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Recent Progress in High Temperature Electrolysis

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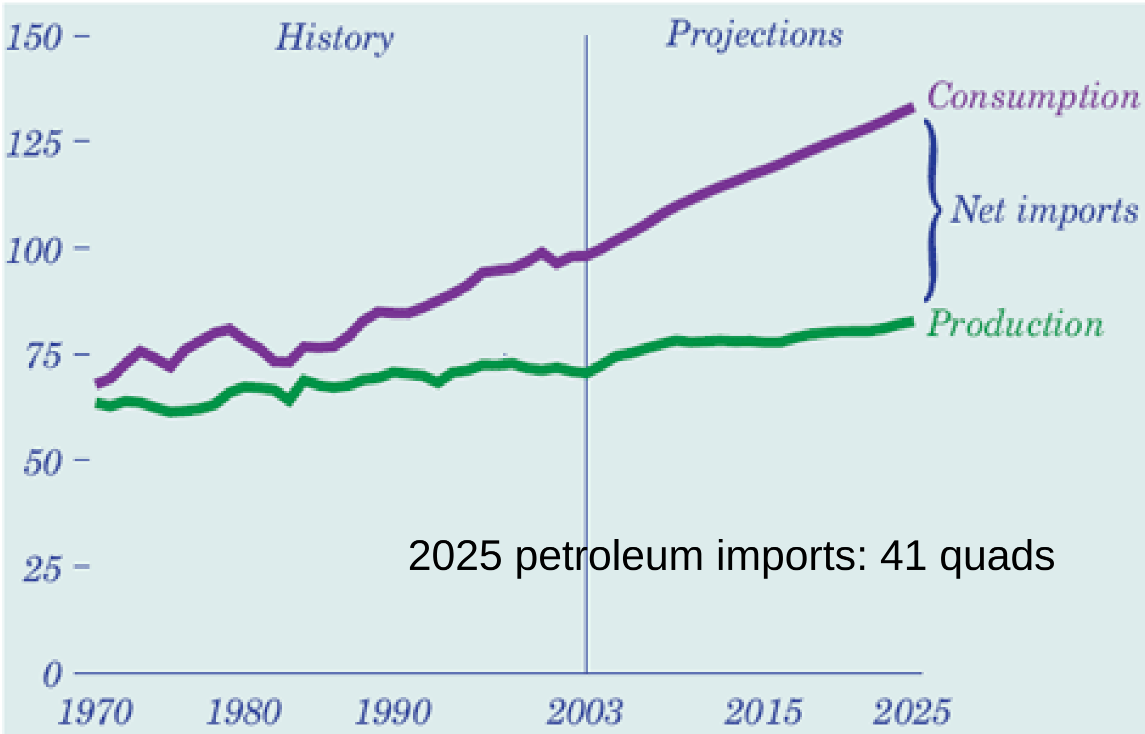
Session 412
AIChE 2007
Salt Lake City, Utah
November 7, 2007

The U.S. is becoming increasingly dependent on imports

Figure 6. Total energy production and consumption, 1970-2025 (quadrillion Btu)



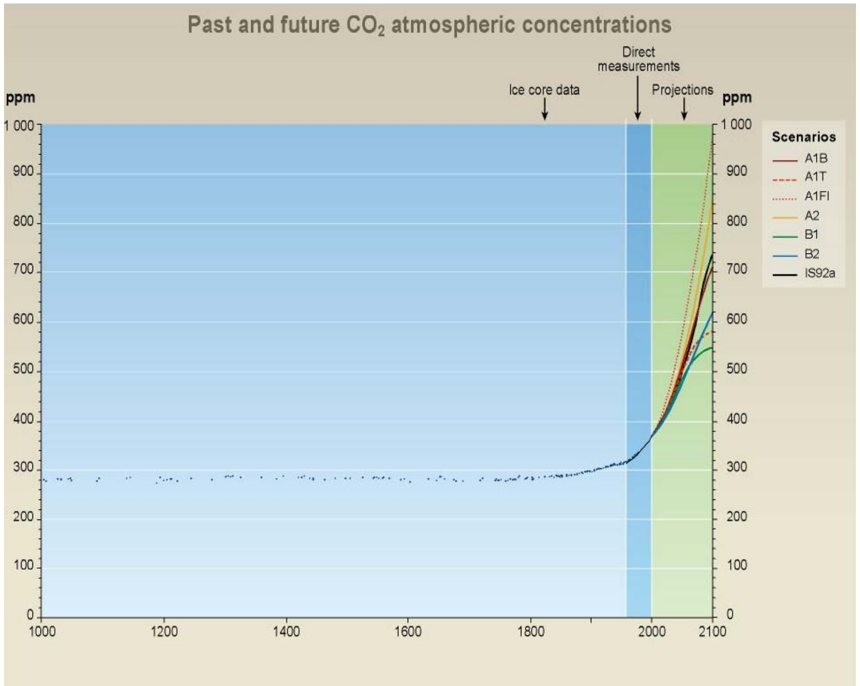
2025 petroleum imports: 41 quads

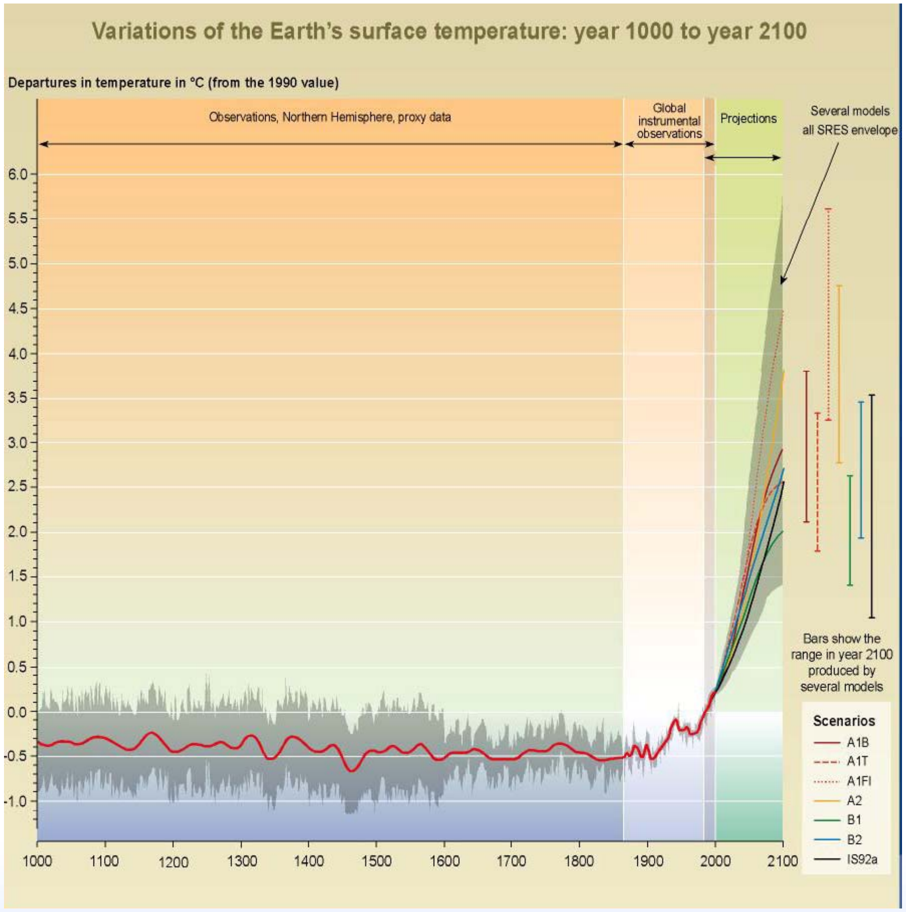
Source: EIA AEO 2005

US Petroleum imports today:
12 million barrels per day
= 25 quad per year
= $800,000 per minute, 24-7

1 quad = a mile-long train of coal every 2 hrs, 24-7 for a year

Greenhouse Gas Emissions & Global Warming





- Controversial issue
- CO_2 atmospheric concentrations going up
- Earth's surface temperature going up

Source: Intergovernmental Panel on Climate Change

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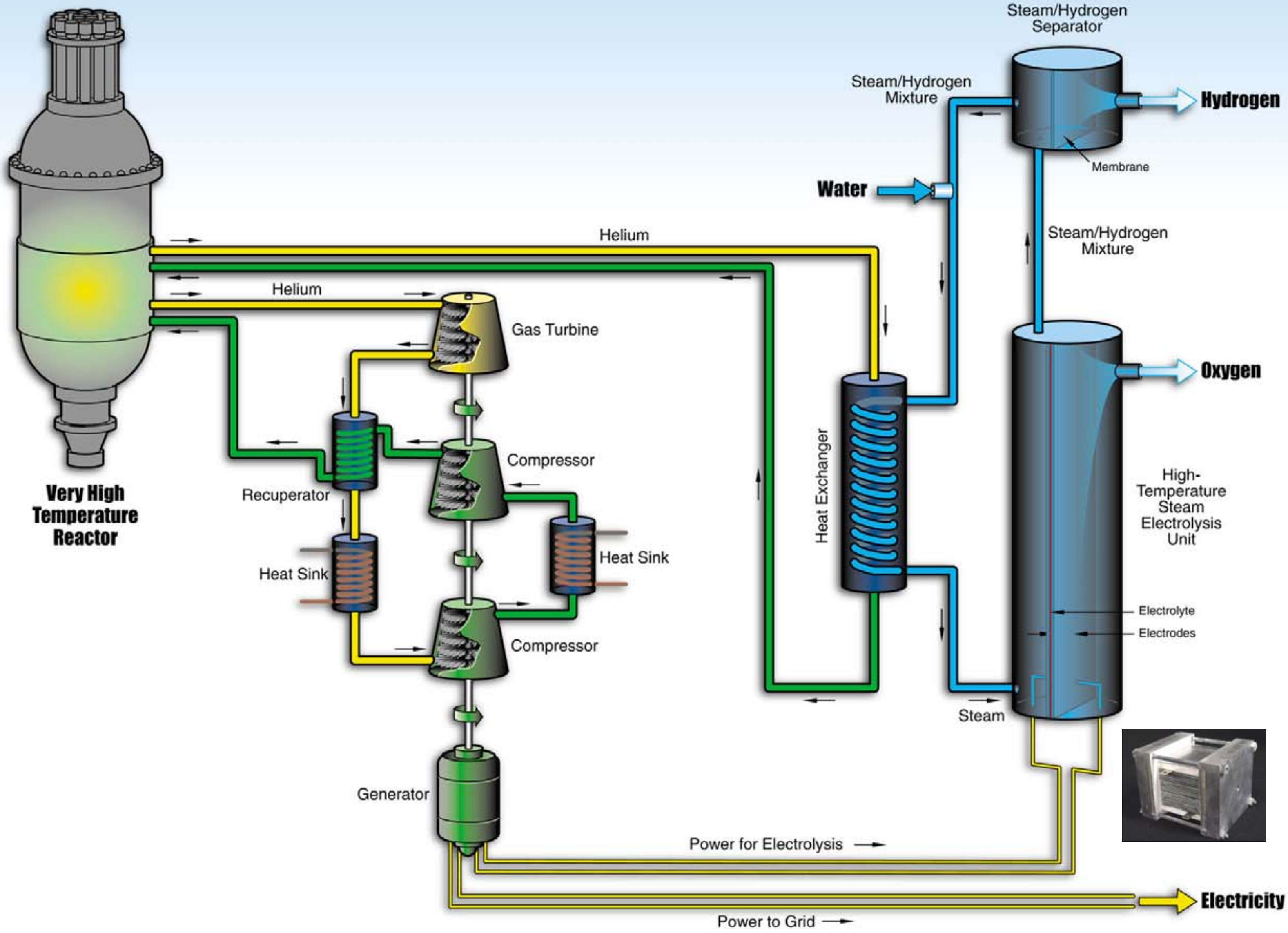
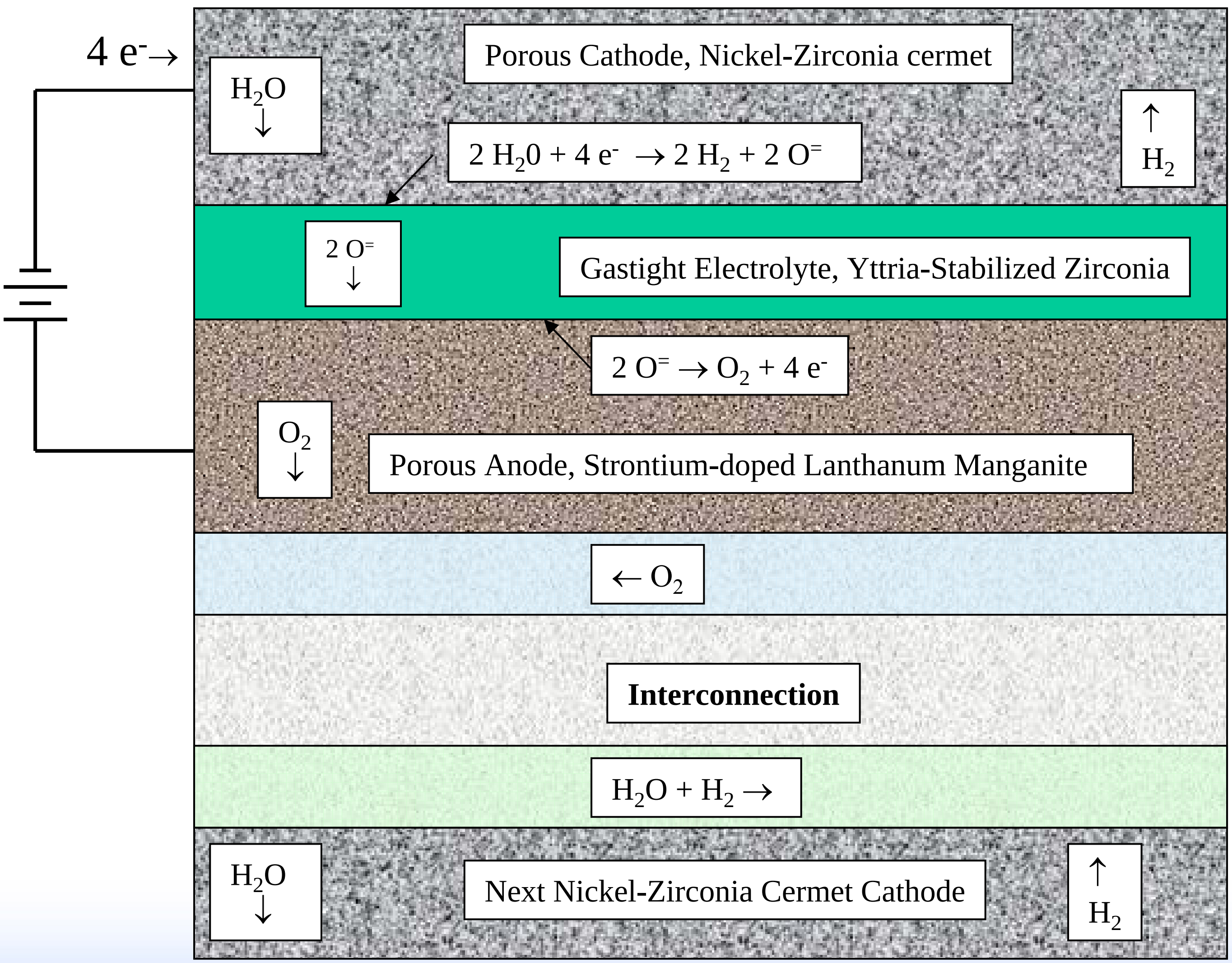
High Temperature Electrolysis Plant



$90\ ^{v}/_{o}\ H_2O + 10\ ^{v}/_{o}\ H_2$ → $25\ ^{v}/_{o}\ H_2O + 75\ ^{v}/_{o}\ H_2$



Typical thicknesses

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

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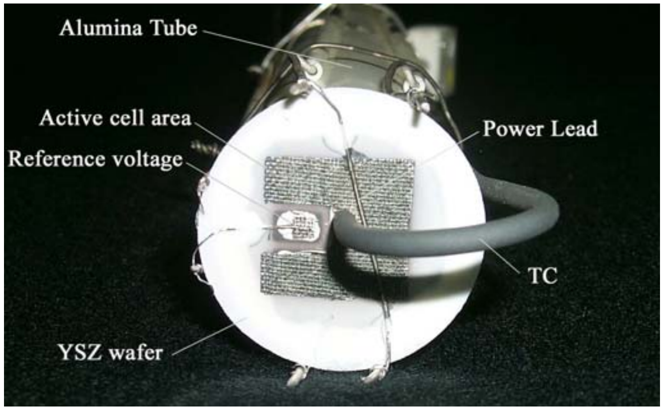
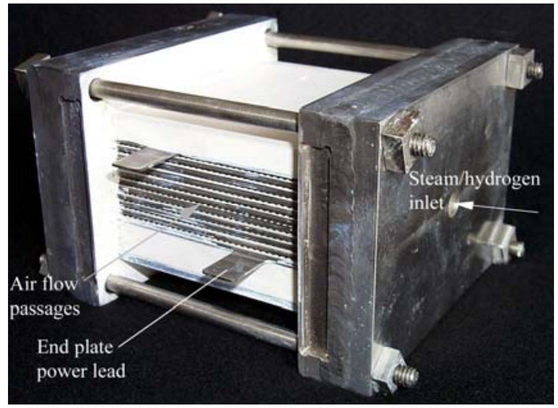
High Temperature Electrolysis: from Button Cells to the Integrated Laboratory Scale Experiment



Button cell (2003) 3.2 cm^2



10-cell stack (2004) 640 cm^2

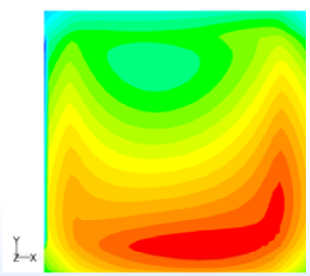
120-cell half-module (2006) 7,680 cm^2

Research Goals:

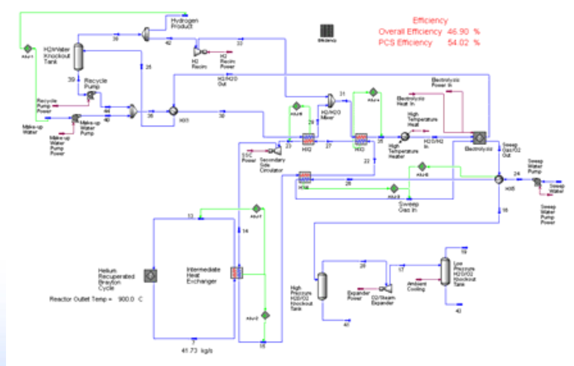
- Develop efficient solid-oxide electrolysis cells, building on solid-oxide fuel cell research
- Decrease cost, increase durability
- Determine reasons for long-term cell degradation
- Optimize plant designs
- Co-electrolyze CO_2 and steam to CO and H_2
- Develop designs to apply nuclear heat and H_2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

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

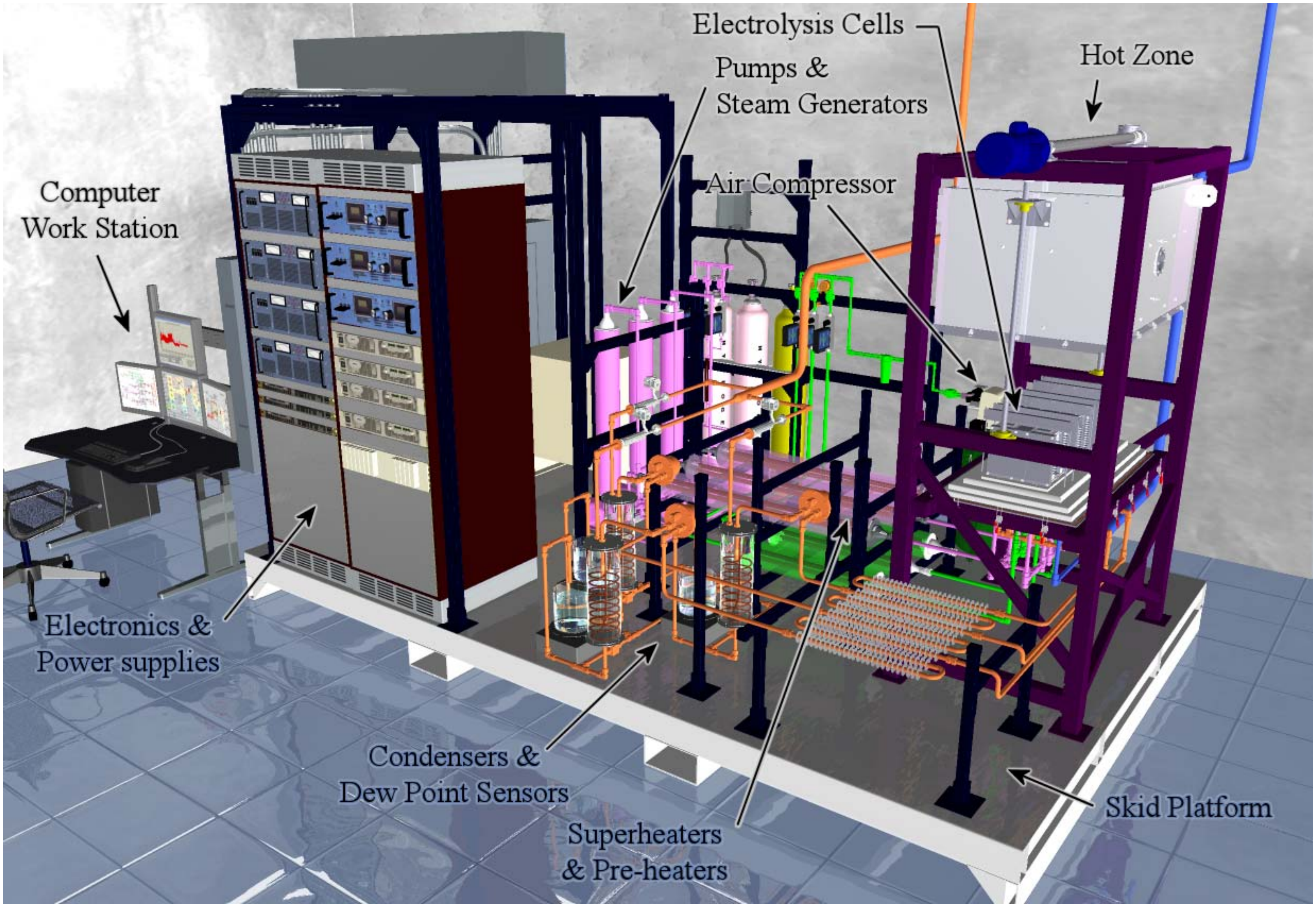
CFD and Flowsheet Analyses



Temperature profile of cell



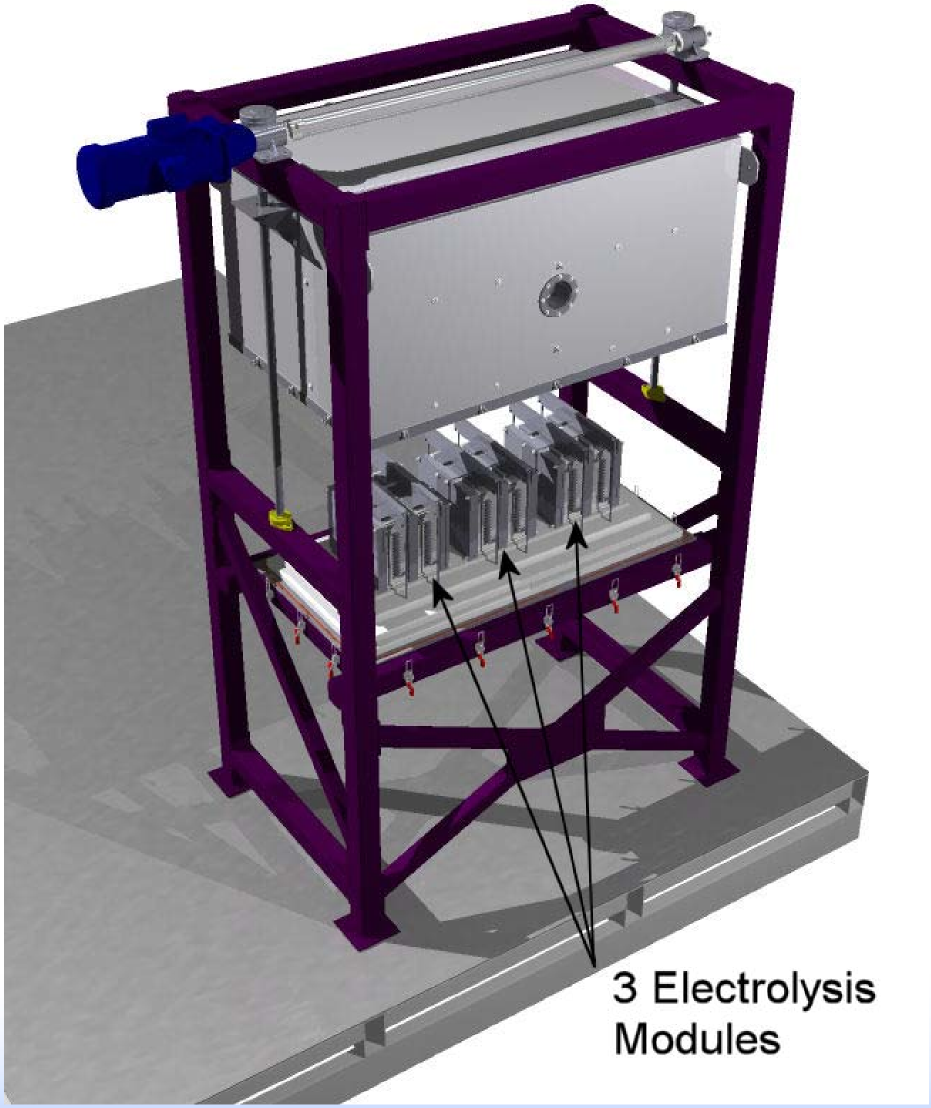
Process Flowsheet for
Reactor-driven commercial plantl

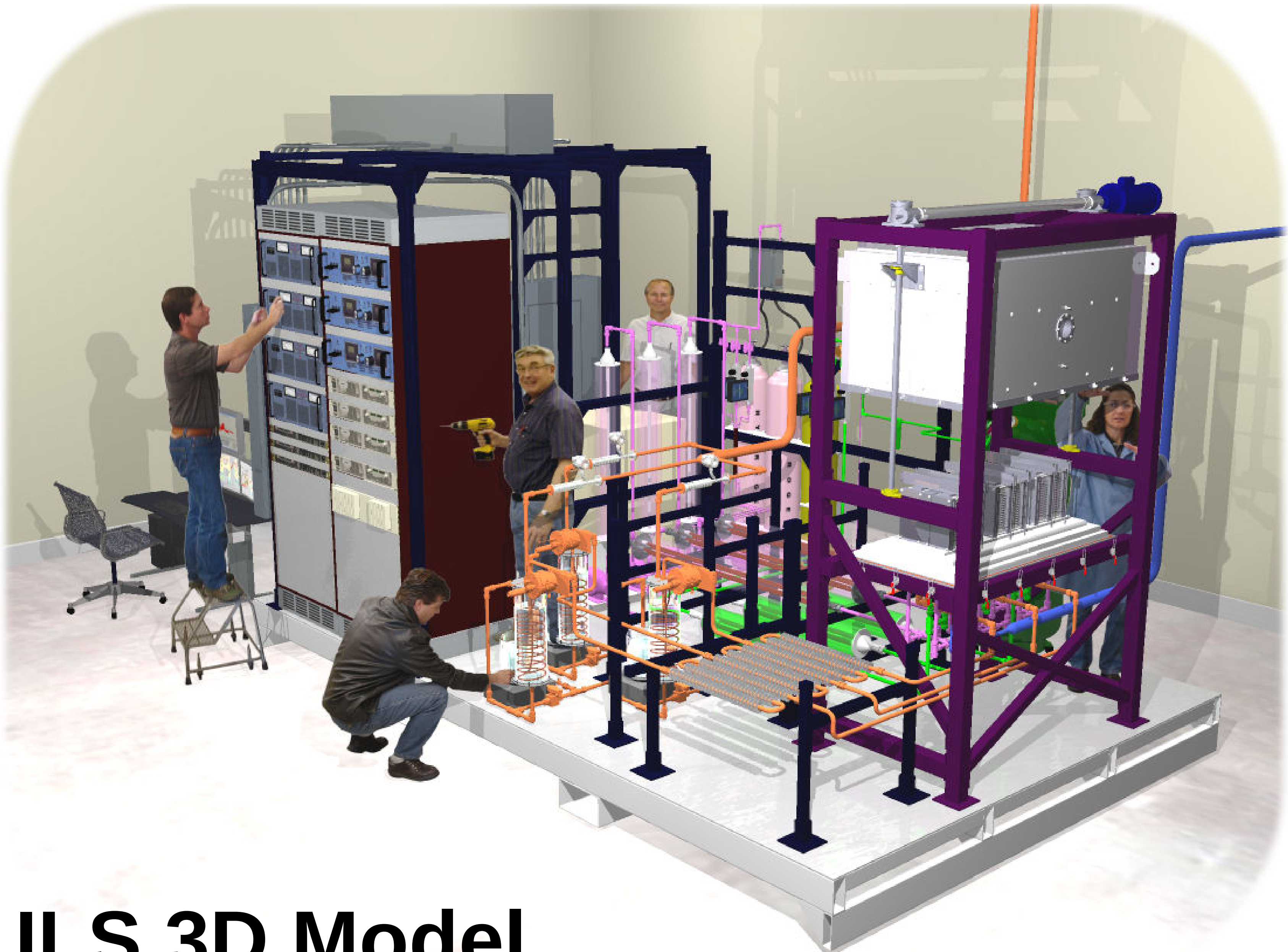

Electrolysis Cells
Pumps &
Steam Generators
Hot Zone
Computer
Work Station
Air Compressor
Electronics &
Power supplies
Condensers &
Dew Point Sensors
Superheaters
& Pre-heaters
Skid Platform

Hot Zone of the HTE ILS

Comparison of nominal and extreme design cases

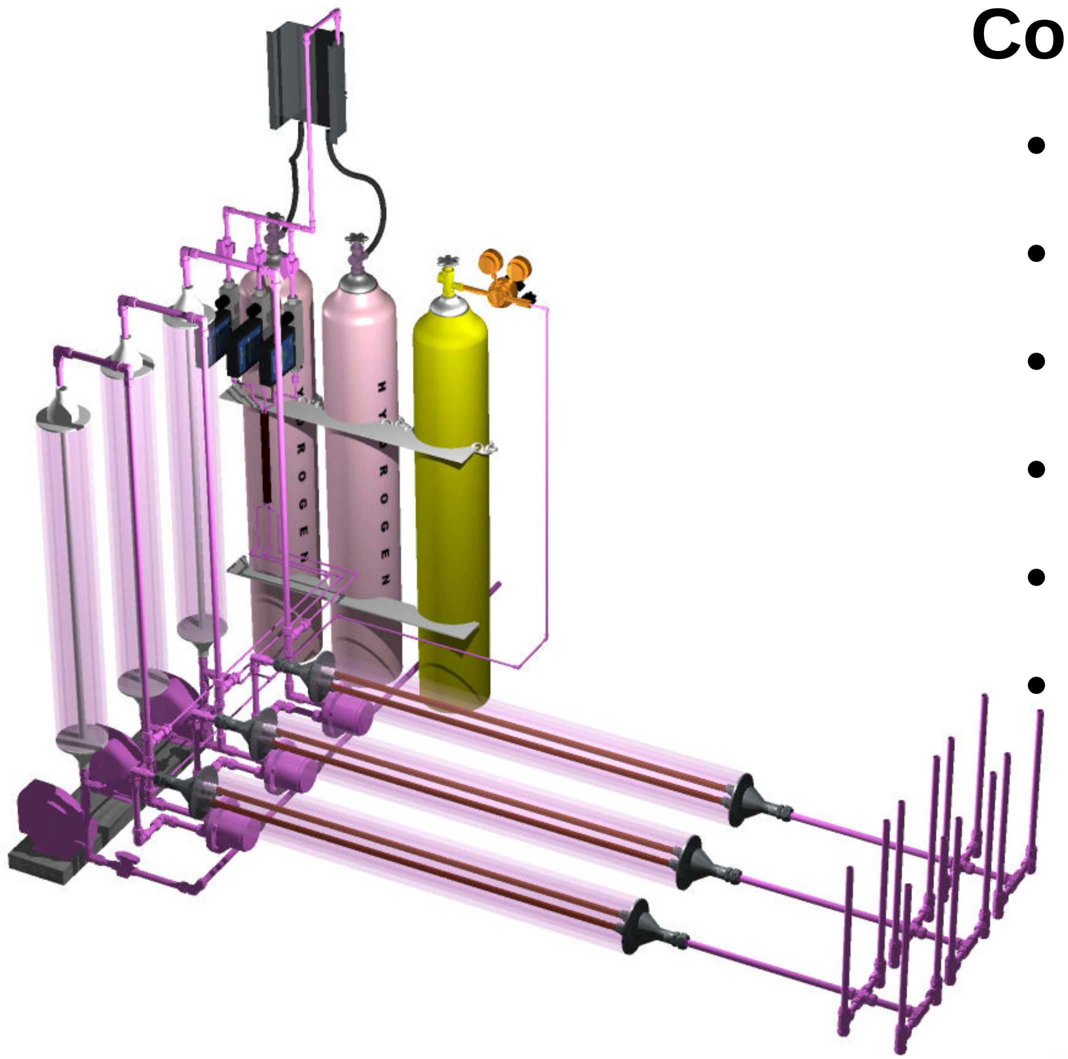
	Nominal Case	Extreme Design Case
ASR (ohm cm^2)	1.5	1.0
Current Density (A/cm^2)	0.25	0.37
Per-cell Voltage, V()	1.283	1.283
Electrolysis Power (kW)	14.54	21.8
Hydrogen Production Rate (NL/hr)	4735	7103





ILS 3D Model

Steam Input Lines

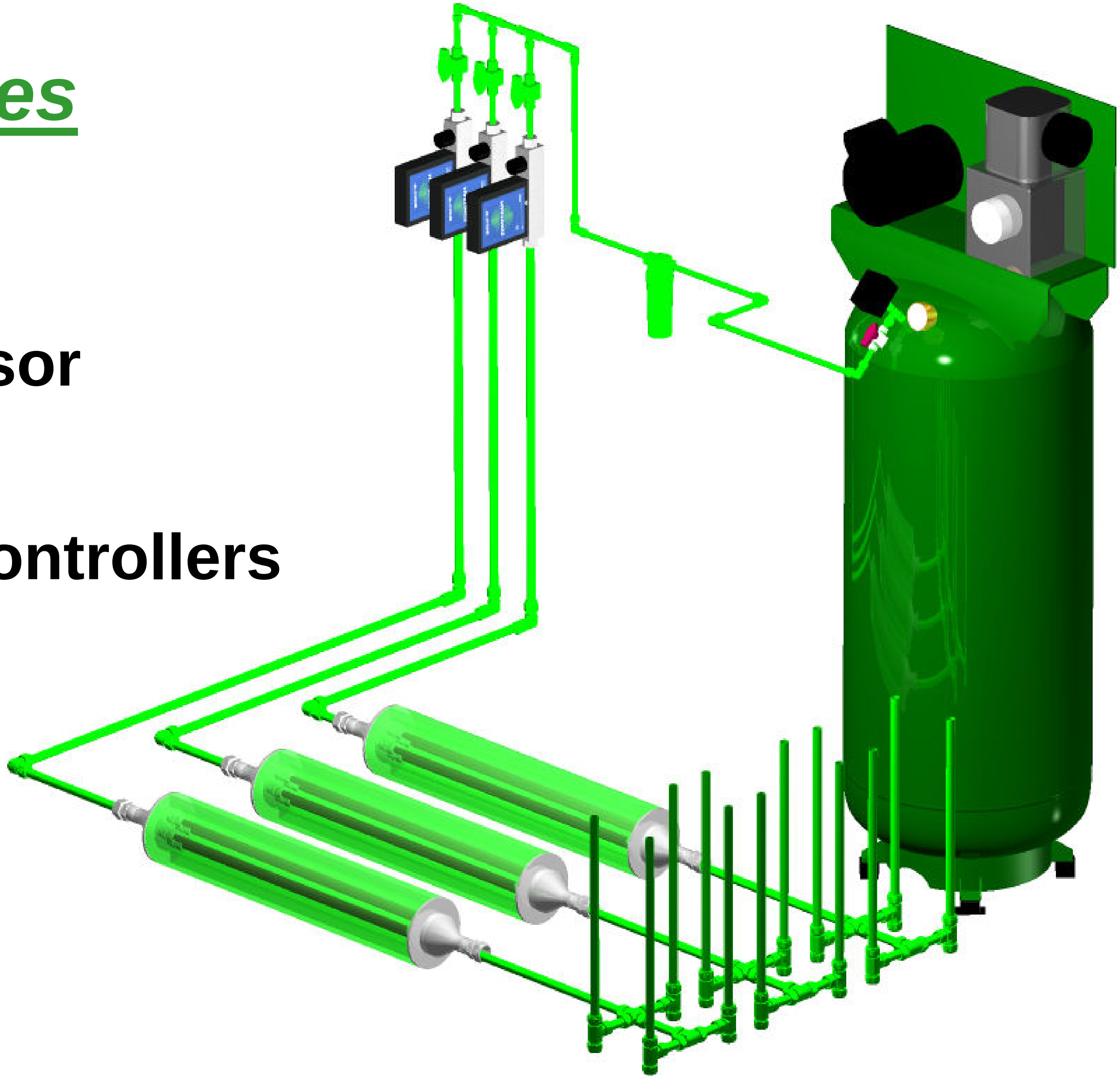


Components--

- **Water Metering pumps**
- **Steam Generators**
- **Humidity Sensor Vessels**
- **Superheaters**
- **Purge Gas – Nitrogen**
- **Reducing Gas – Hydrogen**

Air Input Lines

- **Air Compressor**
- **Filter**
- **Mass Flow Controllers**
- **Air Heaters**



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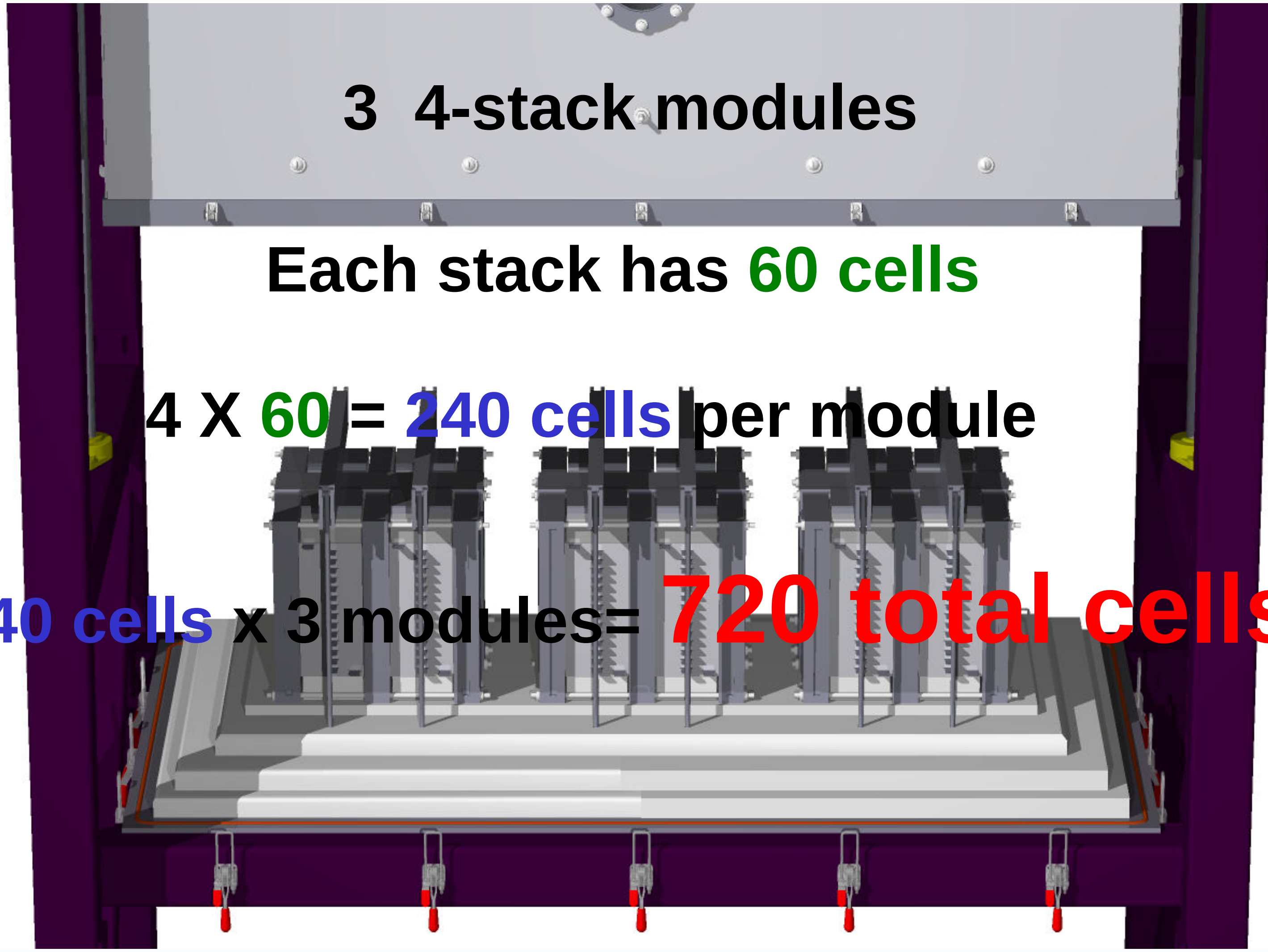
Hot Zone

- **Where Steam is converted to Hydrogen**
- **Houses 3 4-stack electrolysis modules**
- **Operating Temperature Range: 800 to 900ºC**

Hot Zone

Electrolyzer Modules



3 4-stack modules

Each stack has 60 cells

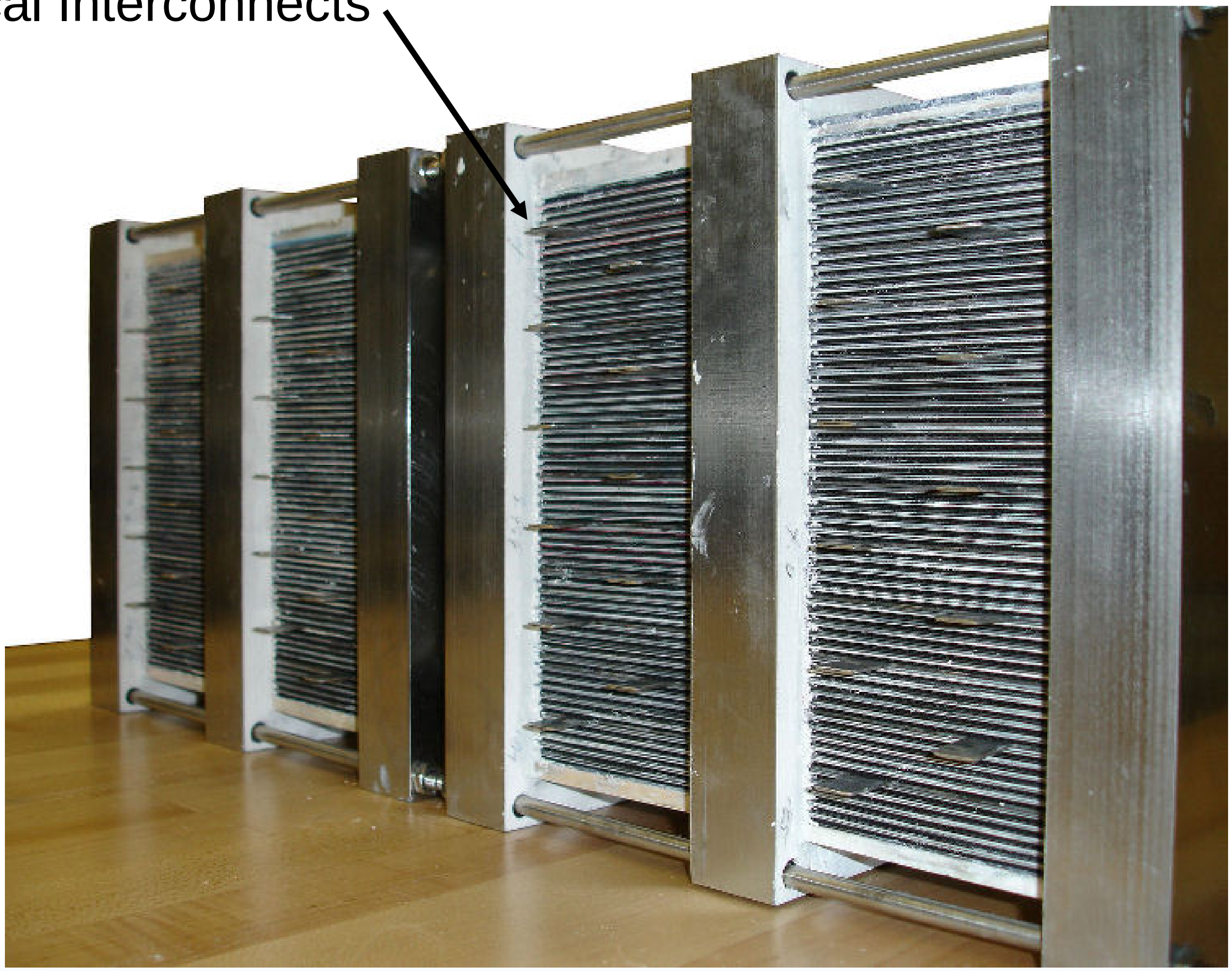
4 X 60 = 240 cells per module

240 cells x 3 modules= 720 total cells

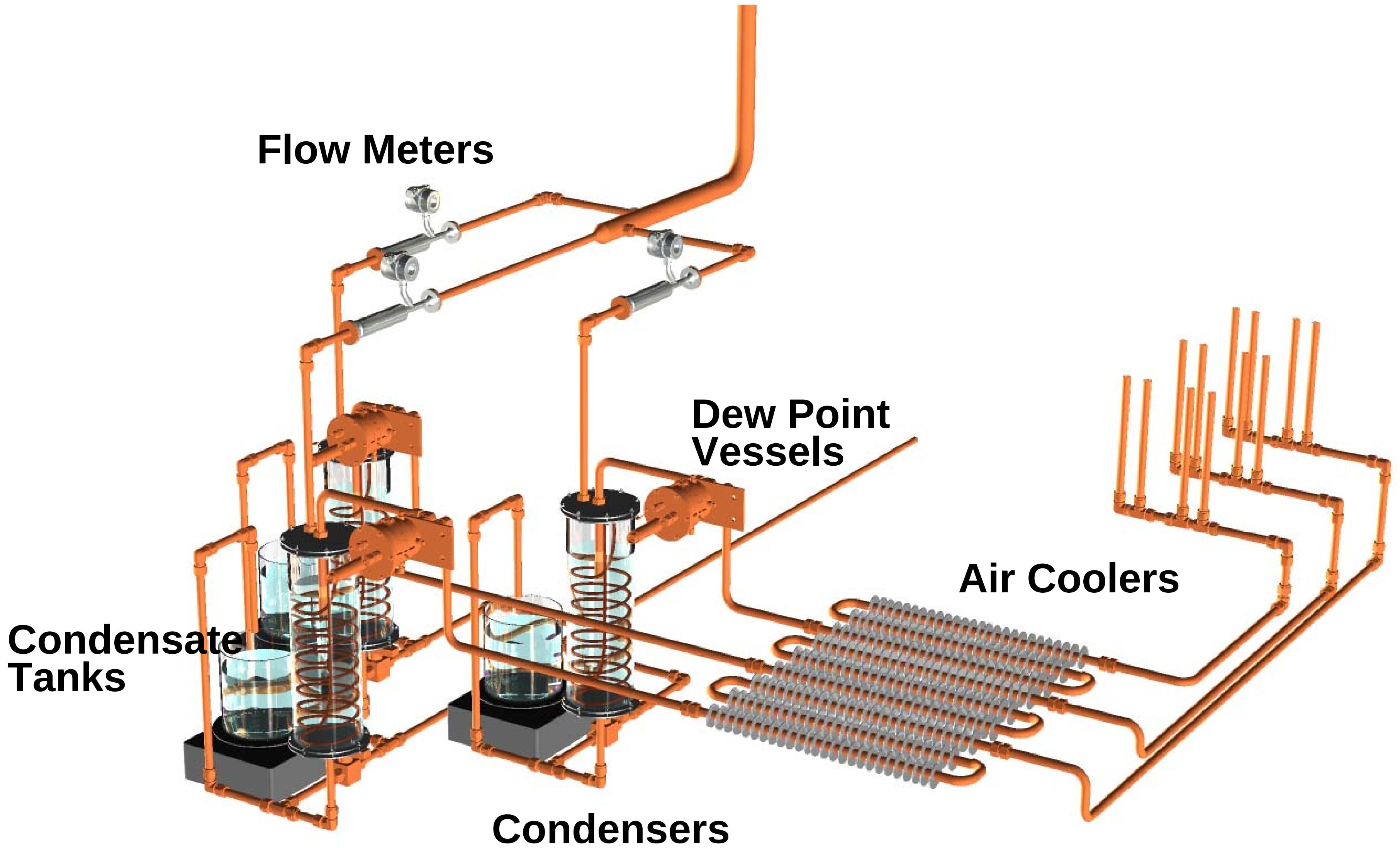
Hot Zone

Fuel Cell Module

Electrical Interconnects



Hydrogen Outlet Lines



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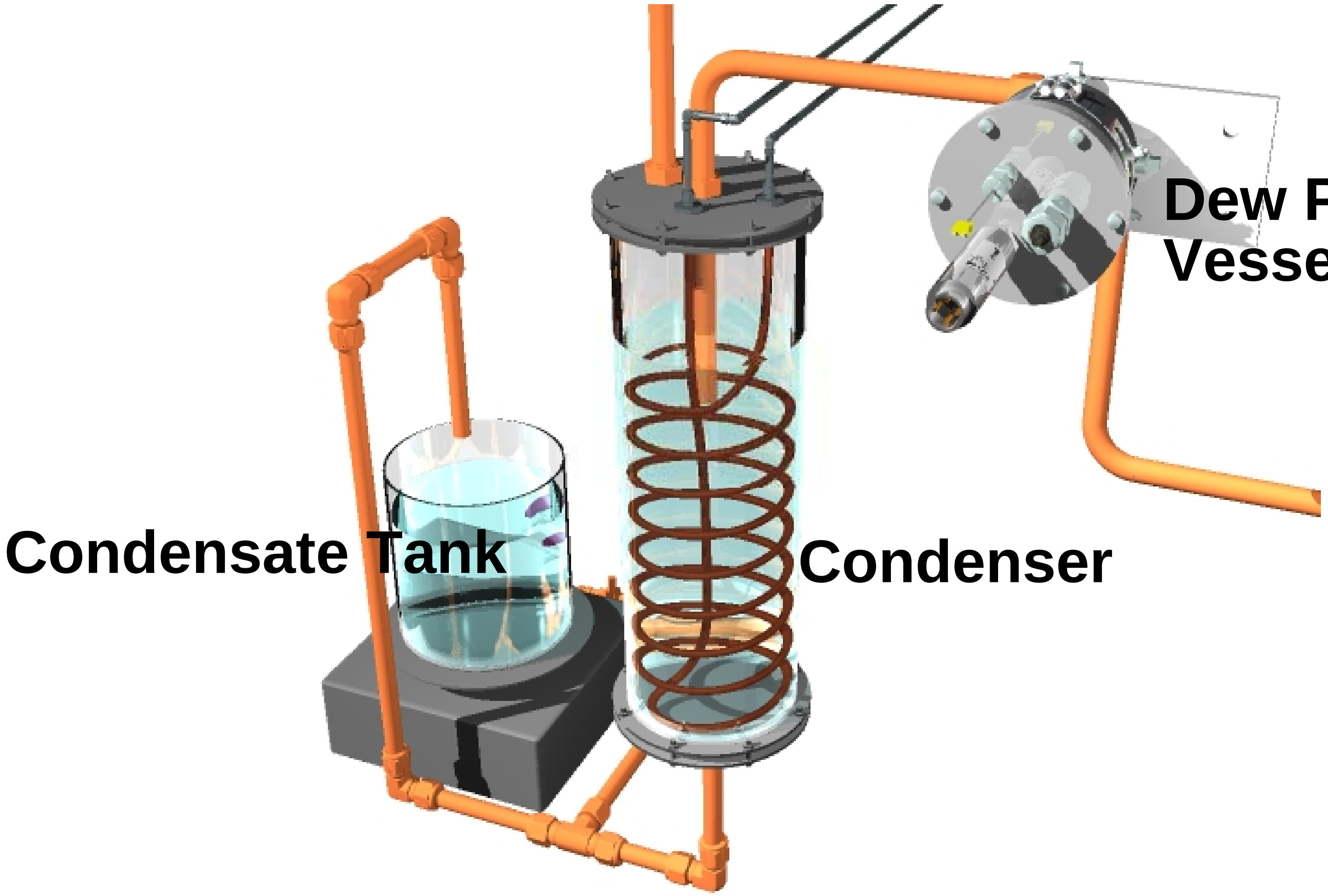
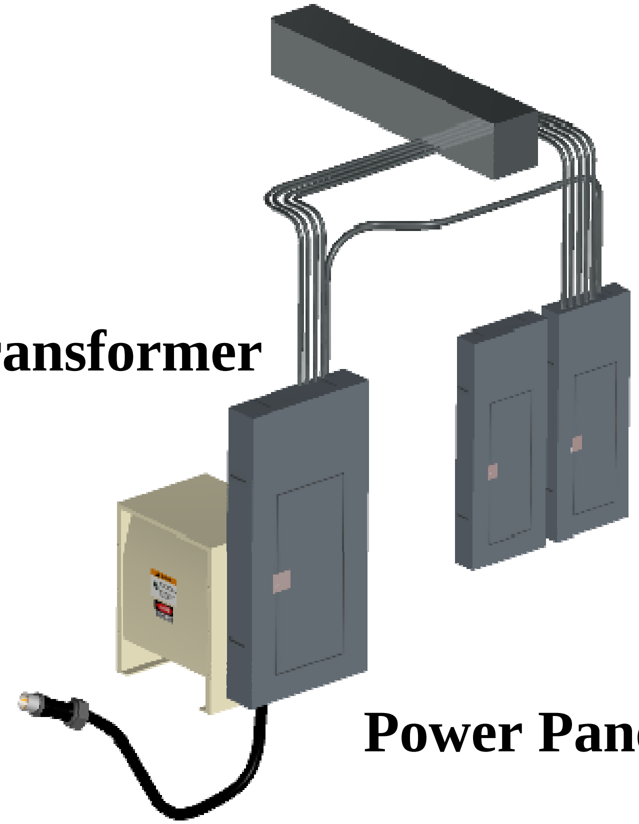


Power Electronics

Transformer



Power Panels

480V Plug

Electronics for Heater and Electrolysis power supplies

Assembled ILS Components

Comparison of nominal and extreme design cases.

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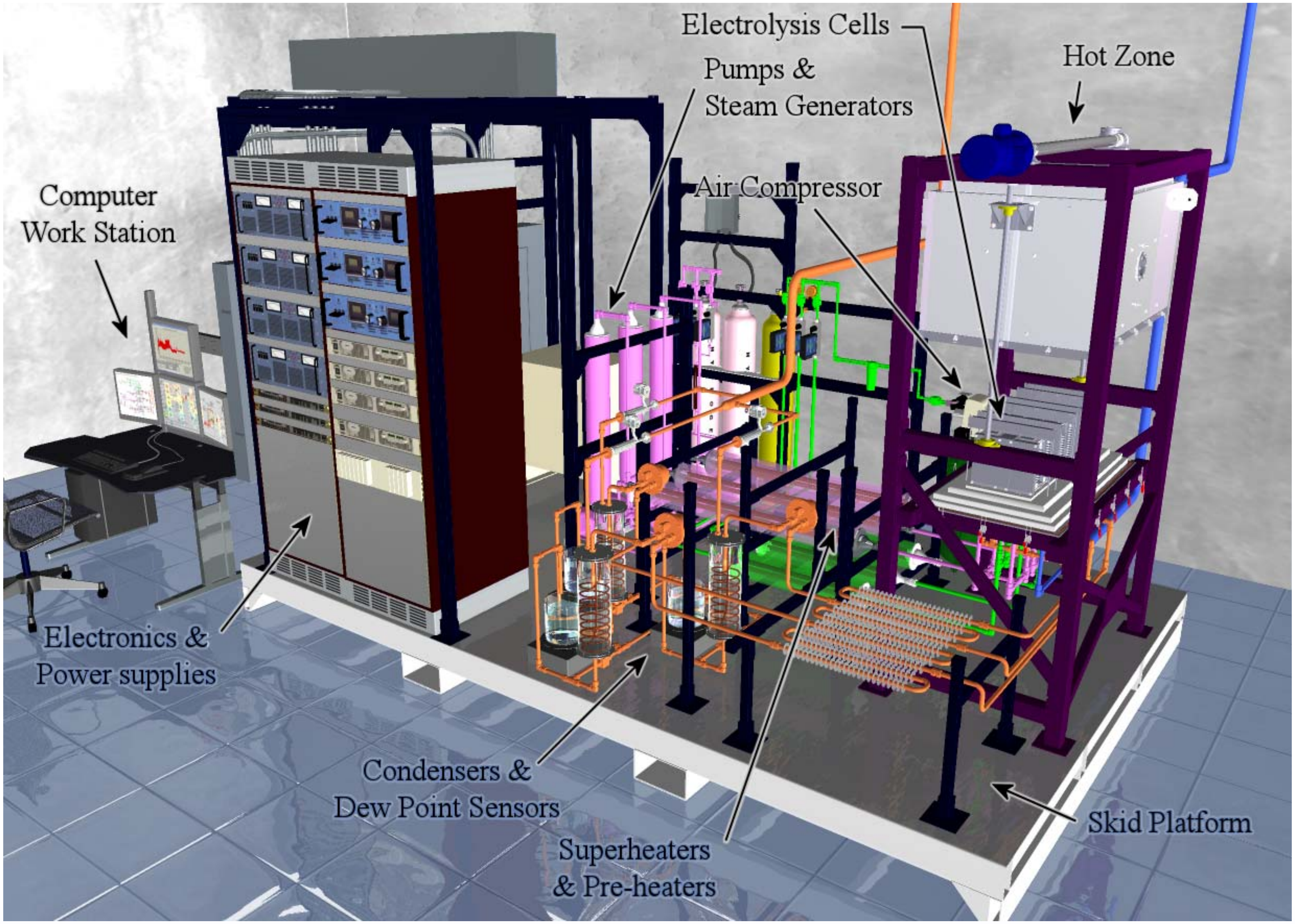
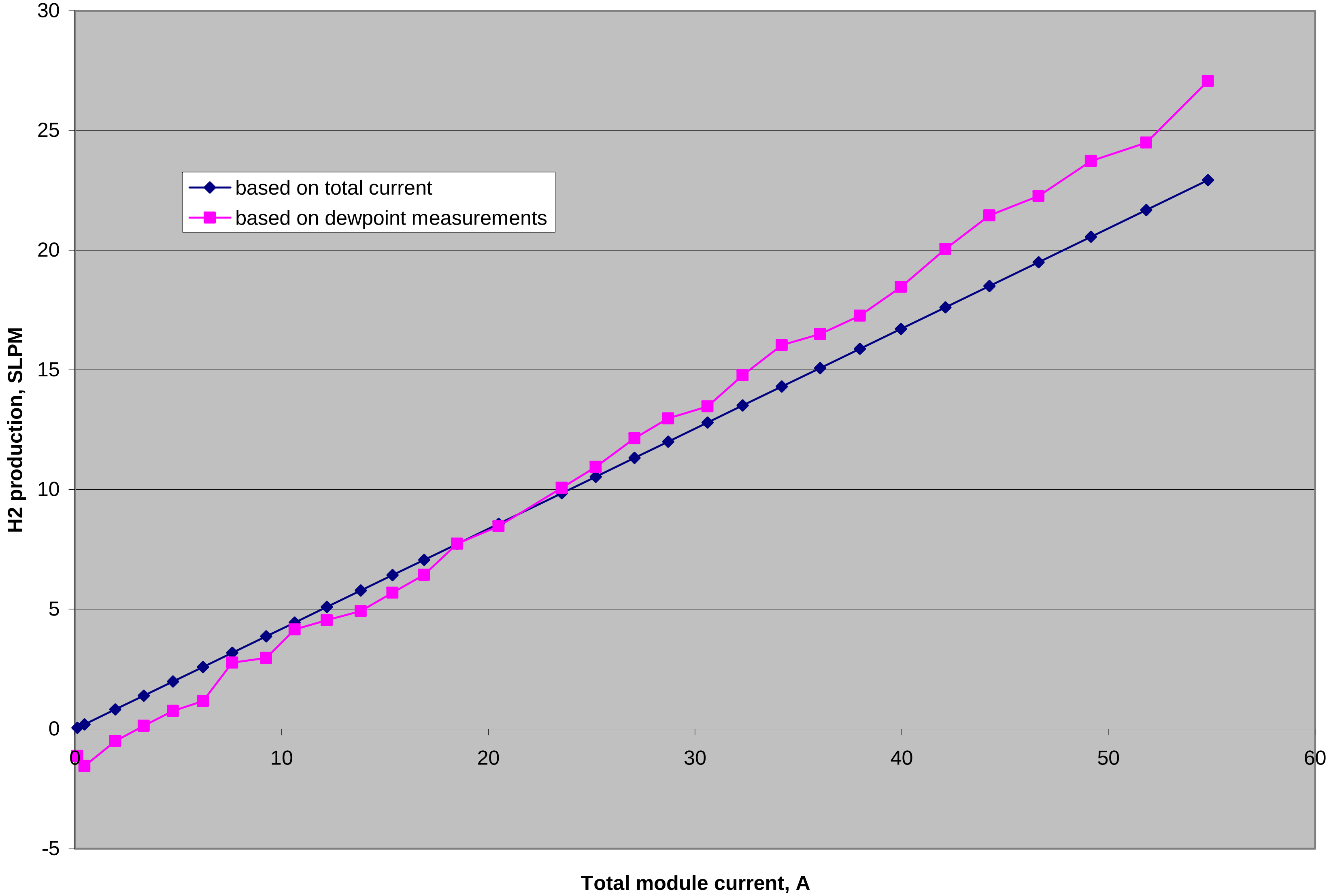
Review of Experiment



Carl Stoots, Joe Hartvigsen and Jim O'Brien in front of the ILS skid as it begins operation with a single module, September 25, 2007



Comparison of the hydrogen production rate as measured by the total current and by the change in dewpoint.

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HTE ILS Operating conditions, Sept. 26, 2007

Steam generator outlet temperature	164° C
Steam-superheater outlet temperature	812° C
Air superheater outlet temperature	748° C
Hot Zone Temperature	810° C
H_2/Steam product outlet temperature	856° C
Deionized water input	34.0 ml (liquid)/min
	42.3 normal liters (steam)/min
H_2 input	3.0 normal liters/min
N_2 input	5.4 normal liters/min
Air input (as sweep gas)	25.0 normal liters/min
Dewpoint at inlet to module	92.3° C
Dewpoint at outlet from module	72.1° C
Module Voltage	78.7 V
Module current	51.7 A
Intermediate voltages of groups of 5 cells	6.0 V – 6.8 V
Temperatures at top of module	
Stack 1	816.8° C
Stack 2	822.5° C
Stack 3	818.3° C
Stack 4	830.7° C
Bottom of module	828° C
H_2 production rate	22 normal liters/min
	1.32 normal m^3/hour

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