Air

$CO + H_2O \rightarrow H_2 + CO_2$

$O_2 + 4e^- \rightarrow H_2 + 2O^-$

Heat

Fuel

Oxidant

Changing International Face of Transportation and Energy

Dr. Mark C. Williams
Director, Research
URS Corporation
Visiting Professor, Tohoku University

Transportation and Energy - Walking Hand in Hand

50 million are sold annually – Japan may be the world's largest producer

China and US are the enormous markets

When will this trend change? If US and China consume 40% of the world's depleting oil reserves, what will the rest of the world use?

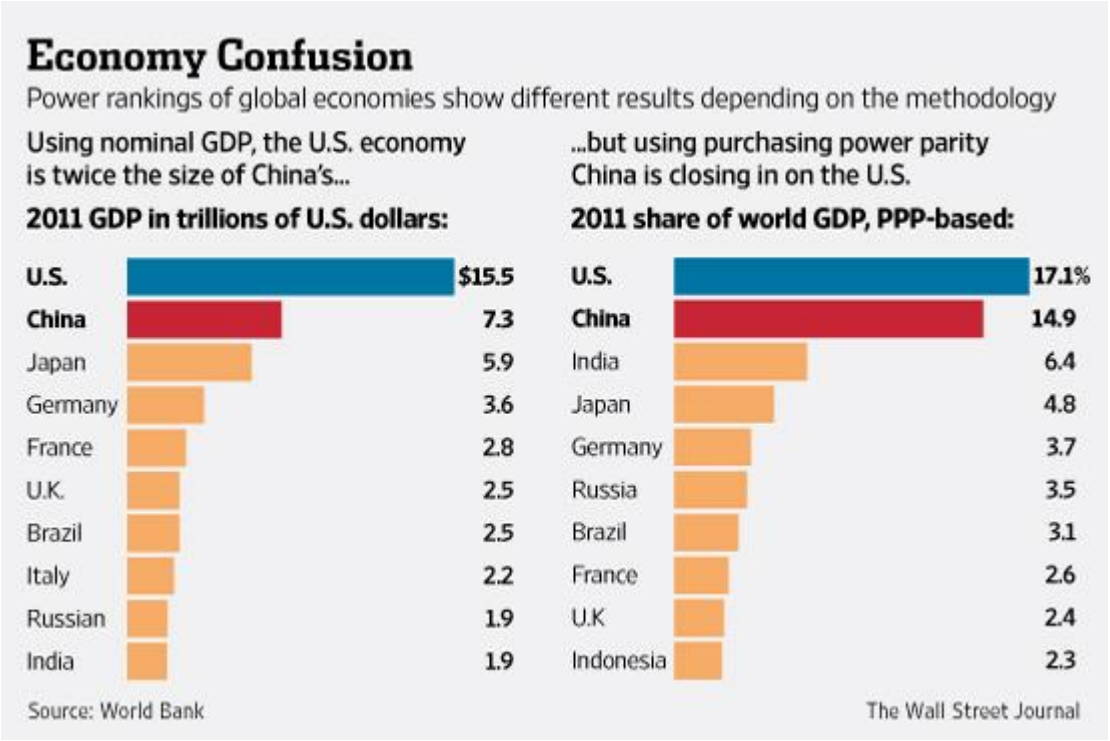
Source: Toyota

2012 World Oil Consumption (EIA)

(million of barrels per day

>10	China (10.3) United States (18.6)
7-10	
4-7	Japan (4.7)
2-4	Brazil (2.8) Canada (2.3) Germany (2.4) India (3.6) Korea, South (2.3) Mexico (2.1) Russia (3.2) Saudi Arabia (2.9)
1-2	Australia (1.1) France (1.7) Indonesia (1.4) Iran (1.7) Italy (1.4) Netherlands (1.0) Singapore (1.4) Spain (1.3) Thailand (1.0) Taiwan (1.1) United Kingdom (1.5)
<1	202 countries

China Closing in…what does it mean… purchasing power

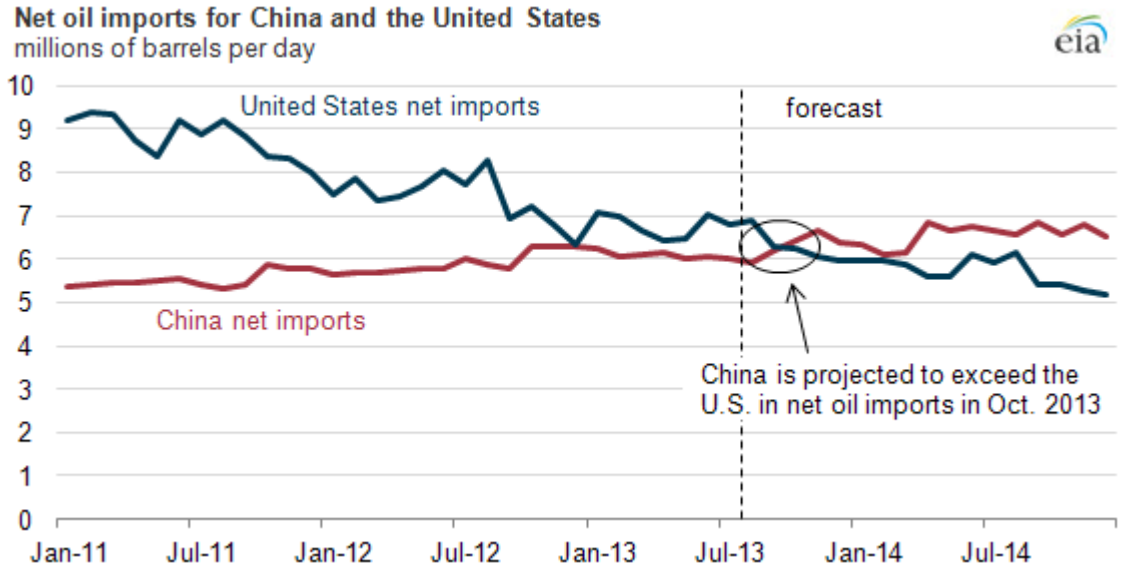


Espionage Impact on Innovation: Losing the Future

- Economic espionage represents “the greatest transfer of wealth in history,” General Keith Alexander, NSA director and commander of U.S. Cyber Command (2014)
- $500 billion in raw innovation is stolen from U.S. companies each year. Raw innovation includes trade secrets, research and development, and products.
- “To put it into perspective, the U.S. will take in $1.5 trillion in income taxes and $2.7 trillion in all taxes in 2013,” Casey Fleming, CEO of BlackOps Partners Corporation

China Now World's Largest Oil Importer

China is the world's most populous country with a fast-growing economy that has led it to be the largest energy consumer in the world



Types of Primary Energy

- **Primary Energy (Stored and Real time)**
  - Oil
  - Coal
  - Natural Gas
  - Biomass
  - Nuclear
  - Solar
  - Wind
  - Hydro
  - Geothermal



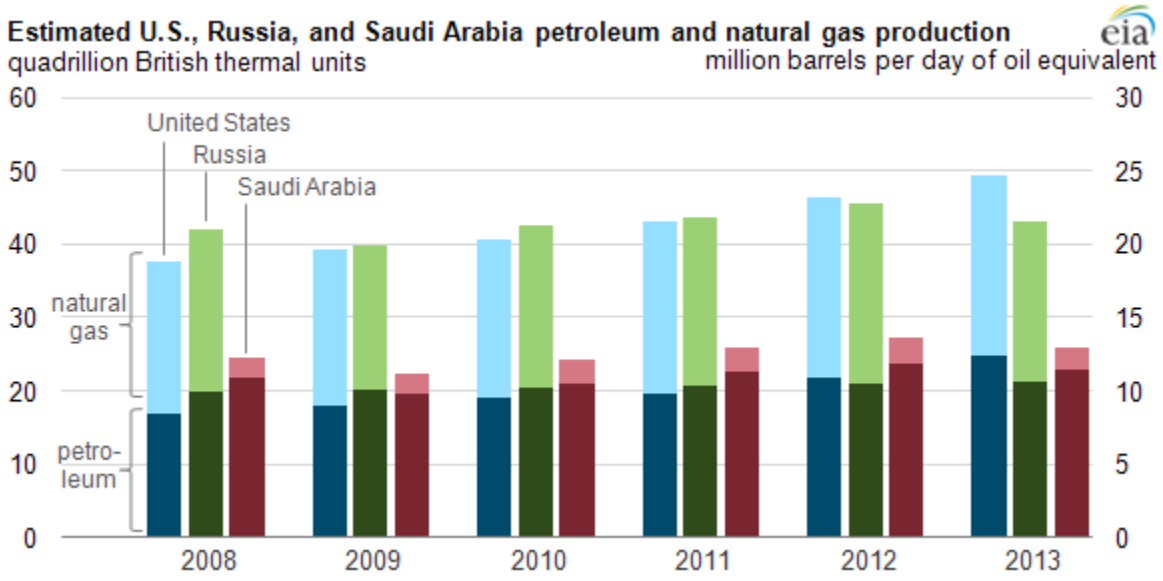





USA Petroleum Transportation Facts

- The world produces/consumes 80 million BBL/day petroleum products
- USA consumes 20 million BBL/day (7 billion BBL/year) petroleum products
- In USA around 2/3 is used for transportation
- Oil is currently $90-100/BBL
- USA imports 8 MM BBL/day
- $300-500 billion/year trade deficit

USA is Now World's Largest Oil and Natural Gas Producer



Oil: where do imports come from for USA?

- **The world is rapidly consuming the finite amounts of stored energy, especially petroleum.**
- **Canada (2-3 million BBL/day - half from tar sands) and Middle East (Saudia Arabia/Kuwait) (1.5 million BBL/day) help supply USA petroleum. Rest are Mexico, Venezuela, Columbia, and Russia.**
- **Canada tar sands contain 300 BBL, one of the world's largest resources ever known, would supply USA for only 40 years. The relentless hunt for oil will continue to the limit of economic viability.**
- **Major expansion in Canadian production expected in near future. North America expected to become world's largest producer.**
- **Canada's largest single source of income and CO2 emissions.**

Geography

Image courtesy of: Norman Einstein

Ft McMurray

- **225 miles to Edmonton**
- **400 miles to Calgary**
- **1300 miles to Denver**

USA Imports Dropping

U.S. Imports of Crude Oil and Petroleum Products (Thousand Barrels)

2000	314,334	319,073	342,602	346,738	353,879	360,960	359,227	377,352	356,996	350,000	339,272	373,653
2001	389,212	326,012	376,103	379,586	388,410	351,959	364,564	360,271	354,529	352,734	348,854	340,804
2002	343,737	305,310	347,145	352,954	364,849	352,585	360,334	368,598	332,235	368,676	368,027	344,088
2003	344,222	305,797	373,370	377,975	400,473	390,023	394,816	395,844	386,032	383,549	351,369	373,031
2004	372,434	367,082	413,811	386,490	414,625	406,817	420,662	424,354	380,278	416,566	402,259	405,726
2005	402,720	384,977	410,119	404,284	434,174	428,105	431,684	429,276	396,864	440,459	422,882	419,997
2006	427,676	379,819	400,010	403,136	443,758	427,579	433,491	455,595	434,721	412,818	390,135	394,344
2007	424,880	340,839	432,648	415,258	440,339	406,587	426,374	422,663	409,380	402,396	395,643	398,950
2008	420,616	367,143	390,528	399,944	399,957	401,942	406,854	406,644	346,859	409,269	386,421	390,817
2009	406,925	338,661	385,841	358,846	355,774	358,083	366,727	346,658	352,675	337,212	333,152	326,556
2010	350,315	314,452	360,262	375,769	376,383	373,317	392,915	383,045	354,677	345,415	332,884	345,099
2011	377,114	298,861	364,400	352,372	366,004	354,169	362,220	345,990	336,767	341,161	334,689	340,463
2012	338,215	304,201	328,759	318,315	344,637	342,727	334,604	337,268	314,256	311,468	305,442	298,960
2013	311,312	258,578	293,125	302,265	311,620	293,713	317,538	316,119	299,380	297,359	279,224	294,548
2014	287,188	256,241	286,437									

USA Energy Independence Now Possible with Conservation

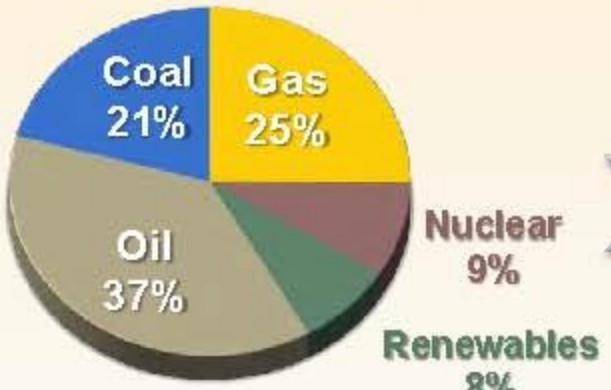
- USA World's Largest Oil Producer
- USA Largest NG Producer
- Still imports 300,000,000 BBL/month
- Cost $1 billion/day
- Opportunity with demand side management to lower consumption through higher automobile fleet efficiency
- 2/3 oil used for transportation
- Opportunity for improvement in stationary power generation with fuel cells
- Opportunity to be energy independent…which means not funding terrorism?

Coal: Transitioning to a Sustainable Energy Future

- **In 2012 40% of the world's electricity needs were provided by coal. Coal is the second source of primary energy after oil. (IEA)**
- **China produces 4.0 billion tons of coal per year (EIA)**
  - China is consuming its coal resources faster than any nation
- **USA produces 1.0 billion tons of coal per year (EIA)**
- **Coal use in North America is being discouraged by environmentalists**
- **Coal may still be mined in NA and exported to countries giving them a low-cost energy advantage**
- **Coal's use world-wide is accelerating.**
- **Coal may last only 150 years**

Energy Demand 2010

98 QBtu / Year
83% Fossil Energy



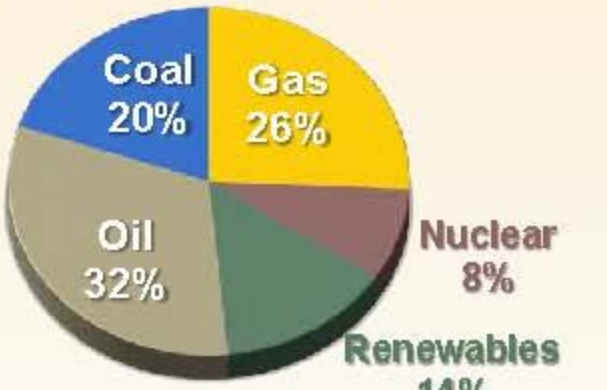
5,634 mmt CO_2

+ 9%

United States

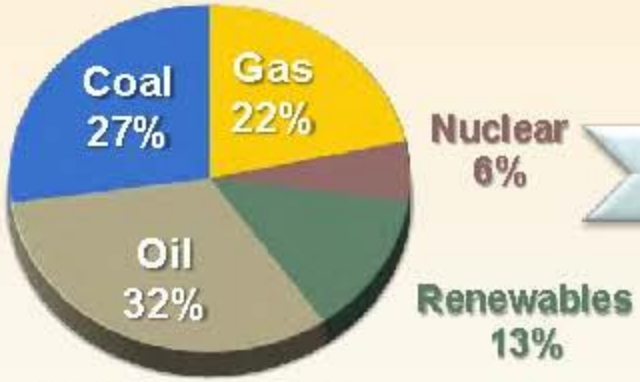
Energy Demand 2035

107 QBtu / Year
77% Fossil Energy



5,758 mmt CO_2

505 QBtu / Year
81% Fossil Energy

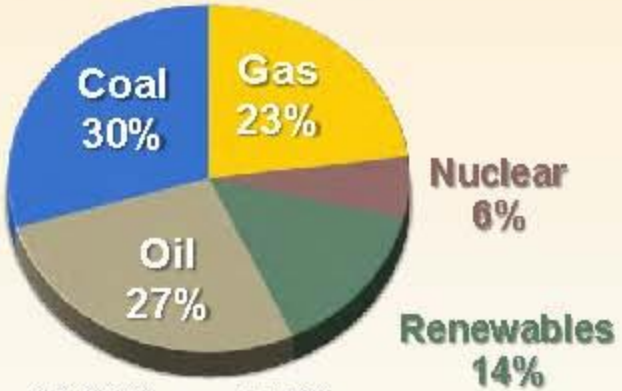


30,190 mmt CO_2

+ 47%

World

741 QBtu / Year
80% Fossil Energy



44,090 mmt CO_2

Sources: U.S. data from EIA, Annual Energy Outlook 2012; World data from IEA, World Energy Outlook 2012

Nuclear Power Plant Efficiency

- The fuel rods will spend about 3 operational cycles (typically 6 years total now) inside the reactor
- Generally when about 3% of their uranium has been fissioned, they will be moved to a spent fuel pool where the short lived isotopes generated by fission can decay away.
- After about 5 years in a spent fuel pool the spent fuel is radioactively and thermally cool enough to handle, and it can be moved to dry storage casks or reprocessed.
- There is no storage facility for nuclear waste in USA.
- In USA all nuclear waste belongs to the Department of Energy and hence to the American people.

Natural Gas

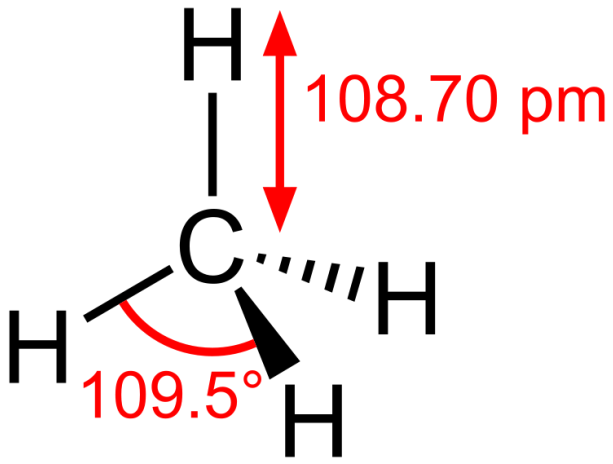
- **We will always have natural gas (methane) on this planet**

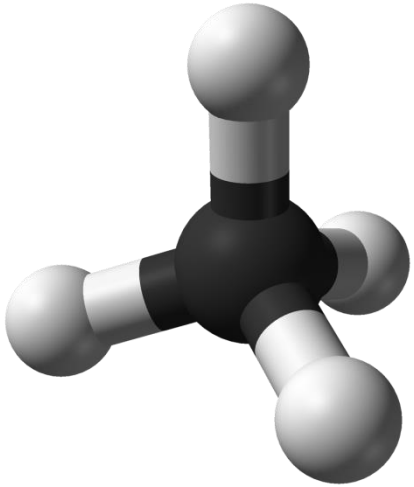
We benefit from the chemical energy extracted from sunlight on this planet

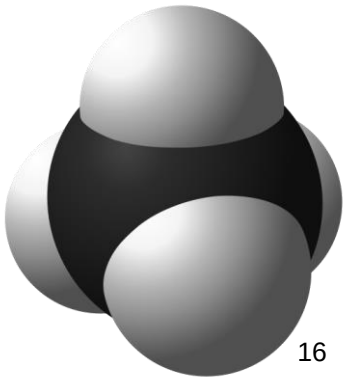
- Coal, petroleum and natural gas are stored chemical energy from the past

As long as there is life and sunlight, we will always have natural gas on this planet in the future

- Methane from human (ADG) and plant and animal and plant residues and wastes captured from sunlight are available



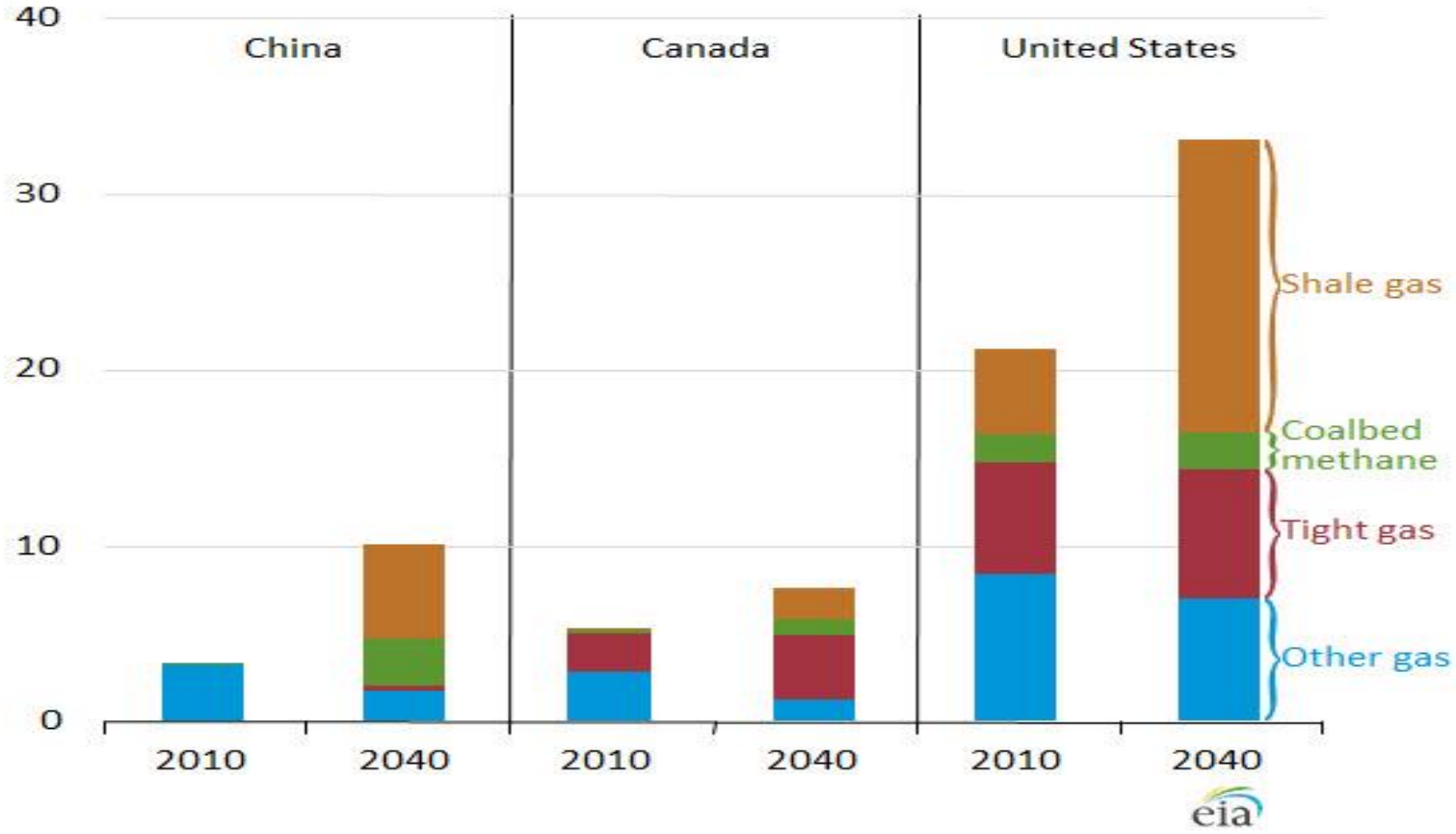




US surpasses Russia as world's top natural gas producer – larger than China and Canada

Figure 42. Natural gas production in China, Canada, and the United States, 2010 and 2040

trillion cubic feet



The Global Natural Gas Resource

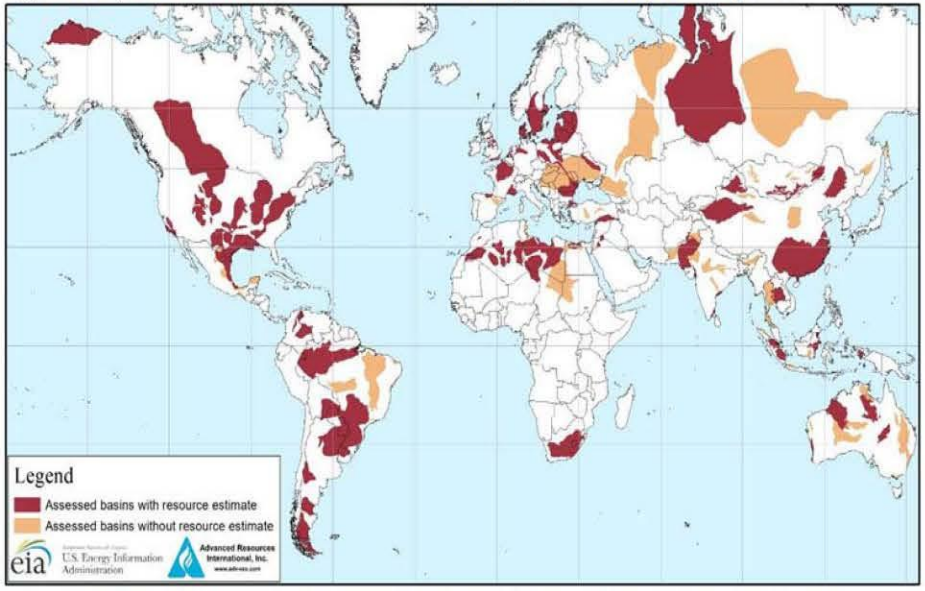
(The result of new science, technology, engineering, math and research)

Source: U.S. Energy Information Administration based on data from various published studies. Canada and Mexico plays from ARI.
Updated: May 9, 2011

The areal extent of US shale gas basins would cover more than half the country.

The areal extent of global shale gas basins would cover almost all of the western hemisphere.

Figure 1. Map of basins with assessed shale oil and shale gas formations, as of May 2013



Source: United States basins from U.S. Energy Information Administration and United States Geological Survey; other basins from ARI based on data from various published studies.

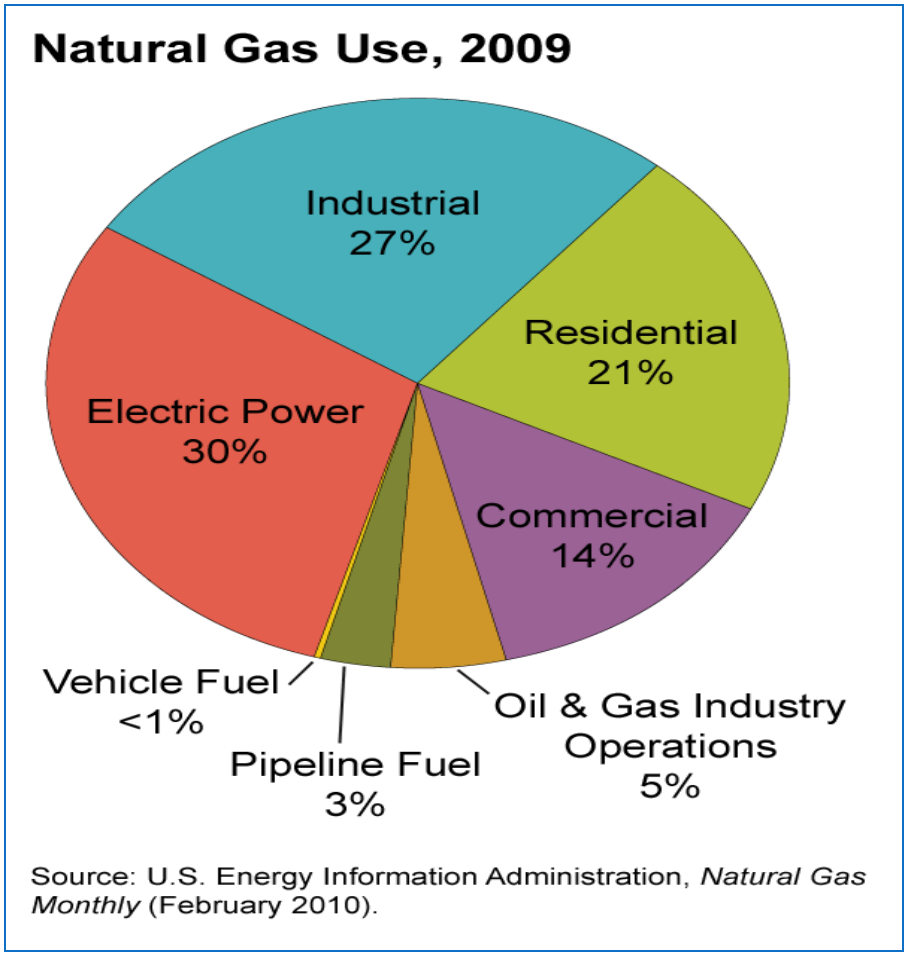
Methane Hydrates

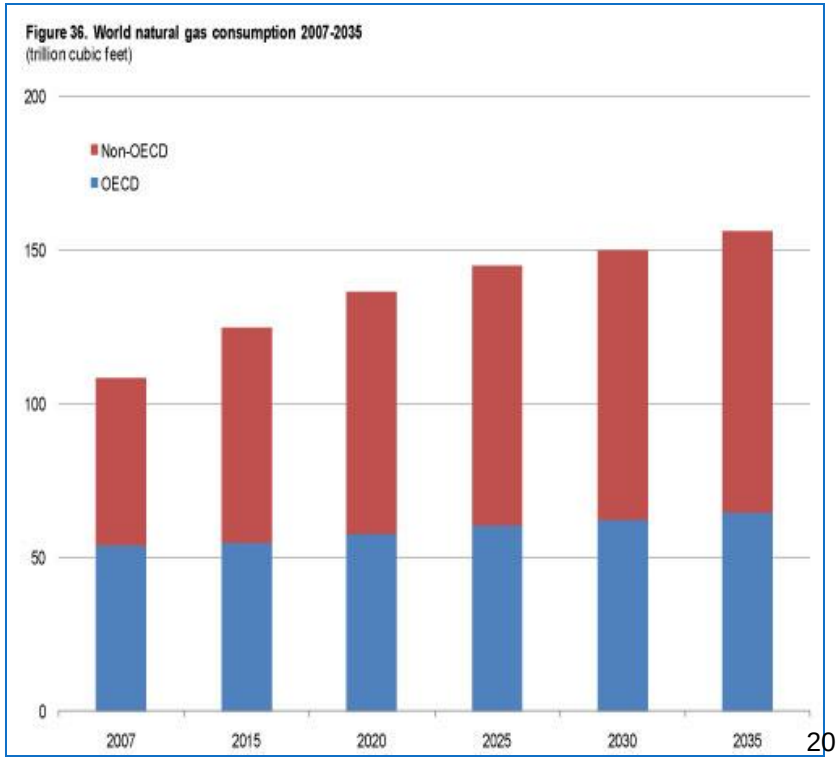
Energy's Next Frontier

- **Resource widespread and bountiful**
  - 50,000 Tcf offshore the U.S. Lower 48
  - 5,000 Tcf or more likely recoverable
- **Better characterization is needed**
  - Sampling and testing of deepwater deposits
  - Role in the natural environment
- **New technology is needed**
  - For safe, efficient extraction
  - Industry expenditure is negligible
- **International Collaboration**
  - Leveraging international funds to expand and accelerate research

Natural gas released from gas hydrate is flared during cooperative DOE-ConocoPhillips-Japanese scientific production test on the Alaska North Slope, March 2012

United States uses 23 trillion cubic feet/year (Tcf/yr) of NG





Stored NG and Transportation Facts

- **US consumes 20 million BBL/day petroleum products**
- **This is the energy equivalent of 27 Tcf/year NG**
- **At the PSU estimate, the Marcellus Shale, if only 1/3 was recovered, could replace US petroleum for transportation for only around 50 years**
- **NG at $5/MMBTU is the energy equivalent of**

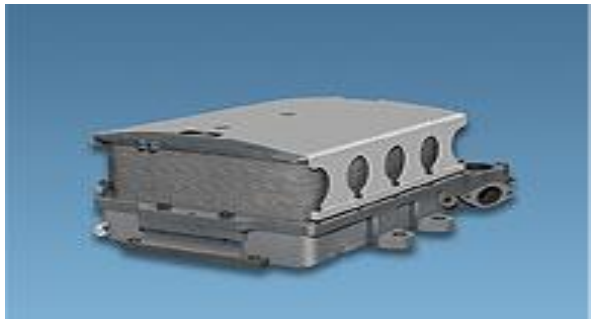
  $28 /BBL oil
- **Oil is currently $105/BBL**

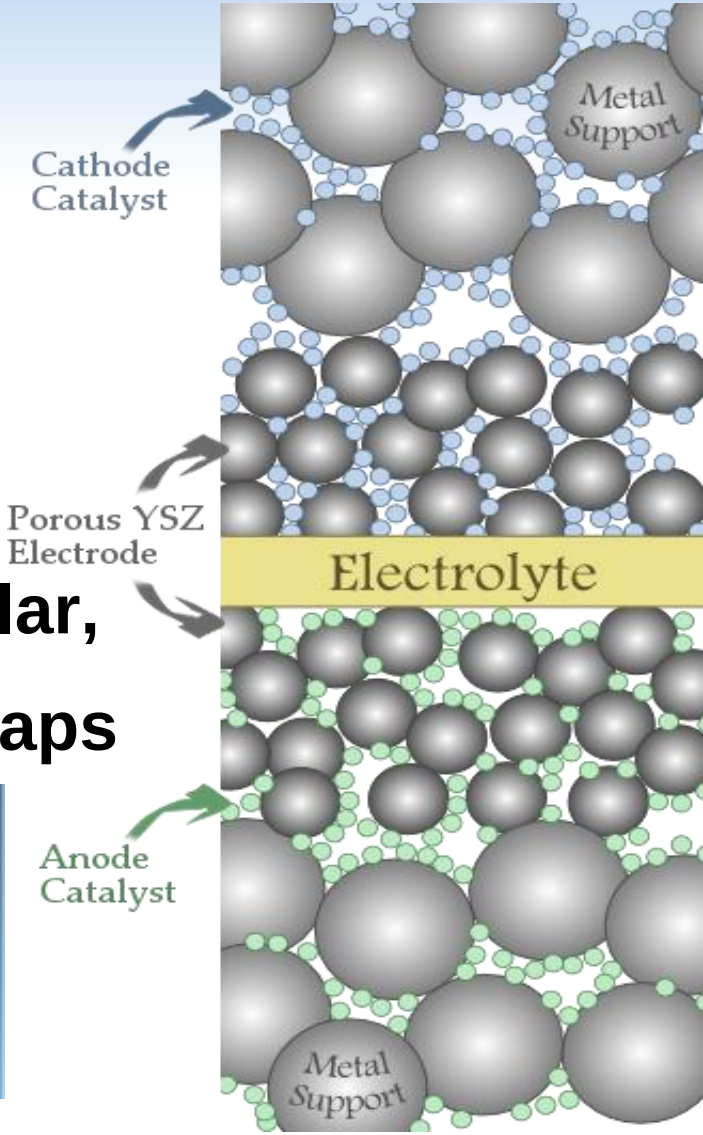
CNG Vehicles

- **Currently, the only natural gas light-duty vehicle manufactured in the U.S. is the Honda Civic ($26,000 list price; 24 city/36 hwy/28 combined gasoline equivalent mpg).**
- **Only roughly 110,000 of the 12 million CNG vehicles worldwide are in the U.S., including aftermarket conversions.**
- **There are roughly 250 million registered passenger vehicles in the US (EIA)**
- **Cost to convert vehicles to NG is estimated $12,500 to $22,500 depending on the vehicle, engine, size of CNG tanks needed, and who does the converting (Green Car Journal, 2011)**
- **Inadequate NG Infrastructure in USA**

Natural Gas Fuel Cells for Transportation

- **Natural gas fuel cells**
  - Direct methane
  - Internal reforming
- **Complete re-look**
- **Metal-supported planar or tubular, intermediate temperature, perhaps SOFC-type**
  - Durability
  - Efficiency





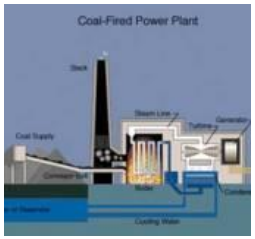
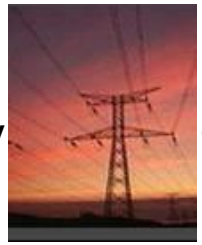
The Future

- **Oil, Coal and nuclear are finite stored energy**
- **These will be going away in the future**
- **These leaves solar, natural gas, biomass, wind, geothermal and hydro**

Powering the Electric Grid from Natural Gas, Biomass, Wind, Hydro, Geothermal and Solar

- **These fuels primarily support the electric electrical grids of the future**
  - Already beginning to happen in USA and Germany
  - First time in US history more electricity is being made from NG than coal
- **The use of this electrical energy for transportation and especially battery vehicles and plug-in hybrids is increasing.**
- **Electrification of local transportation through the electric grid will be key feature once oil is depleted**

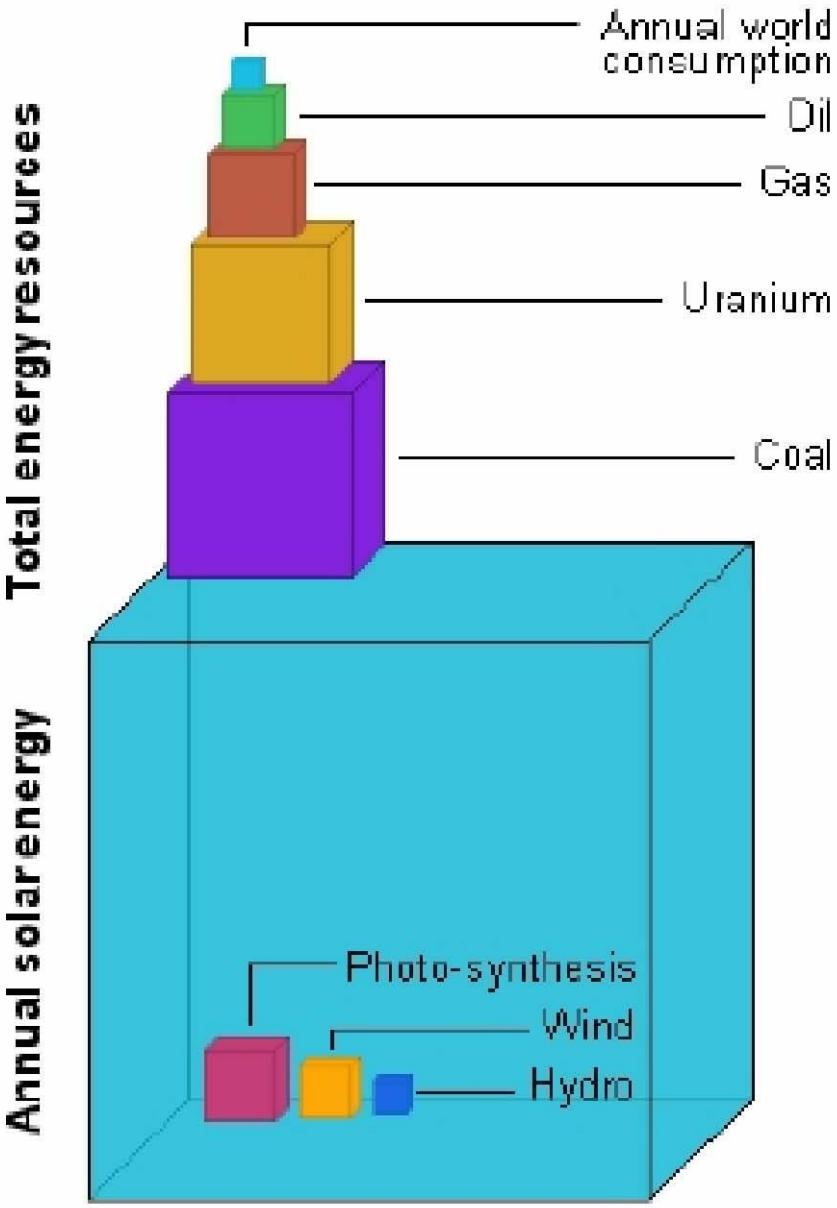
Transitioning from Energy Waste to Wise Energy Use

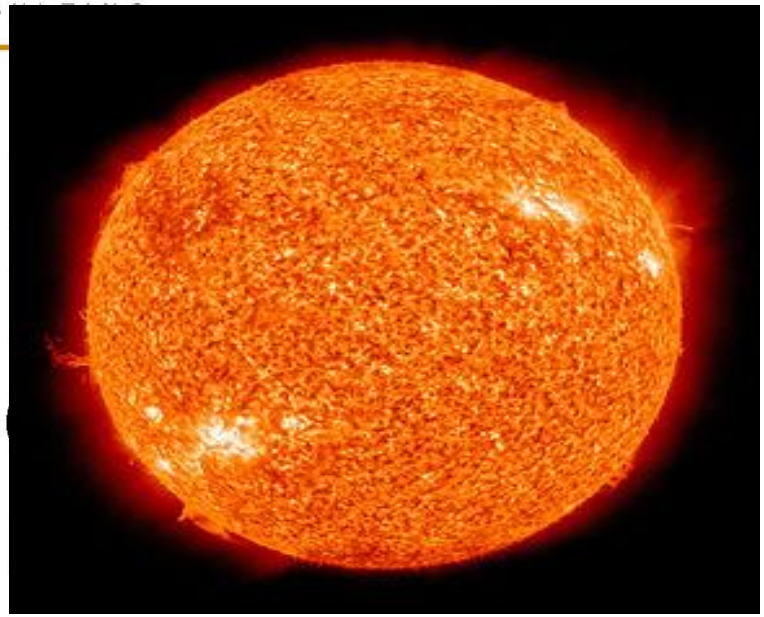
	Generation	Transmission	Distribution	End-Use
Current Technology				Ordinary Lighting 
coal	**electricity**	**electricity**	**electricity**	**~4 Overall Efficiency**
Today				
Loss per step	**~65% loss**	**~ 4.8% loss**	**~ 5.1% loss**	**~ 88% loss**

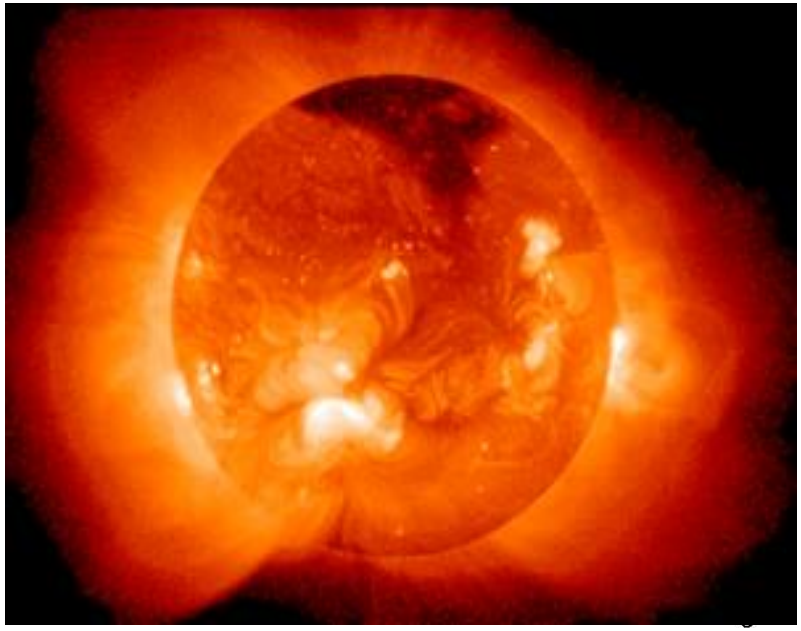
	Coal, gas, renewables		electricity		electricity	Solid-State Lighting
Tomorrow		FC Hybrids		Smart Grid		**~40 Overall Efficiency**
Loss per step		**~40% loss**		**~8% loss**		**~28% loss**

We can increase efficiency by more than **10x**!

Adapted from AEP, Ohio Fuel Cell Coalition, June 2009


Total energy resources
Annual world consumption
Oil
Gas
Uranium
Coal
Annual solar energy
Photo-synthesis
Wind
Hydro





Priority Research

- Light (solar performance and cost) - transportation and stationary
- Energy Storage
  - Natural gas on-board storage
  - Battery (performance and cost)
- Waste heat recovery
- H2 fuel cells for transportation for long distance
- Natural gas fuel cells for transportation
- H2 and fuel production directly from water, CO2 and light
- H2 and liquid fuels indirectly from water, NG and energy (light, thermal)