**CO₂ Sequestration**

- Grow more trees?
- Injection into oil wells?
- Saline aquifer injection?
- Fertilize the southern oceans?
- Deep ocean injection?

**DOE Research**

- Core R&D
  - Capture of CO₂
  - Measurement & verification of CO₂
  - Breakthrough Concepts
- Integration
  - DOE/Oxy Project
- Infrastructure
  - Commercial partnerships
  - Commercialization

**FutureGen Concept**

- Hydrogen Pipeline
- Refinery
- Electric Power Plant
- Coal-Fired IGCC
- CO₂ Pipeline
- Enhanced Oil Recovery
- Geologic Sequestration

**North American Coal Units**

- First Year of Operation
- Many coal plants will need to be replaced or repowered starting in 2020

**What is Oxy-fuel Combustion?**

- 1. Take salt brine from aquifer at high P
- 2. Slurry with coal
- 3. Convert in supercritical water reactor to generate steam
- 4. Reinject CO₂/brine solution

**BYU Proposal to GCEP**
Fuel Cells


http://auto.howstuffworks.com/fuel-cell2.htm

Fuel Cell Virtual Demo

Thermodynamics of H₂ Formation

• Combustion
  \[ \text{CH}_4 + 2\text{O}_2 = \text{CO}_2 + 2\text{H}_2\text{O (liq)} \]  \[ \Delta H = -212.8 \text{ kcal/gmol CH}_4 \]

• Reforming
  \[ \text{CH}_4 + \text{H}_2\text{O(liq)} = \text{CO} + 3\text{H}_2 \]  \[ \Delta H_{\text{rxn}} = +59.79 \text{ kcal/gmol CH}_4 \] (Energy needed!)

CO + ½ O₂ = CO₂  \[ \Delta H = -67.636 \text{ kcal/gmol CO} \]

H₂ + ½ O₂ = H₂O (liq)  \[ \Delta H = -68.317 \text{ kcal/gmol CO} \]

Net Reforming  \[ \Delta H = -212.8 \text{ kcal/gmol CH}_4 \] (same!!)

Enthalpy is independent of path!

If Enthalpy Is the Same, Why Do People Say We Lose Energy by Making Hydrogen?

• Entropy
  – Energy losses at each step of the reformation process!
  – Same for other processes (electrolysis, coal gasification)

H₂ Generation

• Reforming CH₄
• Coal gasification
  \[ \text{C} + \text{H}_2\text{O} \rightleftharpoons \text{CO} + \text{H}_2 \]
• Electrolysis
  \[ \text{H}_2\text{O} + \text{e}^- \rightarrow \text{H}_2 + \frac{1}{2}\text{O}_2 \]
  – Electricity from... coal, nuclear...
• Solar?
• Price???
  – Currently equivalent of $5/gal of gasoline
  – Target: $1.50/gal
  – Huge breakthroughs needed!

GM demo car running on H₂ with fuel cells
Cost: $1 million
Oops!

• We still get the CO₂ if H₂ is obtained from:
  – CH₄
  – Coal
  – Electricity!
• Sources that will give no net CO₂:
  – Not enough
  – Nuclear
  – Not enough
  – Not enough

Are we really supporting nuclear energy?

H₂ Storage

• Pressurized tanks?
  – 8X size of gasoline tanks for same energy
  – 2X efficiency
  – Net = 4X size
  – Weight of tank
• Liquid H₂
  – 30% of energy in H₂ for cooling to -253°C
• Metal Schemes?
  – Cost
  – Weight
  – Release rate of H₂

Transport/Infrastructure

• 1 gasoline truck = 1 H₂ tanker truck
• 1 H₂ tanker truck traveling 500 km consumes 40% of its cargo!
• Pipeline costs of 1.4% of energy per 150 km
  – Shipping from North Africa to Europe consumes 30-40% of energy
• Changing 30-50% of filling stations would require >$500 billion
• Not hard to make car into bomb

Solar CO₂ Converter

• Equilibrium chemistry favors CO at high T
• Zirconia rod melts at ~2700 K
• Demonstrated 10 mole-% CO
• Use with water-gas shift reactor

CO₂ + H₂O → CO₂ + H₂
• Recycle CO₂

• Net Reaction:
  Sun + H₂O → Heat + H₂ + 1/2O₂
  Heat used to generate steam

CO₂ Converter