FREEDOMCAR AND THE HYDROGEN ECONOMY

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Abstract

There has been a great deal of talk over the past few years revolving around the concept of the upcoming 'hydrogen economy.' For a myriad of reasons the need to develop new forms of energy are becoming increasing vital. Political, environmental, and security issues globally are forcing us to look beyond the use of fossil fuels to feed our growing energy needs. It is apparent that a concerted effort is going to be required to force the movement to new forms of energy for our next generation vehicles.

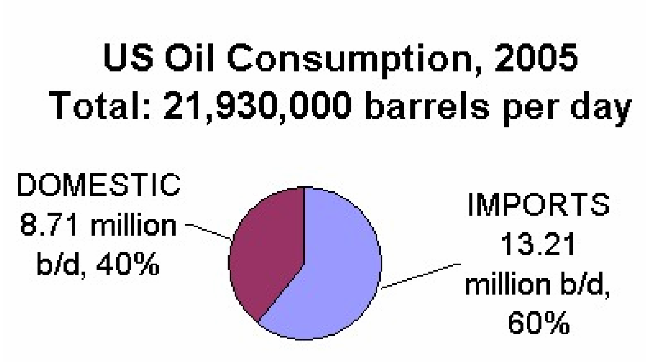
To accelerate the movement to hydrogen as a form of fuel, the government has been taking an ever increasing role in promoting the development of technologies necessary to achieve the goals for this evolutionary technological leap.

This paper summarizes the existing and rapidly approaching problems with our present automotive fossil fuel resources, discusses some of the benefits and issues with converting to fuel cell automobiles, and presents some of the efforts currently being funded by the government to overcome these hurdles.

The Problem

Some alarming facts:

- The United States (U.S.) presently consumes approximately 20 million barrels of oil a day. America comprises less than 5% of the worlds' population while using roughly 25% of its oil, the vast majority of which must be imported.



http://www.gravmag.com/oil.html#consume

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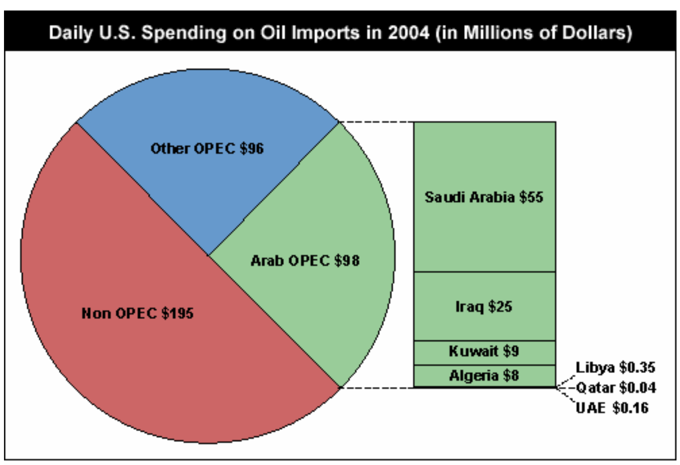
* Prepared by Oak Ridge National Laboratory, managed by UT-Battelle, LLC, for the U.S. Dept. of Energy under contract DE-AC05-00OR22725.

Top World Oil Consumers, 2004*		
	Country	**Total Oil Consumption (million barrels per day)**
1)	United States	20.7
2)	China	6.5
3)	Japan	5.4
4)	Germany	2.6
5)	Russia	2.6
6)	India	2.3
7)	Canada	2.3
8)	Brazil	2.2
9)	South Korea	2.1
10)	France	2.0
11)	Mexico	2.0
**Table includes all countries that consumed more than 2 million bbl/d in 2004.*		

Top World Oil Net Importers, 2004*		
	Country	**Net Oil Imports (million barrels per day)**
1)	United States	12.1
2)	Japan	5.3
3)	China	2.9
4)	Germany	2.4
5)	South Korea	2.2
6)	France	1.9
7)	Italy	1.7
8)	Spain	1.6
9)	India	1.5
10)	Taiwan	1.0
**Table includes all countries that imported more than 1 million bbl/d net in 2004.*		

http://www.eia.doe.gov/emeu/cabs/topworldtables3_4.html

- We spend nearly $300,000/minute overseas to purchase foreign oil, much of it from parts of the world controlled by unstable governments, or governments with somewhat questionable allegiance to the U.S.

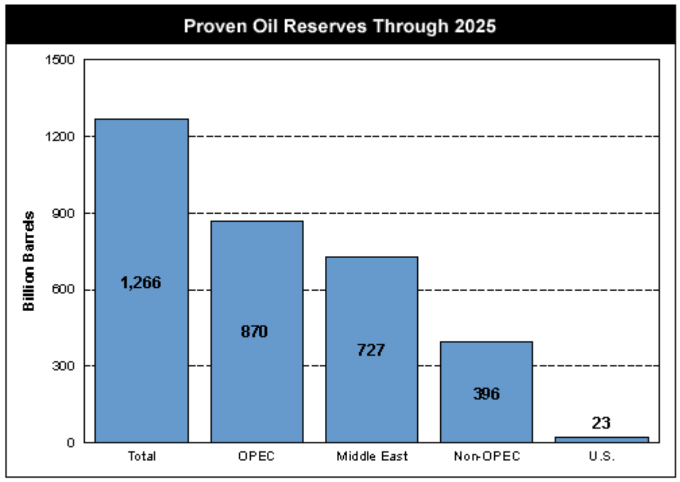


Source: NRDC analysis of Energy Information Administration imports and crude oil spot prices in 2004

- Oil consumption in the developing world, particularly in China and India, represents the fastest growing increase in the demand for oil. These countries are expected to continue their industrial growth and increase their energy needs at a rate of 7% and 5.5% per year respectively.

- The International Energy Agency recently announced that the demand for energy is growing at the fastest rate in 24 years. It is anticipated that worldwide oil consumption will only increase.

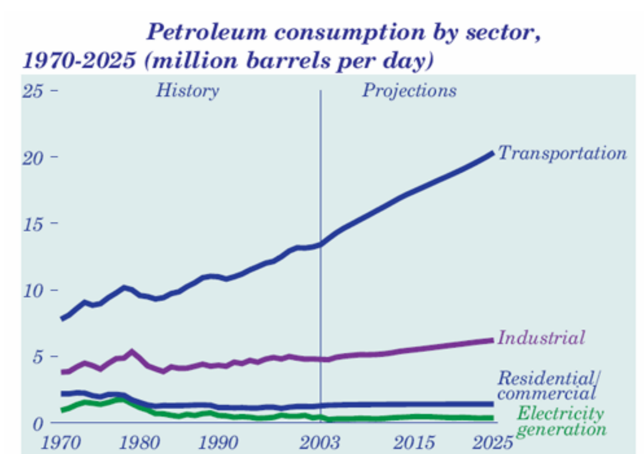
- It is projected we may only have approximately 40 years of reasonably cheap recoverable crude oil remaining.



Source: Energy Information Administration, *Annual Energy Outlook* 2004

- Highway vehicles are currently responsible for over 60% of the carbon monoxide and about 20% of greenhouse gas emissions produced in the U.S.

- The transportation sector is the largest oil consuming sector in the United States. It accounts for 2/3rds of our annual oil consumption.



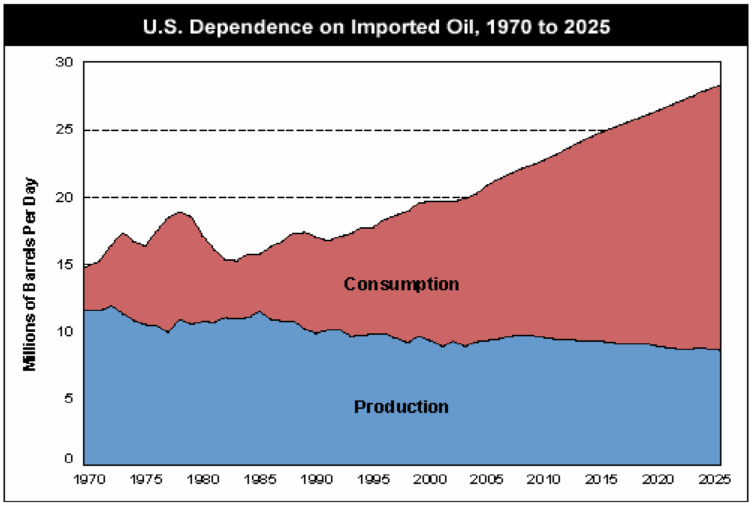
History: Energy Information Administration, Annual Energy Review 2003, DOE/EIA-0384(2003) (Washington, DC, September 2004).
Projections: Table A11.

Released: February 2005

Against this backdrop of disturbing statistics, the necessity for developing new forms of energy to fuel our every increasing automotive needs is glaringly obvious.

By converting to alternate fuel forms, specifically hydrogen, we have the opportunity to accomplish significant benefits.

- Reducing Dependency on Foreign Oil
  Reliance on foreign oil threatens U.S. economic stability due to the uncertainties surrounding available supplies and unpredictable costs in the marketplace. Ramifications of an uncertain oil supply for an economy which depends on this energy source for nearly 3/4ths of its power production can present serious economic consequences as fluctuations occur.



Source: Energy Information Administration, *Annual Energy Outlook 2004*

- Reduction of Greenhouse Gas Emissions
  Every gallon of gasoline consumed in an automobile results in the emission of 5lbs of carbon dioxide gas into the atmosphere. It is believed these emissions are gradually raising the temperature of the planet. It is postulated dramatic climate changes will ultimately occur causing severe environmental effects unless this process is curtailed.

- Reducing Air Pollution
  Internal combustion engines (ICEs) produce poisonous carbon monoxide, nitrogen oxides, and unburned hydrocarbons. These last two components combine in sunlight to create smog and can result in serious health problems including emphysema, chronic respiratory diseases, and fibrosis.

- Improvements in Energy Efficiency
  ICEs capture less than 30% of the energy in the gasoline they consume. Fuel cells can convert 40–65% of hydrogen's energy into electricity.

The Hydrogen Alternative

An affordable source of hydrogen and the development of reliable, cost effective fuel cells are the keys to achieving the goals of a hydrogen economy.

Although hydrogen exists as the most plentiful element in the universe, reserves of it don't occur naturally on Earth. Hydrogen must be extracted from other sources containing hydrocarbons such as natural gas or oil, or from water, which involves expending energy. Today approximately 70% of the electricity in the U.S. comes from coal and natural gas power plants. To convert to hydrogen powered automobiles, our national electrical generating capacity would need to increase significantly.

Serious problems exist with utilizing hydrogen as a fuel in automotive applications, even if production issues are overcome. It is a general consensus that to make automobiles acceptable to consumers in the marketplace, they need the ability to travel at least 300 miles between refueling. A gallon of gas contains about 2600 times the energy of a gallon of hydrogen. To achieve anywhere close to the energy density needed to emulate that of gasoline, the hydrogen gas will need to be compressed and stored at extremely high pressures. At these high pressures, cars will require much larger fuel tanks, taking up to several times the volume of a present day gas tank.

Aside from production and storage issues, delivery, safety, and public acceptance loom as formidable obstacles to overcome. Not to mention cost and reliability. Current fuel cell technologies are expensive and high temperature fuel cells are prone to material breakdown and shortened operating lifetimes.

The Government Role

The need for alternative automotive technologies to power the next generation of vehicles has been foreseen for some time. In 1993, The Clinton/Gore Administration initiated the Partnership for a New Generation of Vehicles (PNGV), a partnership between the federal government and the U.S. Council for Automotive Research (USCAR), whose members include DaimlerChryser, Ford, and General Motors. The goal of the partnership was to plan and manage research and development activities resulting in increasing the efficiency of conventional vehicles, and develop technologies for a new class of vehicles with up to 80 mpg without sacrificing affordability, utility, safety, and comfort. There were specific targets and milestones created to chart the progress of this program to 2004, at which time production vehicles were to be on the road. Although the program began without a targeted vehicle technology, during the first few years the focus was channeled primarily into ICE /hybrid vehicles.

In 2001 when the Bush Administration came to Washington and the PNGV program was reinvented. PNGV evolved into the FreedomCAR program. No longer was a midsize sedan the overriding vehicle target. By this time the popularity of the SUV had greatly diminished the market value of the sedan. The program became concentrated on technologies rather than a single vehicle, with the understanding that technological advances could be applied across different vehicle platforms. It also took on 2010 and 2015 targets addressing both hybrid and fuel cell powered vehicles along with technology targets to enable the transition to a hydrogen economy.

Today, the Department of Energy’s FreedomCAR and Vehicle Technologies Program (FCVT) oversees and coordinates research activities in four major areas. Within each of these areas, multiple sectors of research have been identified.

- Vehicle Systems Technologies
    - Heavy Vehicle Systems
    - Energy Storage Technologies
    - Advanced Power Electronics and Electric Machines
    - Hybrid Systems
    - Testing and Evaluation
    - Electric Vehicles
    - Ancillary Systems
- Advanced Materials Technologies
    - Propulsion Materials
    - Lightweight Materials
    - High Temperature Materials
- Fuels Technologies
    - Advanced Petroleum Based Fuels
    - Non-Petroleum Based Fuels
    - EPAct

    - Environmental Impacts
- Engine and Emission Control Technologies
    - Combustion and Emission Control
    - Light Truck Engines
    - Heavy Truck Engines
    - Engine Boosting
    - Off Highway Vehicles

Power Electronics and Electric Machinery research is devoted to realizing the FCVT goal of achieving future fuel cell powertrains with costs comparable to convention ICE/automatic transmission systems. Specifically, the propulsion system must deliver at least 55 kW for 18 seconds and 30 kW of continuous power at a system cost of $12/kW peak while maintaining a 15 year life.

In the interim, before the move to the hydrogen economy, FreedomCAR goals have been established for both hybrid electrics and ICEs operating on hydrogen.

Specific areas of research in power electronics are concentrated on long term, novel advances in the field. Challenges exist in expanding temperature capabilities of electronic systems, developing cost effective motors, and reducing the weight and volume of both power electronics and motors. Currently research is being performed at national laboratories, universities, and within industry on all facets of these challenges.

Efforts are underway to develop new inverter topologies. These include combining functionalities within modules to reduce size and cost. Ongoing projects include tasks aimed at the integration of multiple inverters into a single unit which shares components to reduce size and cost, the development of a novel power conversion module which combines a converter in the front end of an inverter with minimal components and increased reliability, as well as new cascade inverter topologies.

Direct current (dc) to dc converter research efforts have increased over the past few years as new hybrid systems with varying dc bus voltage levels are emerging. Both unidirectional and bidirectional topologies are being developed under the FCVT program. Integration and modularity in designs are being optimized as well as the development of new topologies and innovations to reduce or eliminate magnetic components.

New semiconductor materials are being examined for use in these applications. Silcon carbide (SiC) and gallium nitride (GaN) switches and diodes are being evaluated to determine their benefit in future automotive applications. The ability of these wide-bandgap devices to operate at higher temperatures and faster switching speeds with lower losses are currently being assessed. Ultimately, the use of these components may result in significantly reduced cooling requirements and a reduction in the size of passive components thereby leading to cost and volume benefits.

Capacitor research is a strong emphasis as the need for higher temperature, smaller, less costly dc bus capacitors has been realized. Film and ceramic capacitors are being developed to tolerate the harsh environmental conditions that fuel cell and hybrid vehicles will be subjected to. Investigations are underway on new dielectric materials to minimize size while increasing the operational temperatures of these components.

As part of the FCVT program, research is ongoing to develop low cost, high temperature bonded and sintered magnets for use in permanent magnet motors.

In concert with the pursuit for new magnetic materials, novel new motor designs are continually being developed. Research and development (R&D) efforts are underway on new high speed motors as well as different methods of extending the constant power speed ratio through innovations in motor and inverter designs.

High temperature packaging is an area in which a lot of attention is now being directed. New methods to reduce the thermal resistances between dies and the baseplates are being investigated. Means of eliminating wire bonds and achieving double sided cooling of devices are being studied. In the field of thermal control, new packaging methodologies for inverters as well as different cooling methods utilizing two-phase techniques such as spray and jet impingement cooling are being researched.

While efforts continue to reduce the size, weight, and volume of the drivetrain system these improvements must be realized while simultaneously reducing costs in order to gain customer acceptance of these advanced electric, hybrid, and fuel cell vehicles of the future.

Summary

The transportation sector currently consumes two-thirds of the petroleum used in the U.S. America's transportation system is over 95% dependent on petroleum as an energy source. Highway vehicles are responsible for over 60% of the carbon monoxide emissions and approximately 20% of the greenhouse gas emissions.

The FreedomCAR program is pushing technological advances through it's commitment to the advancement of hydrogen fueled vehicle technologies. The program is focused on long term, far reaching advanced automotive developments which will ultimately lead to reductions in oil imports and air pollutants resulting in a more stable economy, increased domestic security, and a healthier populous.

However, the move to a hydrogen economy is still in its early stages. Considerable problems exist with the development of this vision. Hydrogen production, delivery, and storage, fuel cell cost and durability, safety and public acceptance of this technology all present hurdles that must be overcome.

In the interim, R&D resulting in continued innovations which serve near term hybrid vehicle development can provide stepping stones in the move to fuel cell vehicles to ultimately provide a clean and sustainable transportation energy future.