-alkyl esters of long chain fatty acids from plant or animal matter. It **MUST** meet the standards of the American Society for Testing and Materials (ASTM) specification D6751 or it should not be called “biodiesel.”

Biodiesel – General Definitions

- Made from vegetable oils, used cooking oils and methanol or ethanol
- Can be produced in small reactors or on an industrial basis
- B100 is carbon neutral
- Energy density 93% of diesel-gal.
- Greatly reduced emissions except NOx
- 55% reduction in PM and HC's!
No Sulphur
- Can be mixed with Diesel in any proportion
- Most OEM's allow mixtures up to B20
- Lubricity of Biodiesel may make it useful as a lubricant additive for ULSD



Biodiesel blend, n.: A blend of biodiesel fuel meeting ASTM D 6751 with petroleum-based diesel fuel designated BXX, where XX is the volume percent of biodiesel.

Biodiesel Is An Evolving Fuel

- 1st Gen FAME (Fatty Acid Methyl Ester)
Fuels (Biodiesel)

Feedstocks can include:

Rapeseed, Canola

Soy

Palm Oil

Sunflower Seed

Jatropha

Tallow

- Feedstock can impact:

Stability

Cetane

Cold flow properties

NOx emissions

Boiling range



2nd Generation Fuels Include Ethanol

Biomass to Liquids via Gasification and Fischer-Tropsch

Feedstock can be forest waste, purpose-grown crops, (Like Algae)

municipal waste

Low to zero sulfur, aromatics

High cetane

Lubricity, cold flow need adjustment

Example – Choren Energy

DME is CH₃OCH₃

Colorless gas at STP

Properties very similar to LPG

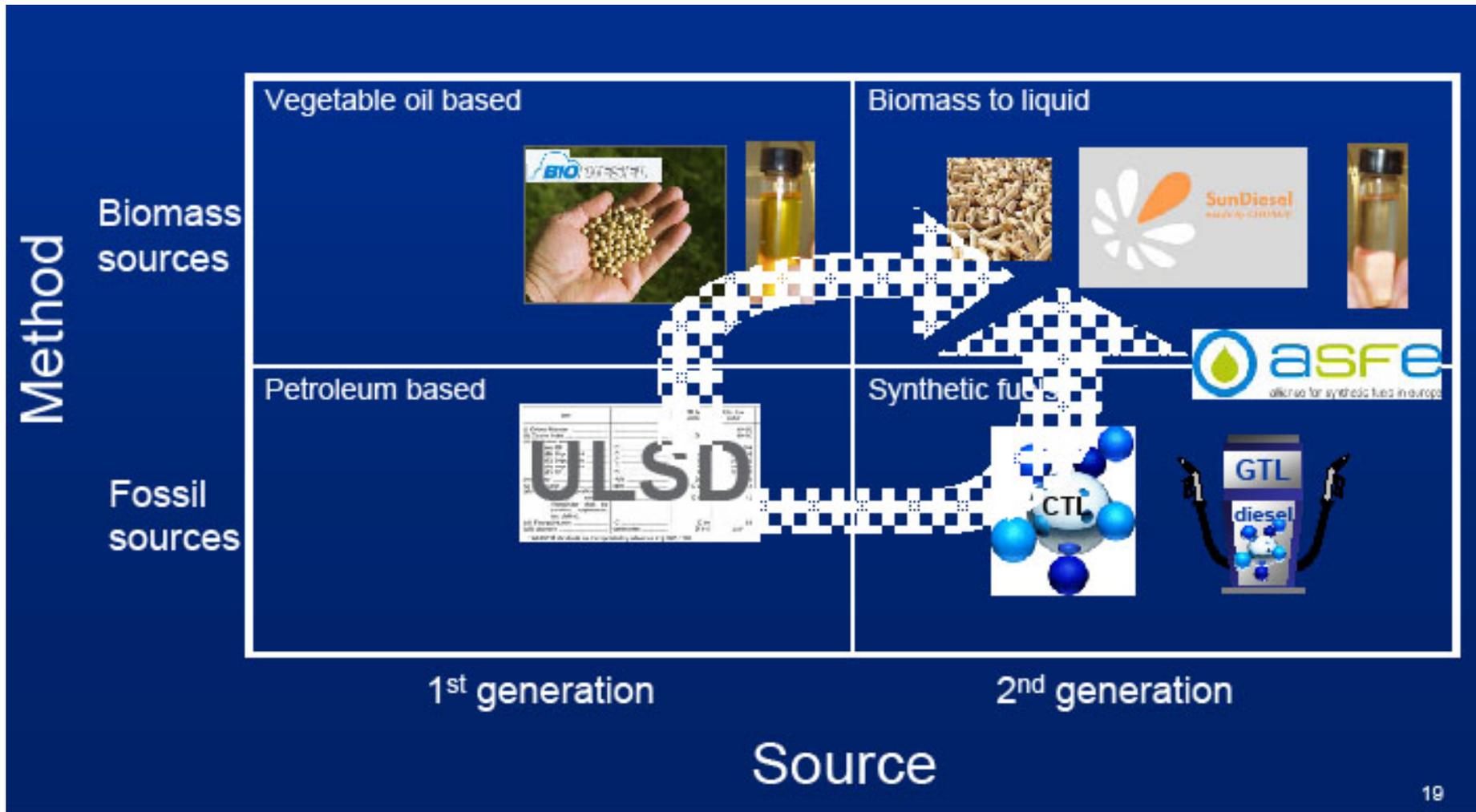
Made from CO + H₂

Boils at -25C, Cetane 55-60, Autoign Temp 250'C (Diesel 206'C)

Feedstock can be anything from turkey processing waste to auto shredder residue

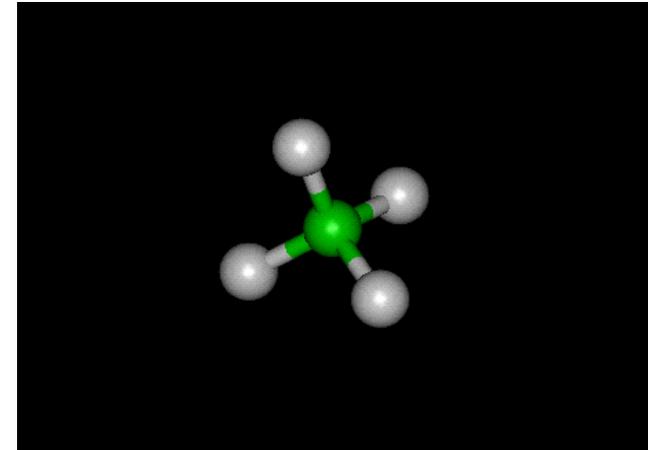
More questions than answers about product properties

Where We May Be Headed

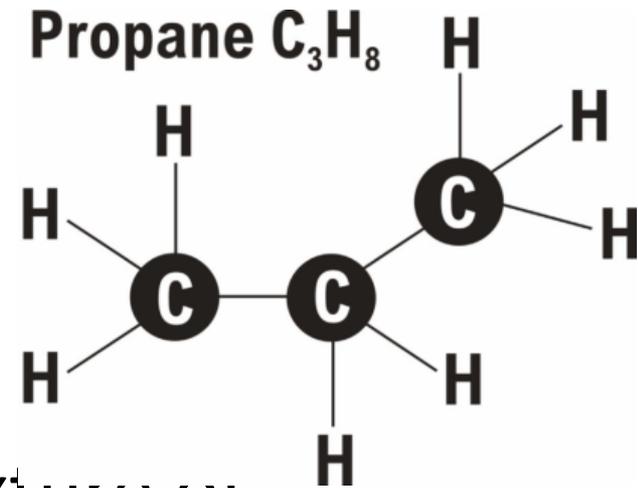


What Is Methane (CNG)?

- **Simplest Hydrocarbon CH₄**
- **Lighter than air**
- **Cryogenic (approx -250°F)**
- **CNG is refrigerated to form LNG**
- **Always a gas when delivered to engine**
- **Requires spark ignition, low compression (diesel's can't run on CNG)**
- **CNG contains trace impurities, such as heavier hydrocarbons, but no sulphur.**
- **Very clean burning**
- **Modern storage system pressurize this gas to 3600 PSI or carry it in liquid form (LNG)**
- **Energy density :**
 - 116 %of diesel-Wt**
 - 18% of diesel-gal.**



What is LPG/Propane?



- Liquefied Petroleum Gas is a mixture of propane (at least 90%) and small amounts of other chemicals. It's most popular use is for residential heating. In the U.S. about 3% of LPG is used in transportation. Globally over ten million vehicles run on LPG
- It is normally a gas but, compressible to a transportable liquid. It is nontoxic, colorless and virtually odorless. As with natural gas, a strong identifying odor is added so the gas can be readily detected.
- Unlike CNG, it is NOT cryogenic!

Hydrogen

- **By weight has the greatest energy density of any fuel: 283% of diesel**
- **Problem: It is extremely light!**
- **Smallest atom in the universe, hard to contain**
- **It is a cryogenic fuel.**
- **Transition from liquid to gas requires expansion to 800 times the liquid volume**
- **Can be used as a fuel in internal combustion engines**
- **Must be extremely pure (99.9%) to be used as fuel in fuel cells.**
- **Current technology requires approx 4000kw of energy (usually electricity) to produce 1000kw of useable hydrogen**
- **Many other infrastructure issues to be solved!**

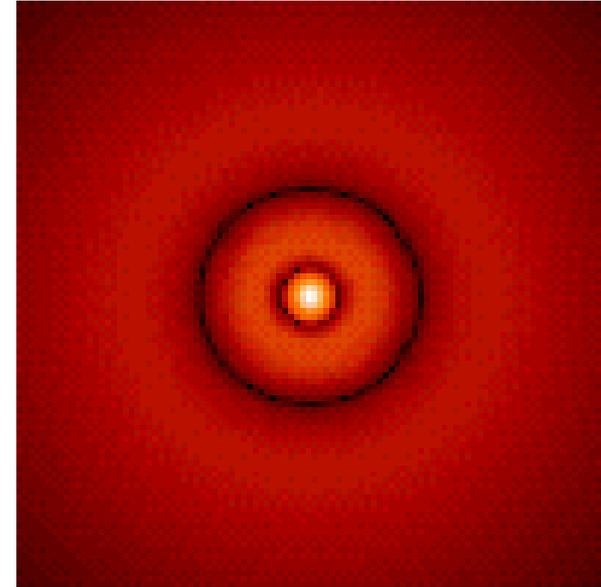
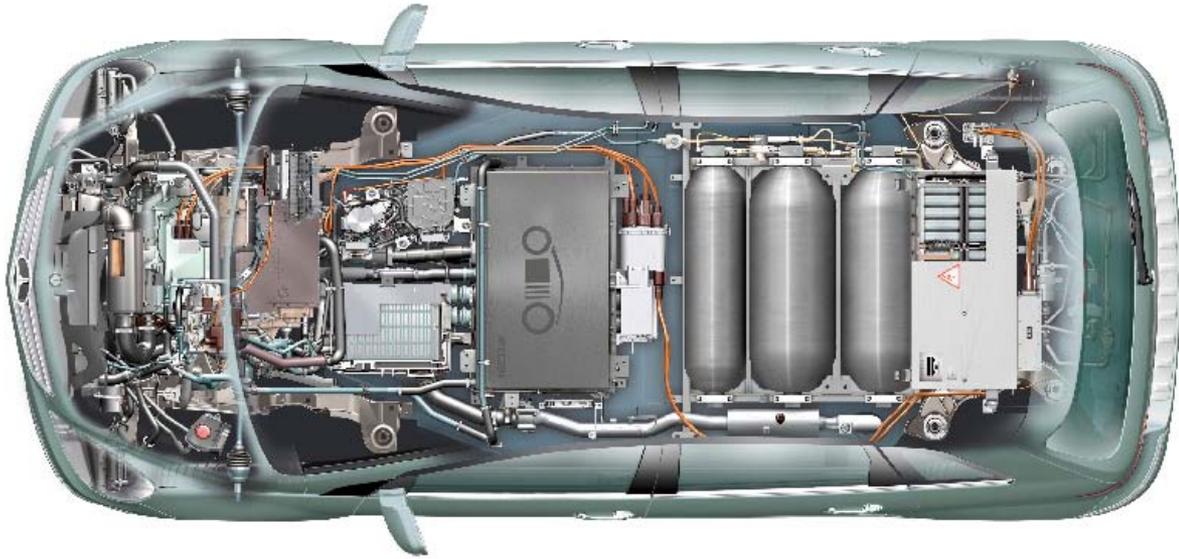


Photo credit: US. D.O.E.

Fuel Cells

- Fuel cells convert Hydrogen and Oxygen into water, electricity and heat.
- Fuel cells require significant amount of Platinum, currently selling at approx. \$1550/Oz.
- Fuel cells are easily poisoned by impurities in hydrogen, especially CO. CO is a by-product of the most popular method of Hydrogen extraction, Steam reforming of Methane. Service life of automotive fuel cells is a challenge.



One of the latest fuel cell designs

Decision Making for Fuel Economy : Technology Matrix

	Technology/Price	Fuel economy	Range	Fuel/Availability
Gas direct injection				
Diesel				
Hybrid				
Flex Fuel-E-85				
CNG				
Plug in hybrid				
Range extender electric				
Hydrogen				

Source: SAE Hybrid Symposium, Synovate data, Feb 2007

Summary

- To transition away from fossil fuels there is no single solution.
- All “sustainable” alternatives have a role to play in future transportation
- All “sustainable” alternatives have pros & cons
- We are NOT “energy independent” in electric drive technology
- We ARE “energy independent” in renewable fuels
- Only wind, solar, geothermal and nuclear energy sources are truly Carbon free.