Nuclear Energy in the Production of Fuels for Transportation

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High Temperature Electrolysis,
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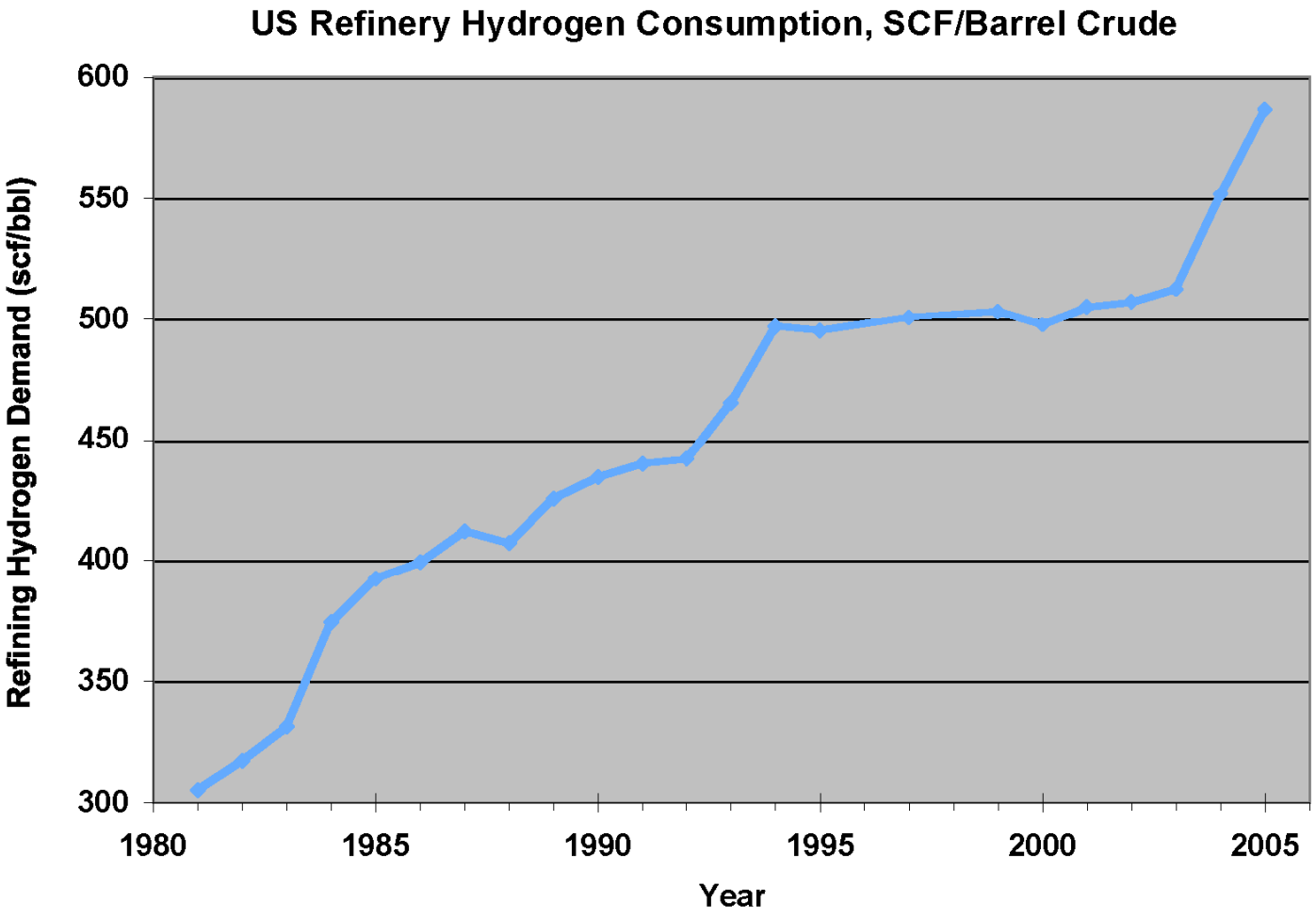
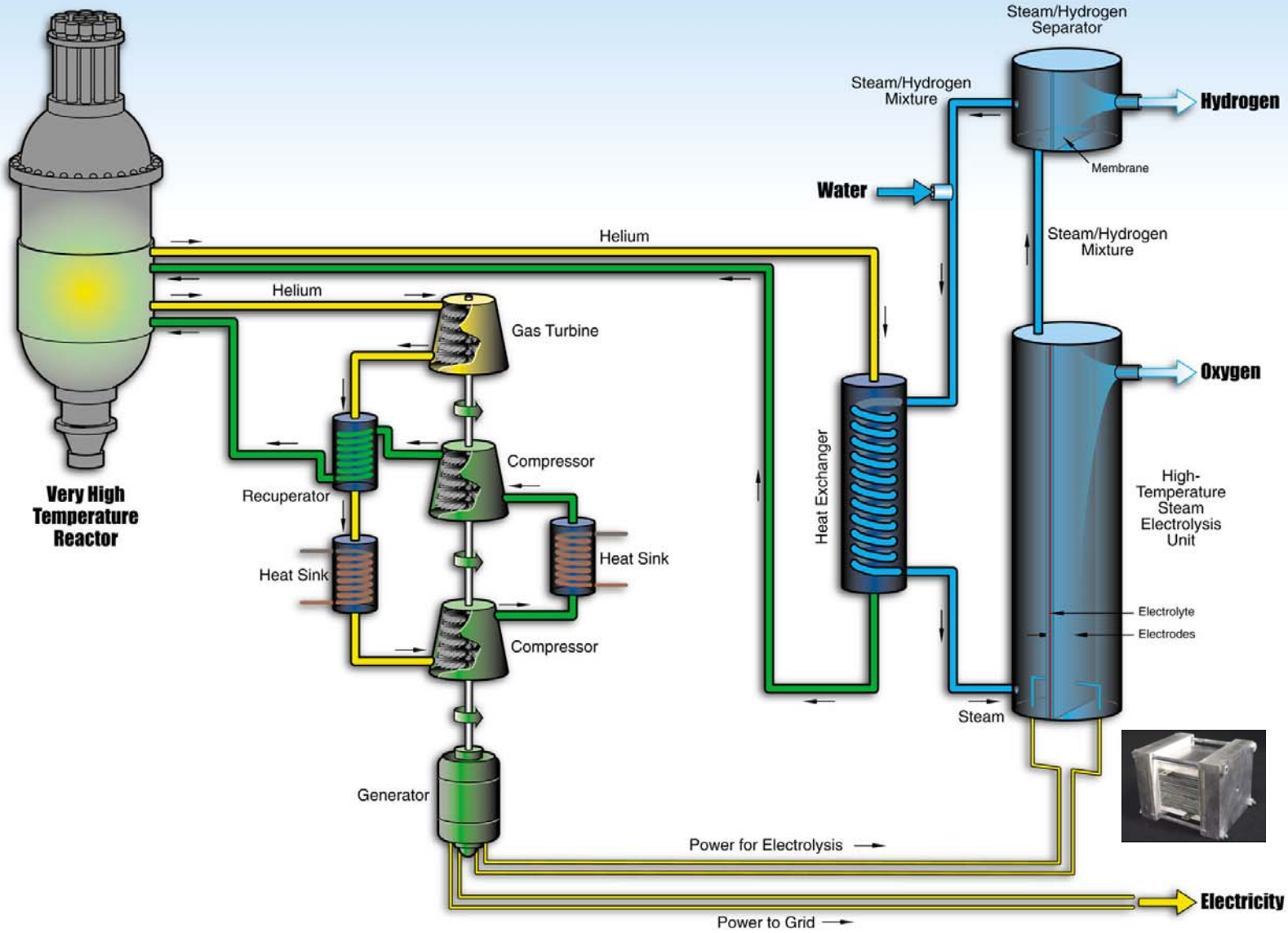


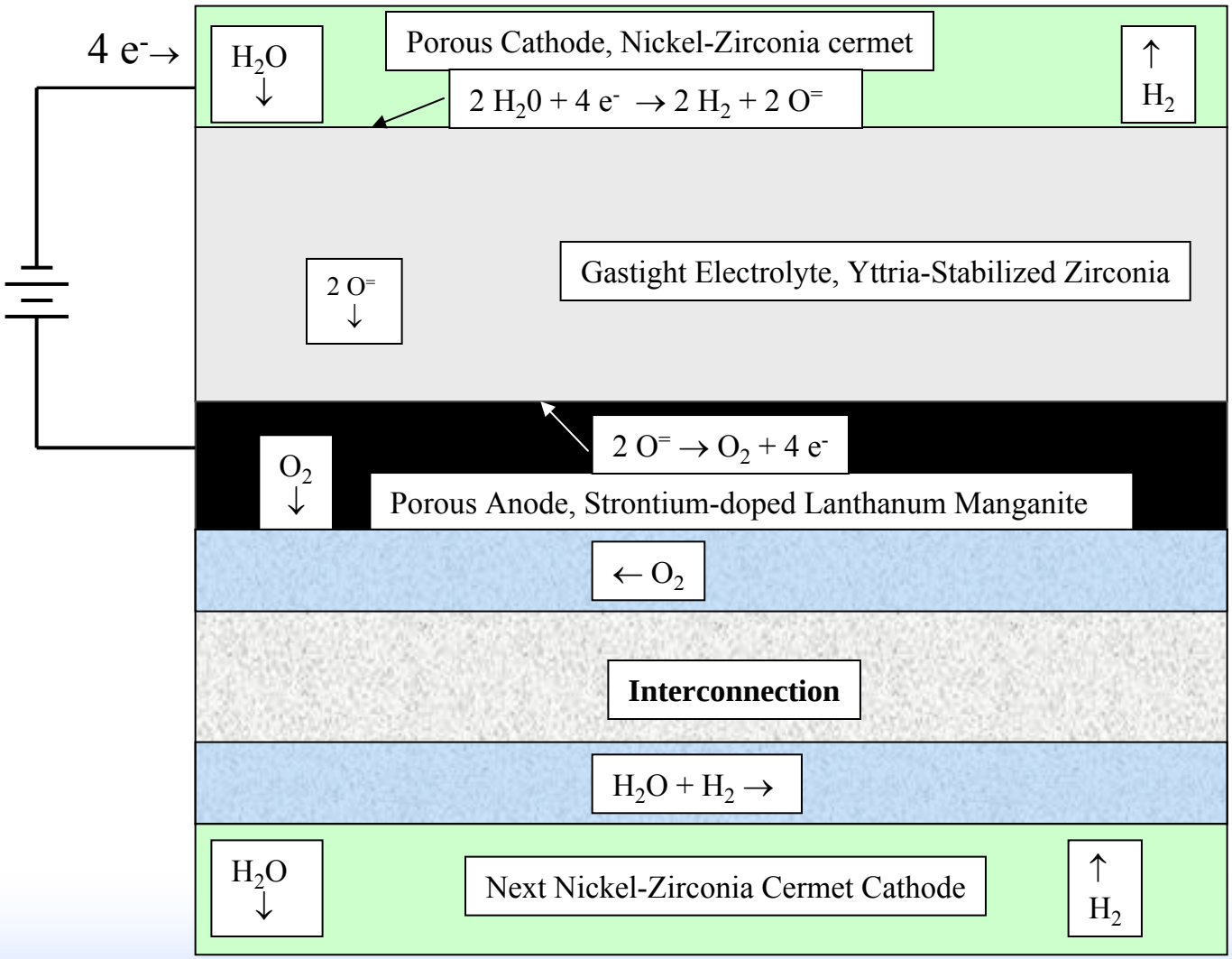
500 scf H_2 = 1.2 kg H_2

High Temperature Electrolysis Plant



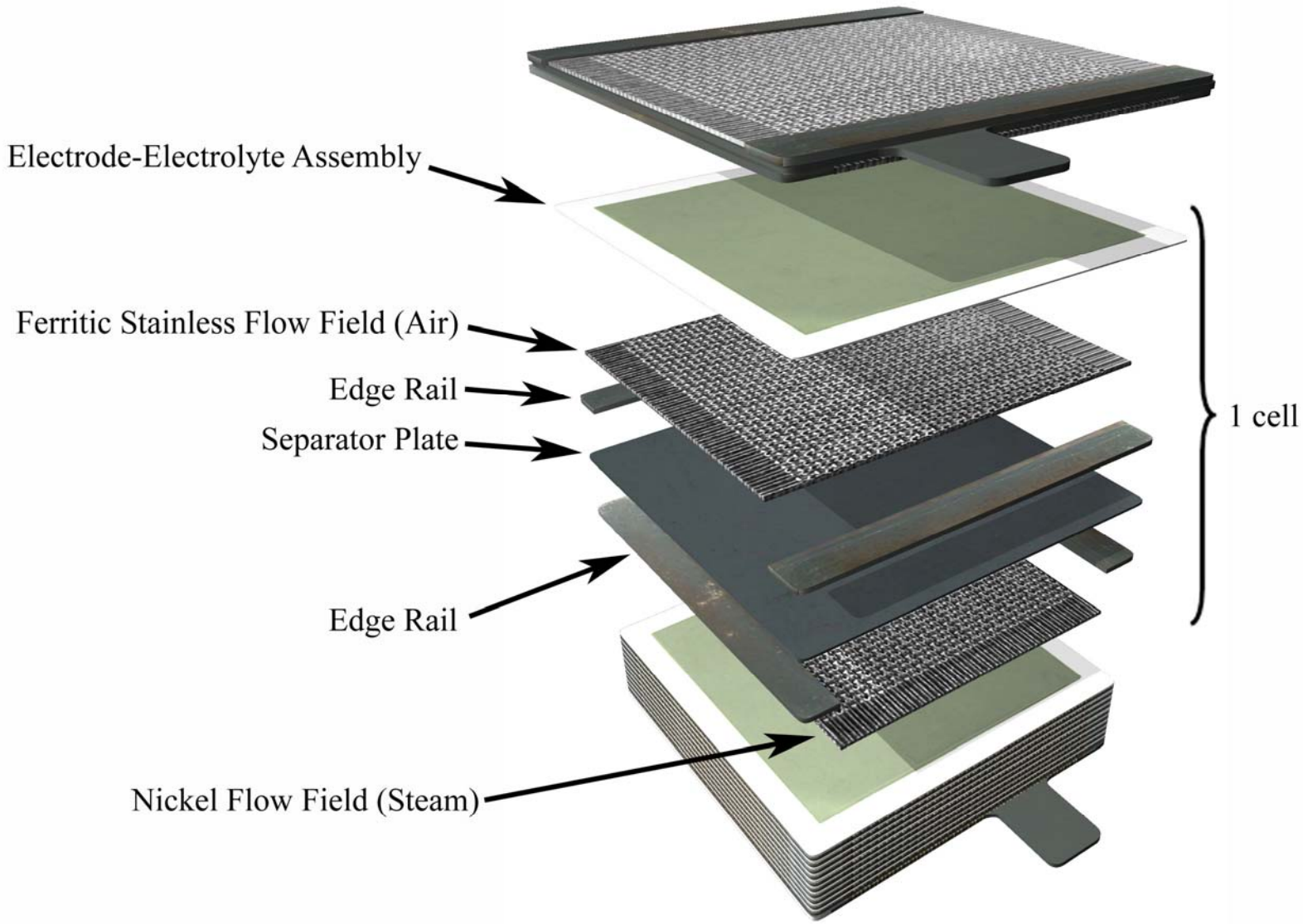
90 v/o H_2O + 10 v/o H_2

25 v/o H_2O + 75 v/o H_2

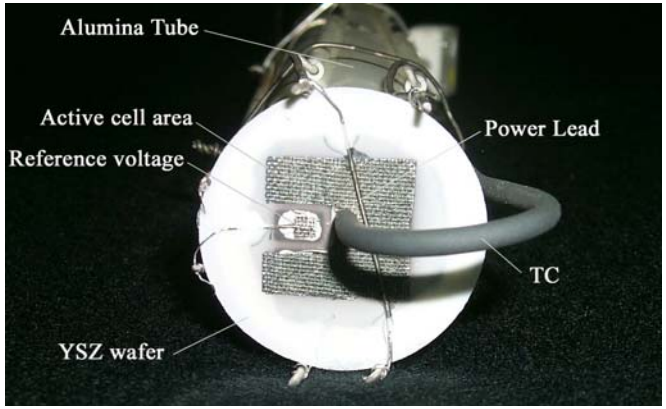


Typical thicknesses

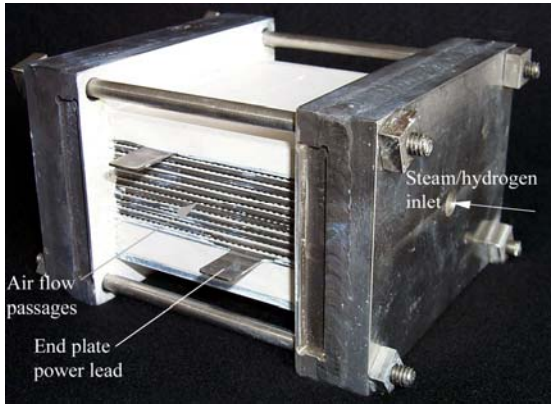
	Electrolyte-supported	Cathode-supported
Cathode	0.05 mm	1.500 mm
Electrolyte	0.10 mm	0.01 mm
Anode	0.05 mm	0.05 mm
Interconnection	1 – 2.5 mm	


Electrode-Electrolyte Assembly
Ferritic Stainless Flow Field (Air)
Edge Rail
Separator Plate
Edge Rail
Nickel Flow Field (Steam)
1 cell

High Temperature Electrolysis: from Button Cells to the Integrated Laboratory Scale Experiment



Button cell (2003) 3.2 cm^2



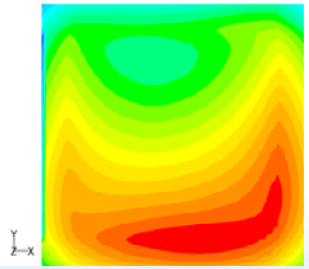
10-cell stack (2004) 640 cm^2

120-cell half-module (2006) 7,680 cm^2

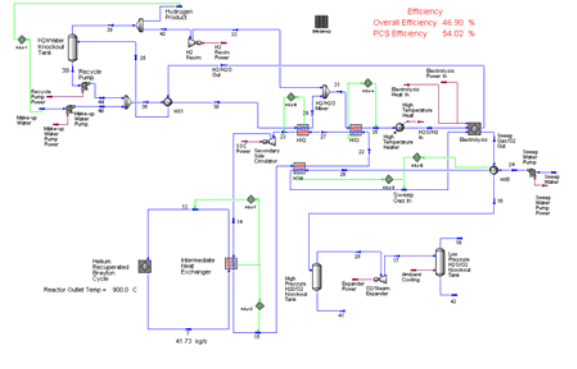
Research Goals:

- Develop efficient solid-oxide electrolysis cells, building on solid-oxide fuel cell research
- Decrease cost, increase durability
- Determine reasons for long-term cell degradation
- Optimize plant designs
- Co-electrolyze CO_2 and steam to CO and H_2
- Develop designs to apply nuclear heat and H_2 to heavy petroleum and oil sand upgrading
- Integrate nuclear energy sources and fossil/biomass carbon sources for hydrocarbon synthesis

CFD and Flowsheet Analyses



Temperature profile of cell



Process Flowsheet for Reactor-driven commercial plantl

Integrated Laboratory Scale (operational 8-22-07) 720 cells, 3 modules (2008) 46,080 cm^2

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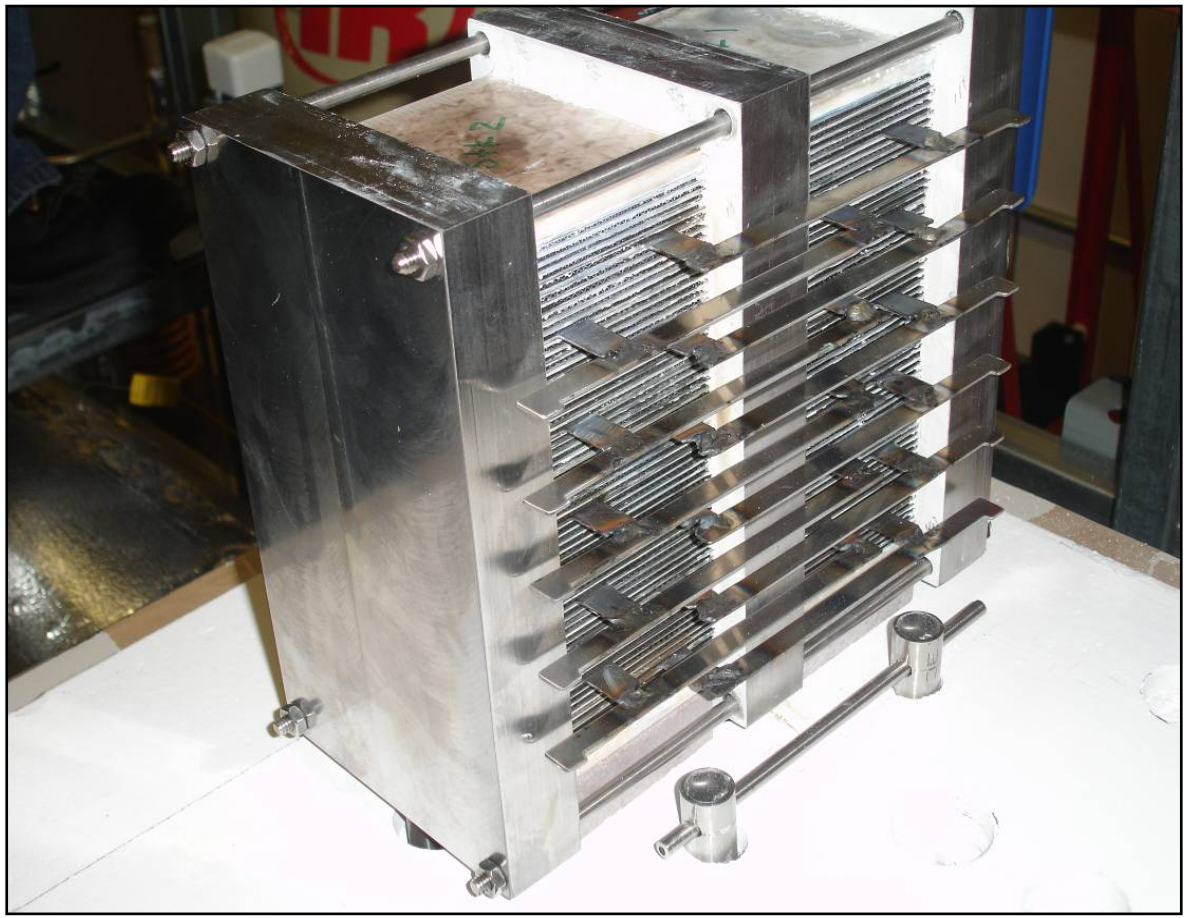
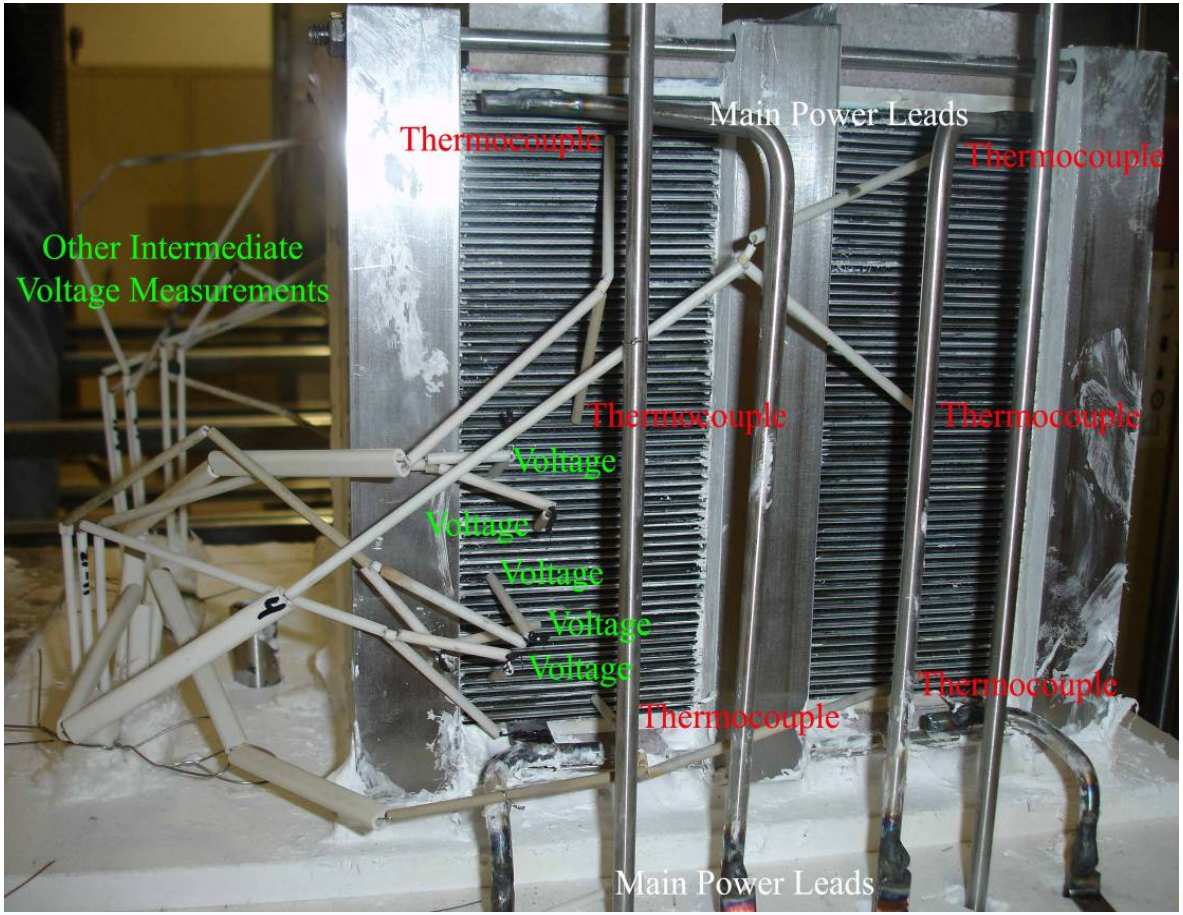
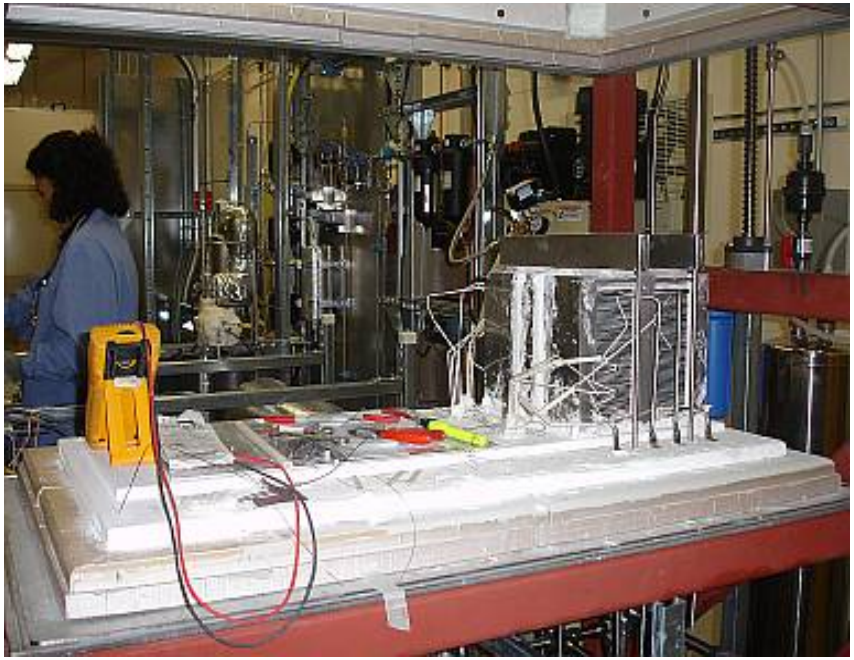
Assembled ILS Components

ILS Module Installation



ILS Module Installation





Start of Testing

Initial operations began Aug 24, 2007

Module testing began Sept 24, 2007

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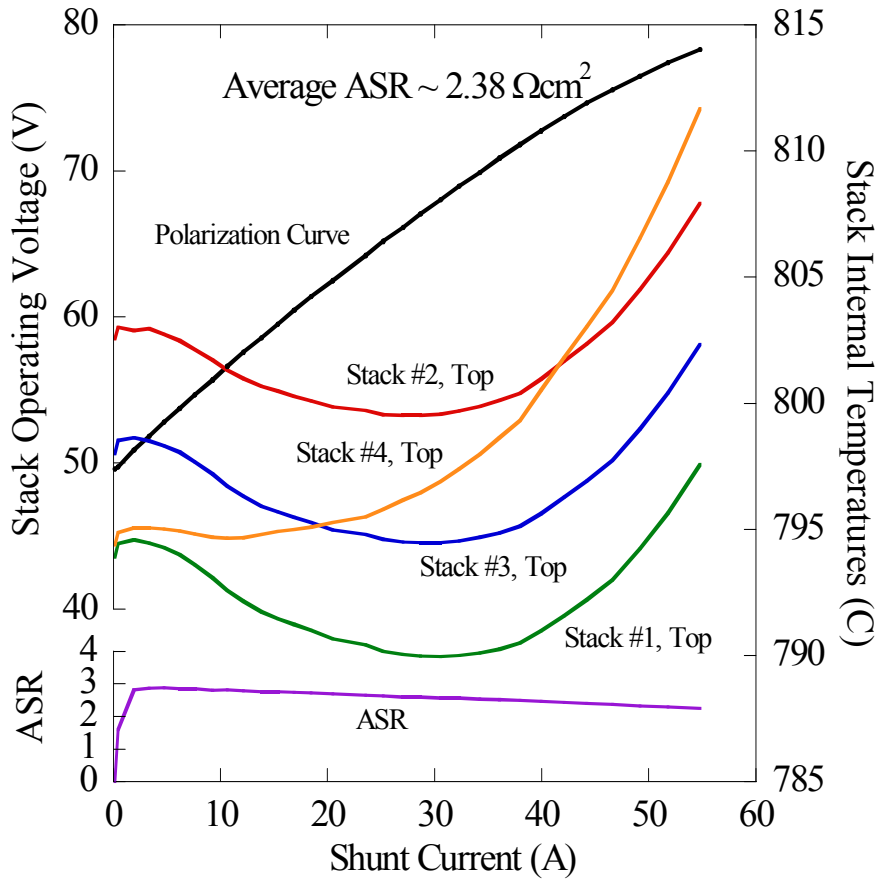
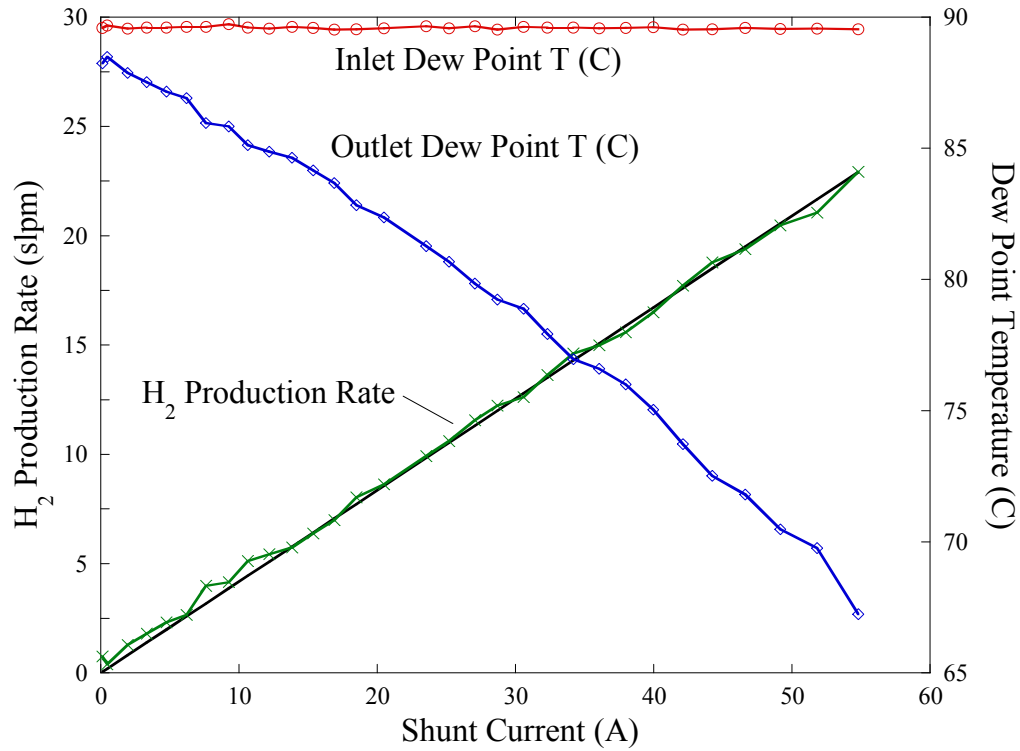
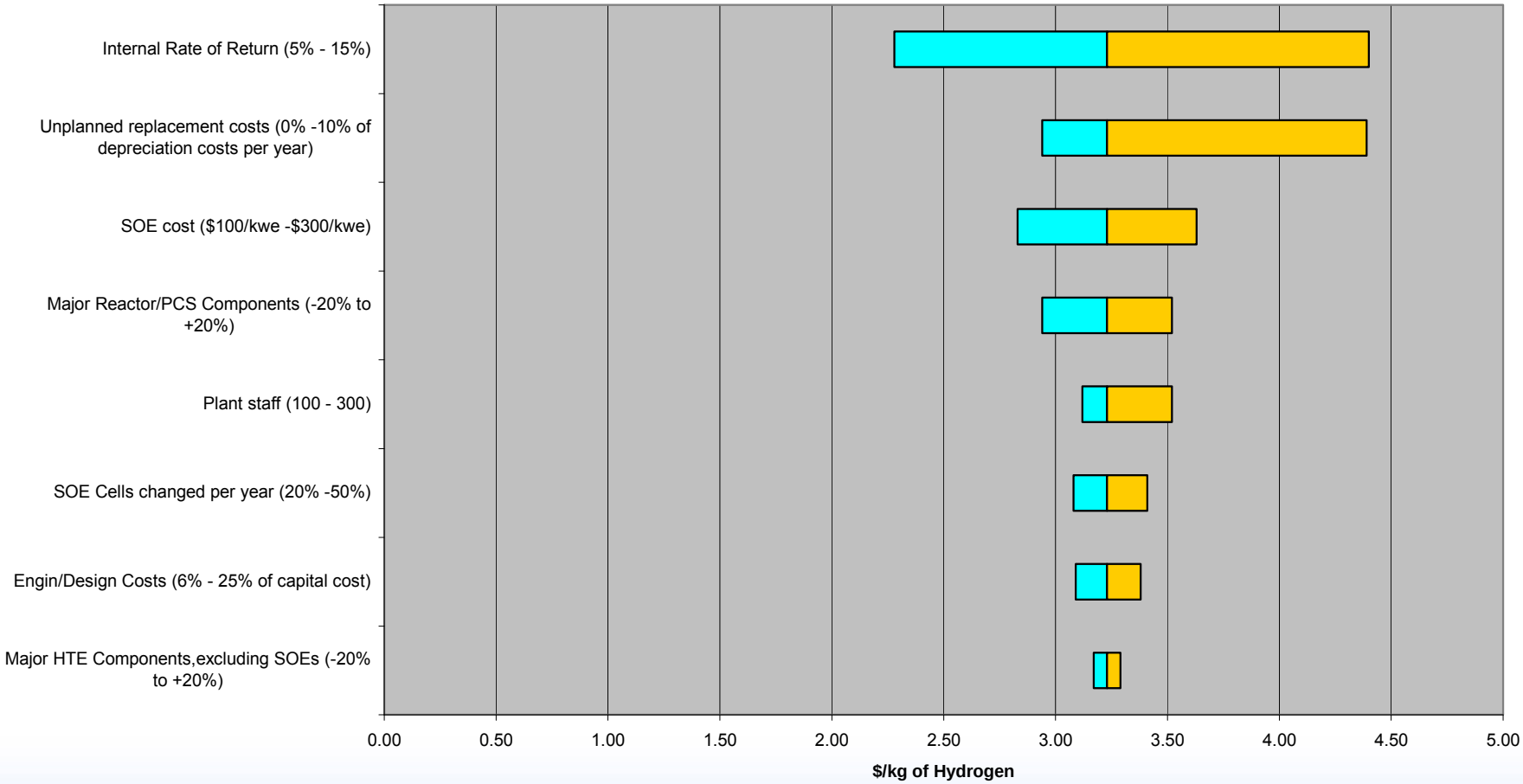
ILS Module Sweep Data





VHTR/HTE Economic Sensitivity Analysis

(For plant gate cost ~$3.23/kg hydrogen and 10% internal rate of return)



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Co-Electrolysis

- Primarily a "proof-of-principle" research project
- Investigate the feasibility of producing syngas

Syngas

$2H_2$ and CO

- using high-temperature co-electrolysis of H_2O and CO_2

$$2\ H_2O + CO_2 \rightarrow 2\ H_2 + CO + 1.5\ O_2$$

- while taking advantage of solid oxide fuel cell technology.

SYNTHETIC FUELS

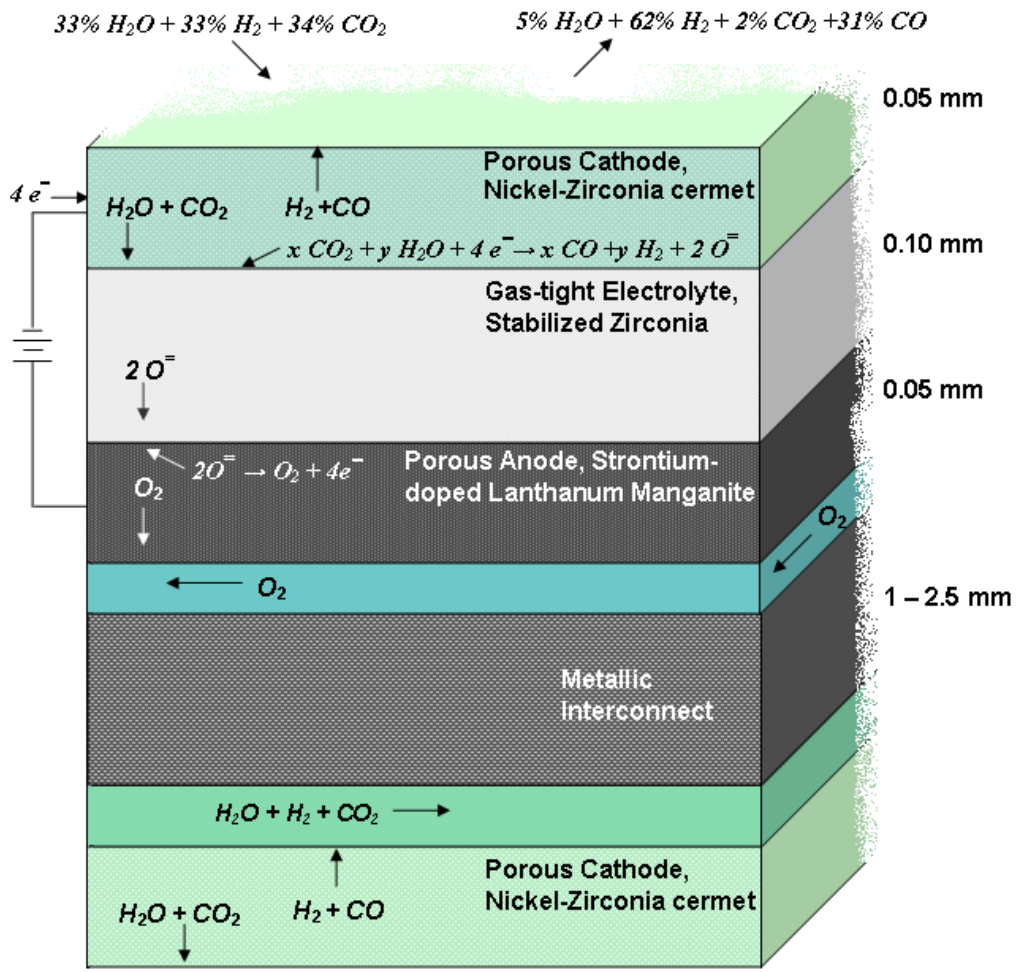
- Nothing New About Synfuels
  - Produced via the Fischer-Tropsch process

Syngas

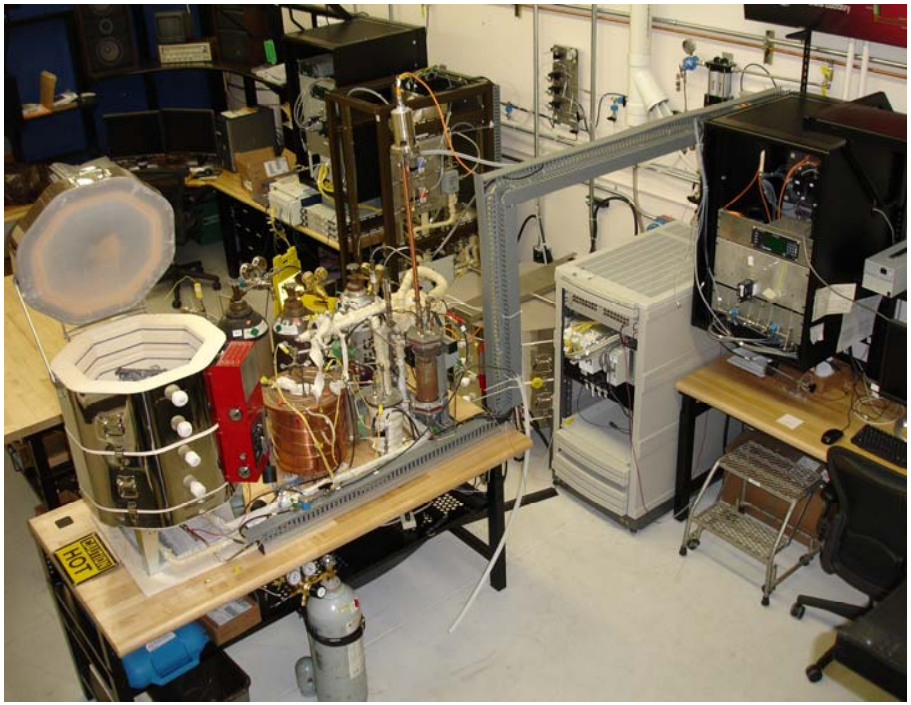
- $nCO + (2n+1)H_2 \rightarrow C_nH_{2n+2} + nH_2O$

  - Discovered before WWII
  - Pressure primarily determines *n*
- Production of Synfuels requires Syngas
  - Previous H_2 production releases large amounts of CO_2

Co-electrolysis in an solid oxide cell



INL Coelectrolysis Experiment



Products of Fischer Tropsch Synthesis

Progressive steps in the use of hydrogen produced through nuclear energy

- Upgrading of current heavy crude oils for the production of gasoline
- Upgrading of the Athabasca Oilsands for the production of diesel and gasoline
- Catalytic addition of H_2 to coal (hydrogenation) to produce gasoline
- Fischer-Tropsch synthesis of diesel and jet fuel using CO from coal gasification and H_2 from nuclear energy
- Co-electrolysis of CO_2 from biomass and steam to produce CO and H_2 for synthetic, GHG-neutral, gasoline, diesel and jet fuels
- Nuclear production of H_2 for use in fuel-cell-powered vehicles.

Areas for University Involvement

- Investigation of causes and mechanisms for degraded performance during long-term cell and plant operation
  - Surface science, interfacial modeling, changes in morphology, transport of Cr, Sr and Si at 800 – 900°C
  - Corrosion in hot, high oxygen environments, protective coatings, valves and instrumentation
- Integration of nuclear hydrogen production into the upgrading and refining of unconventional fossil resources (heavy crude, oilsands, oilshale,..) and biomass
- Dynamic Modeling of the interaction of chemical plants with a reactor heat/hydrogen source
- Dynamic economic modeling to account for varying fuel/electricity price relationships

Conclusions

- Conventional electrolysis is available today
- High temperature electrolysis is under development and will be more efficient
- HTE Experimental results from 25-cell stack and 2x60-cell half-module, fabricated by Ceramatec,
  - Hydrogen production rates in excess of 160 normal liters/hour were maintained with a 25-cell solid-oxide electrolysis stack for 1000 hours
  - Hydrogen production greater than 800 normal liters/hour was achieved in the half-module test for a 2040 hr test
  - An Integrated Laboratory Scale experiment is now being build, has produced 1320 normal liters/hour and is designed for >5 normal m^3/hour
- In the near-term hydrogen from nuclear energy will be used to upgrade crude and later to synthesize conventional gasoline and diesel fuel from renewable carbon sources
- In the long-term pure hydrogen from nuclear energy may power vehicles directly through fuel cells