Electrochemical Technologies for the Transportation and Energy Industry of the Future

Dr. Mark C. Williams
Program Manager
AECOM
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

Types of Primary Energy

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








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**

Energy Conversion Technologies for Electrified Transport

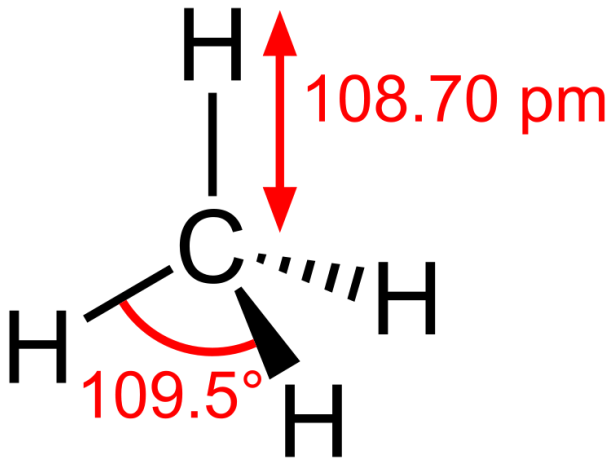
- Natural gas fuel cells represent conversion of chemical to electrical (c →e);
- Batteries and electrolysers/fuel cells, electrical to chemical to electrical (e → c →e);
- Hydrogen, chemical to chemical to electrical (c → c →e);
- Solar, light to electrical (λ→e); and
- Solar synthesis, light to chemical to electrical (λ → c →e).

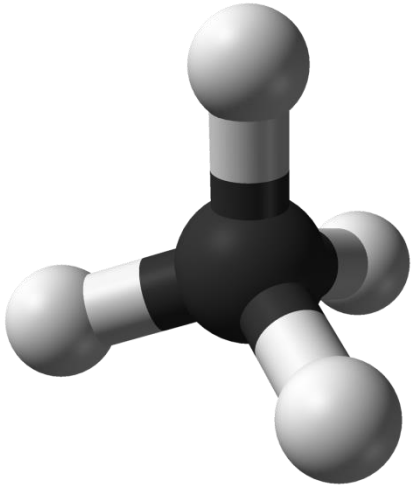
Natural Gas

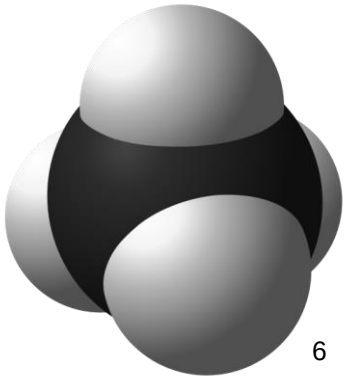
- **We will always have natural gas (methane) on this planet**

- **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

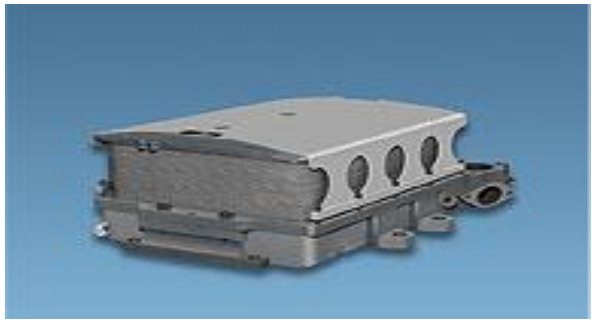


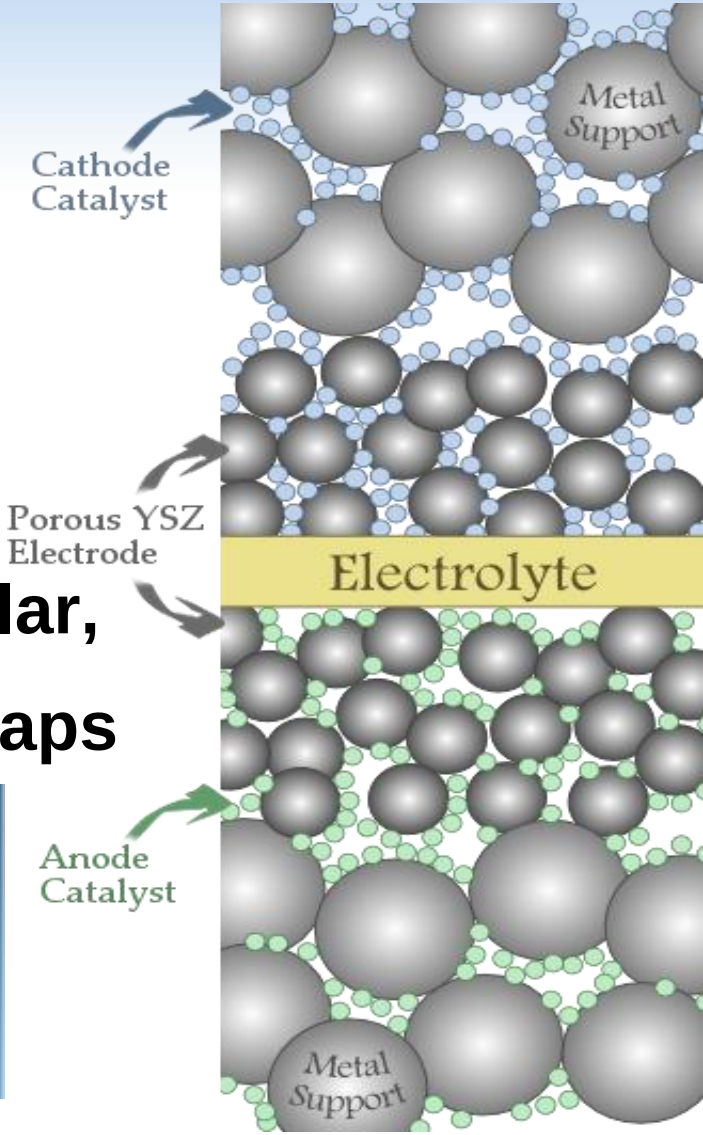




Natural Gas Fuel Cells for Transportation

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





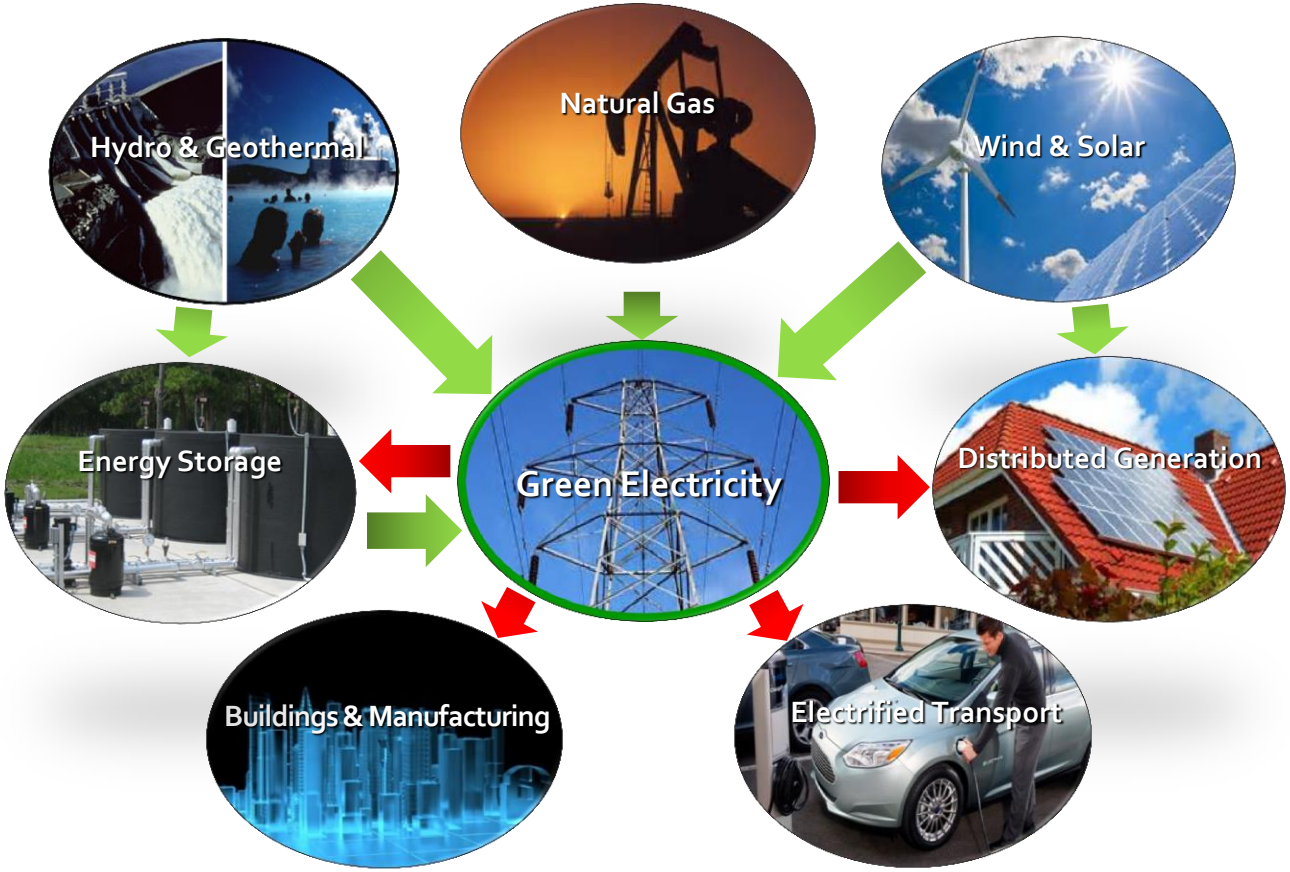
Hydrogen

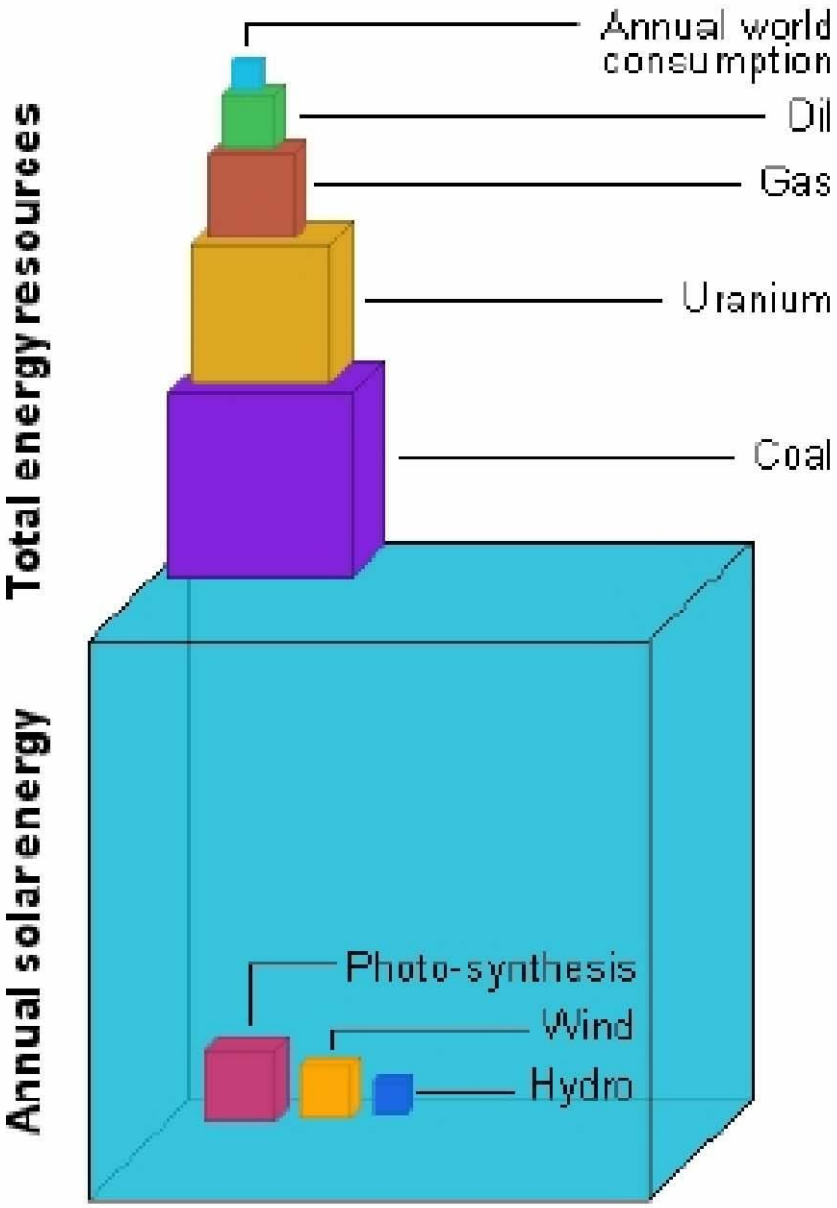
- **Hydrogen fuel cell vehicles will require a hydrogen infrastructure.**
- **Natural gas is currently the principle method to generate hydrogen. Production from renewable energy – wind, solar, geothermal and biomass is also possible for the future.**
- **The use of hydrogen for vehicles may require the development of two infrastructures – one for natural gas and one for hydrogen.**
- **In future H2 and fuel production could be directly synthesized from water, CO2 and light. H2 and liquid fuels could be indirectly synthesized from water, NG and energy (light, thermal).**

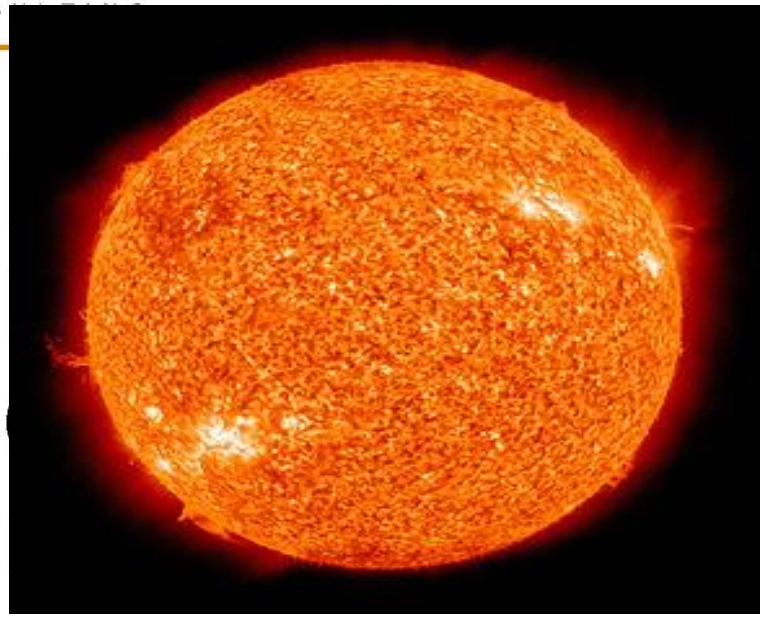
Batteries

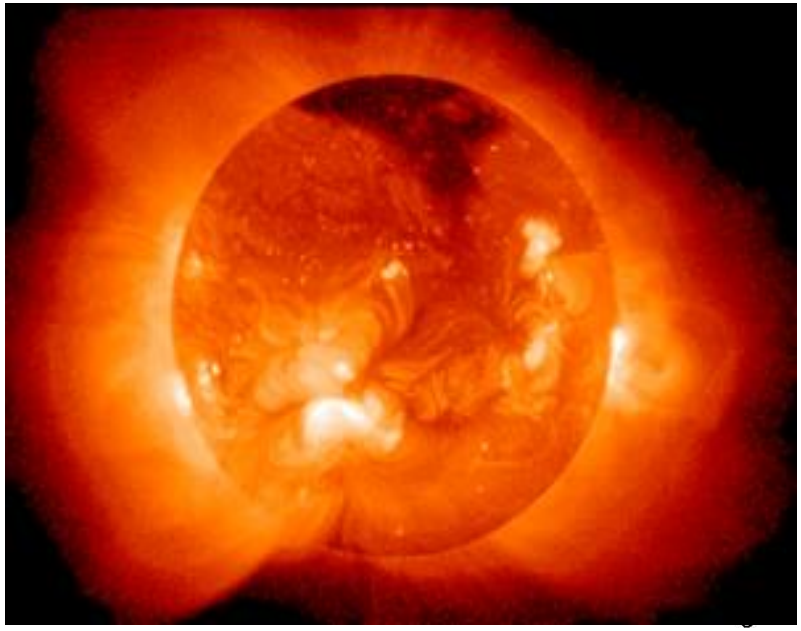
- **Battery/storage chemicals are a key possibility for the future. Electricity is needed to charge these chemicals.**
- **The chemical energy is then converted back to electrical energy. So it is in reality a way to store electrical energy.**
- **Electrolysers convert electrical energy and/or thermal energy into chemical energy. An electrolyser combined with a fuel cell is actually a rechargeable battery.**

Grid of Future




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





Priority Research for Electrified Transportation

- Light (solar performance and cost)
- Natural gas on-board storage
- Electrolyers/fuel cells
- Batteries (performance and cost)
- 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)