Non-Electric Applications of Nuclear Power: Hydrogen Production

Status of the Sulfur-Iodine Engineering Demonstration Loop

Robert Buckingham

18 April, 2007

Thermochemical cycles decompose water rather than carbon-based fuels to produce hydrogen

- Carbon-neutral, unlike steam reforming of methane
- Many cycles have been studied, including UT-3, Calcium-Bromide, and Sulfur-Iodine (S-I)
- Temperatures above 800C suitable for HTGR
- Unit operations of hydrogen plant scale economically like a refinery or chemical plant
- S-I Cycle invented at General Atomics in 1970's

Details of the Sulfur-Iodine Cycle

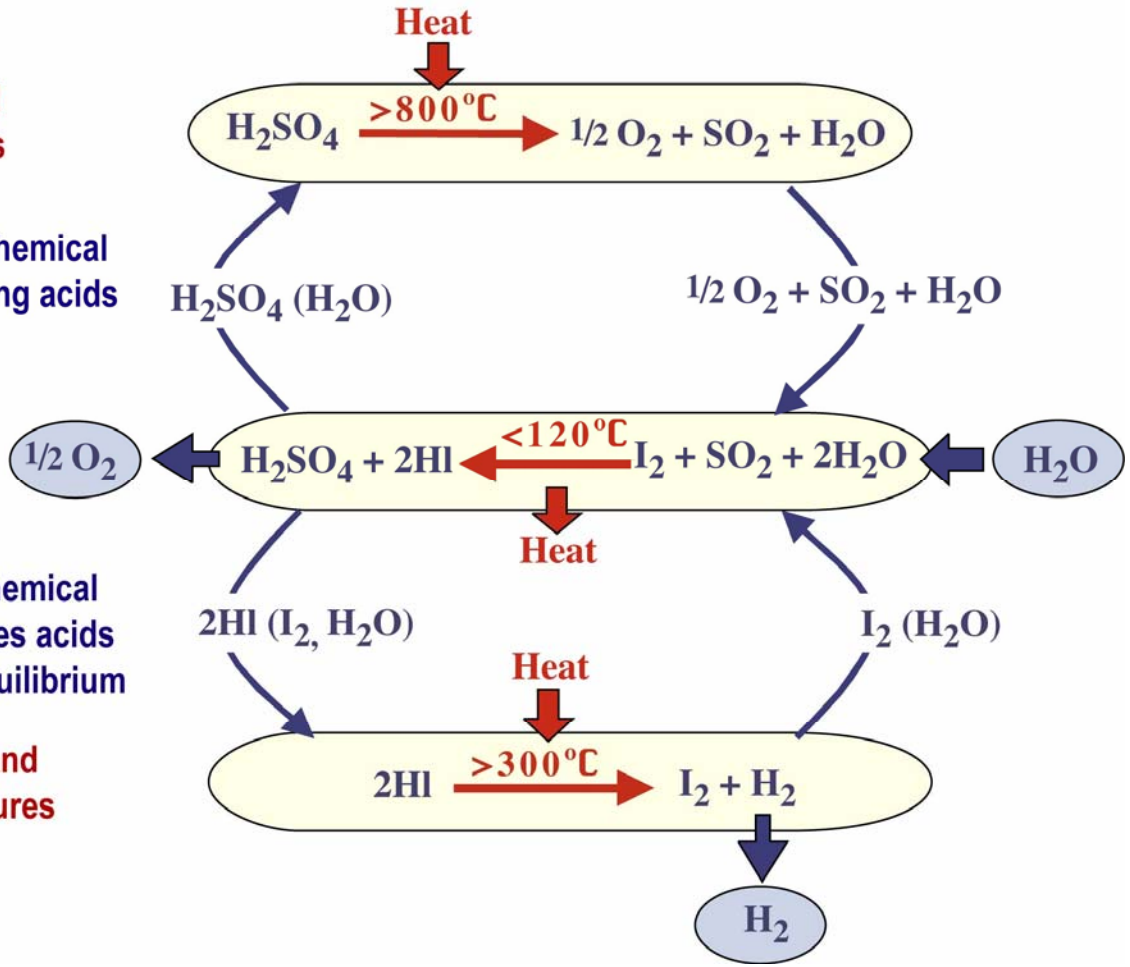
Sulfuric acid is concentrated and decomposed at high temperatures

Excess water shifts chemical equilibrium by hydrating acids

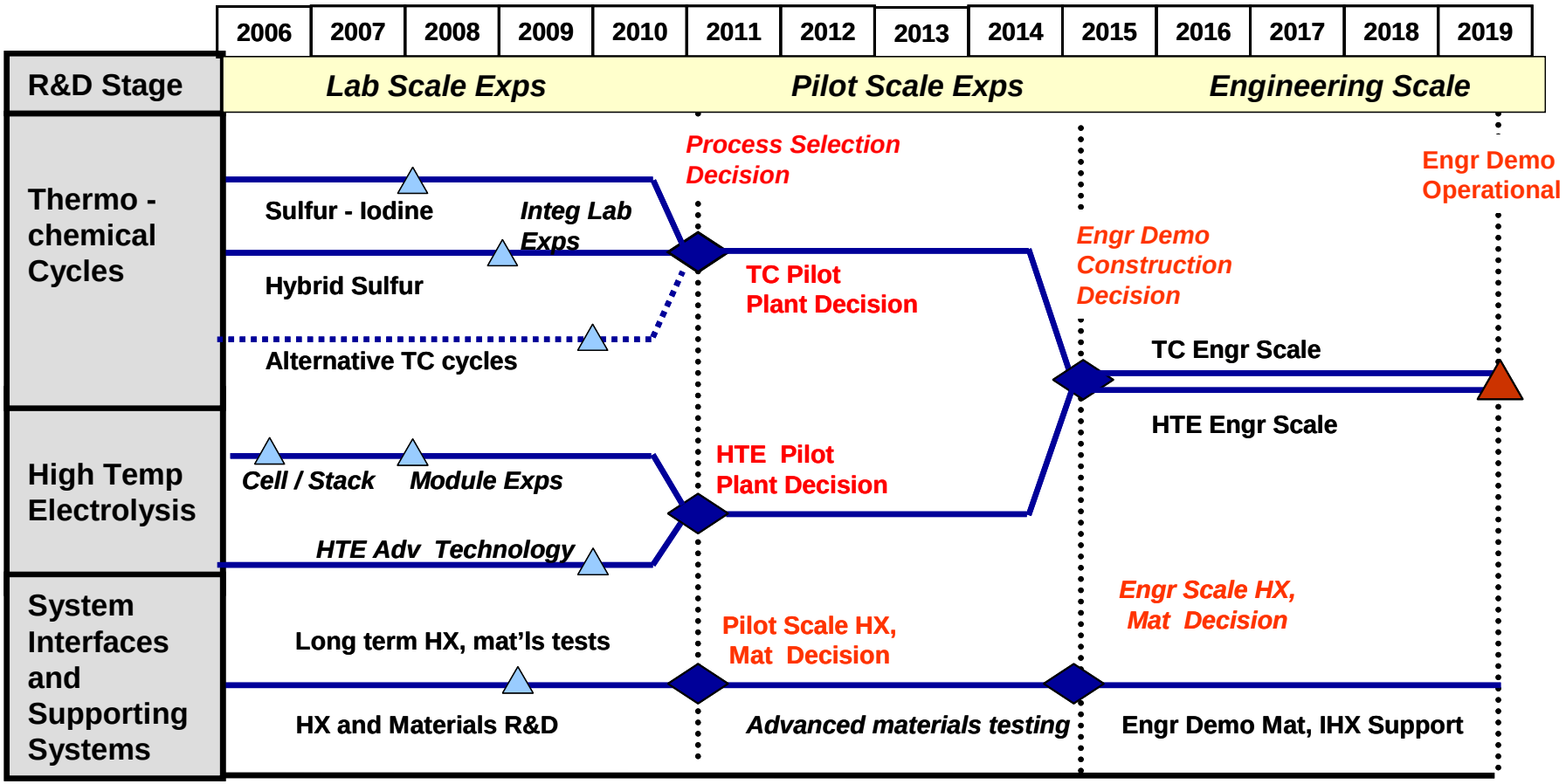
Bunsen reaction produces acids and releases waste heat to the environment at low temperatures

Excess iodine shifts chemical equilibrium and separates acids by liquid-liquid phase equilibrium

Hydrogen iodide is concentrated and decomposed at moderate temperatures



The DOE Nuclear Hydrogen Initiative has selected the Sulfur-Iodine Thermochemical cycle for early demonstration



Project objectives support pilot plant design

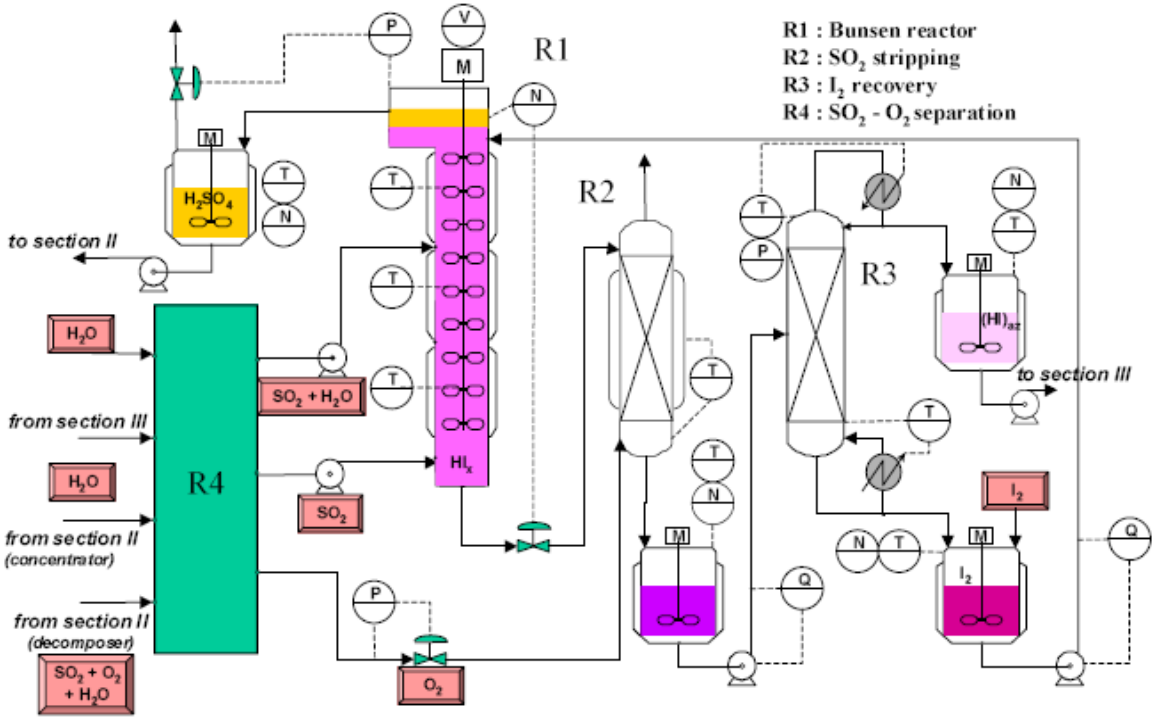
- **International Nuclear Energy Research Initiative (INERI) Integrated Lab-Scale (ILS) Demonstration**
  - Engineering materials
  - Engineering pressures
  - 100-200 standard liters per hour of hydrogen
  - Possible scaleup to 1000 liters per hour

A closed loop demonstration facility is under construction at General Atomics

- **Sandia National Laboratory- USA**
  - Project lead
  - Sulfuric acid decomposition
- **Commissariat à l'Energie Atomique - France**
  - H2SO4 and HI generation (Bunsen reaction)
- **General Atomics - USA**
  - Facility coordinator
  - HI decomposition

Section 1 (Bunsen Reaction) produces two acid phases in the main reactor …

$$9I2 + SO2 + 16H2O \rightarrow (2HI + 10H2O + 8I2) + (H2SO4 + 4H2O)$$



Net Reaction =

$SO2 + I2 + 2H2O \rightarrow H2SO4 + 2HI$

Exothermic Reaction

$\Delta H = -52.626$ kcal/mole

$\Delta G = -10.737$ kcal/mole

I2 Melting Point ~ 114°C

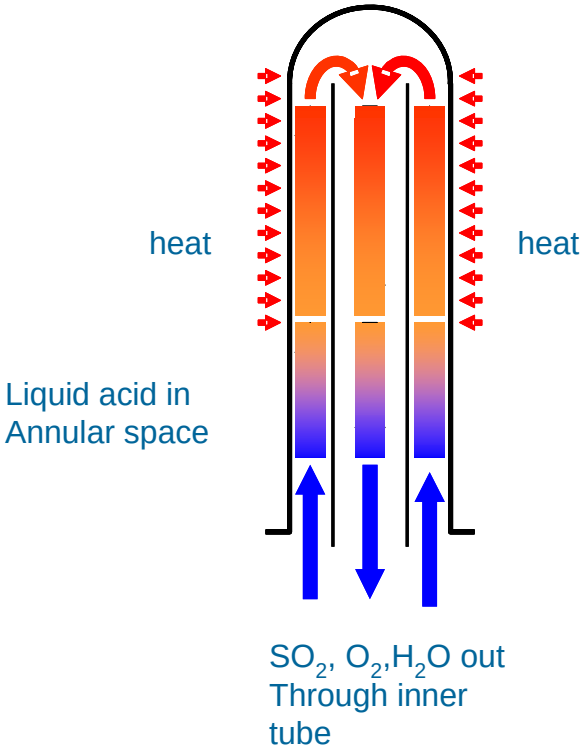
Undesirable side reactions possible at higher temperatures, but temperatures up to 150°C are being considered

CEA has constructed a Bunsen reaction device in France

- Equipment assembly is complete in Marcoule
- Testing with water and air is complete
- Testing with chemicals is underway
- Equipment is scheduled to arrive at General Atomics before July 2007

Section 2 (sulfuric acid decomposition) generates SO2 for return to the Bunsen reaction …

Integrated Bayonet Acid Decomposer Design Concept



Net Reaction =

$H_2SO_4 \rightarrow SO_2 + H_2O + \frac{1}{2}O_2$

SO_3 is an intermediate component

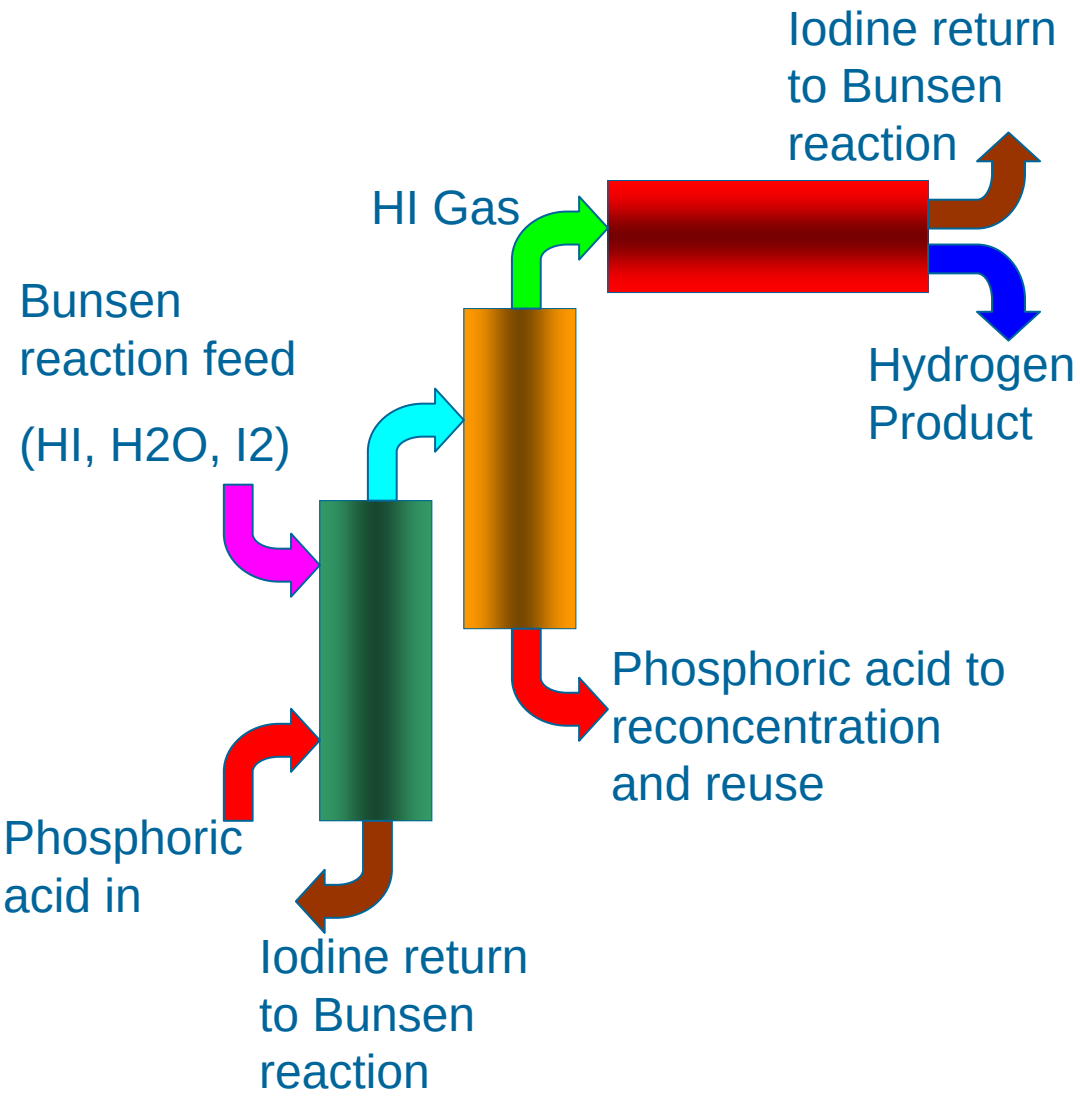
Acid boiling, superheating, decomposition, and heat recuperation are combined into a single unit

Use of silicon carbide eliminates metal creep at high temperatures and pressure drops

SNL has constructed a sulfuric acid decomposition device in New Mexico …

- Equipment assembly is complete in Albuquerque
- Testing with water and air is complete
- Testing with chemicals is complete
- Equipment is scheduled to arrive at General Atomics before May 2007

Section 3 (hydriodic acid decomposition) generates the product hydrogen …



Net Reaction =

$2HI \rightarrow H_2 + I_2$

Iodine removed from HI/water with phosphoric acid for return to Bunsen reaction

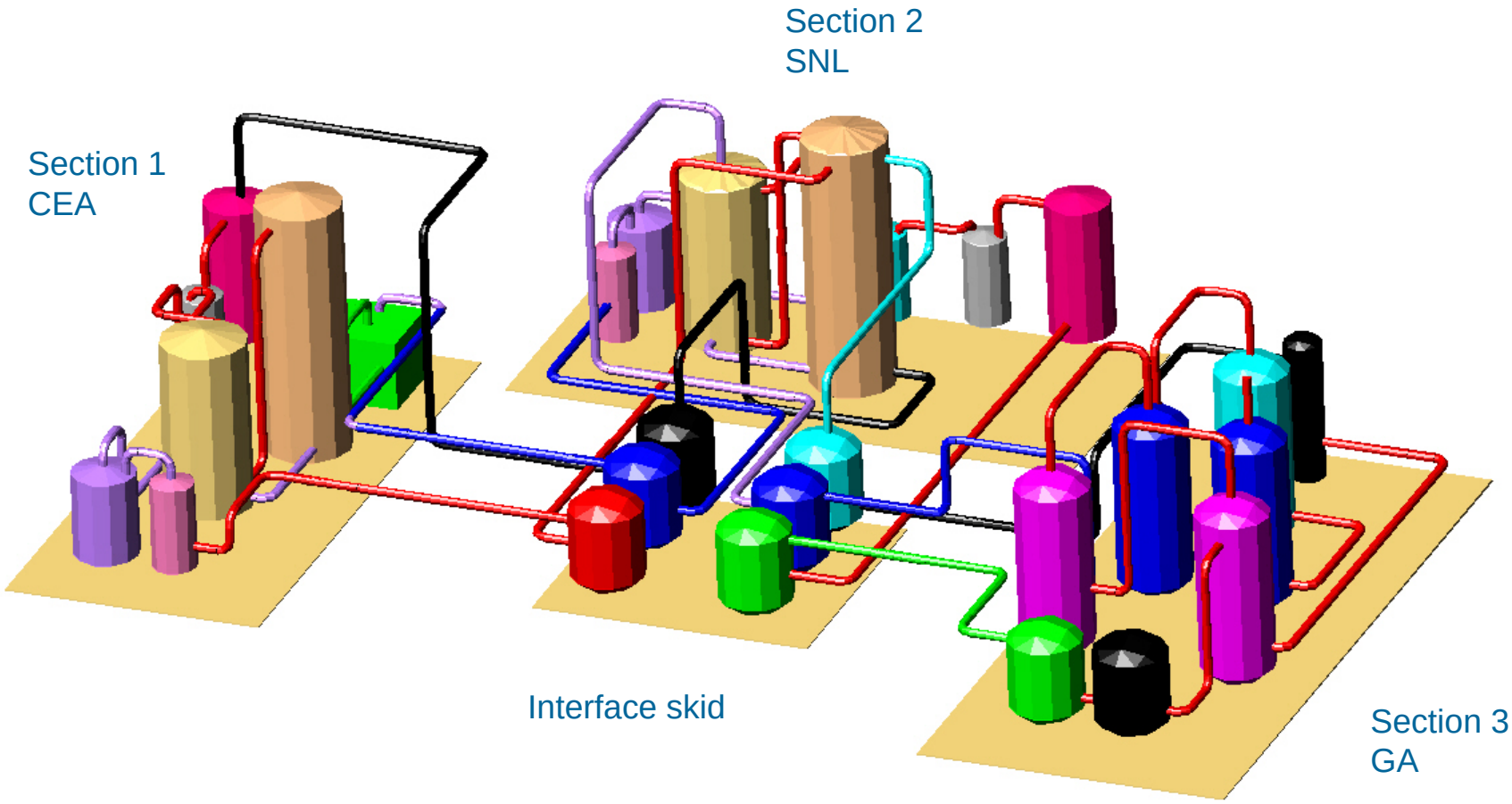
Pure HI then distilled away from water/phosphoric acid. Phosphoric acid is reconcentrated and reused.

HI then decomposed over a carbon catalyst

GA has constructed a hydriodic acid decomposition device in California …

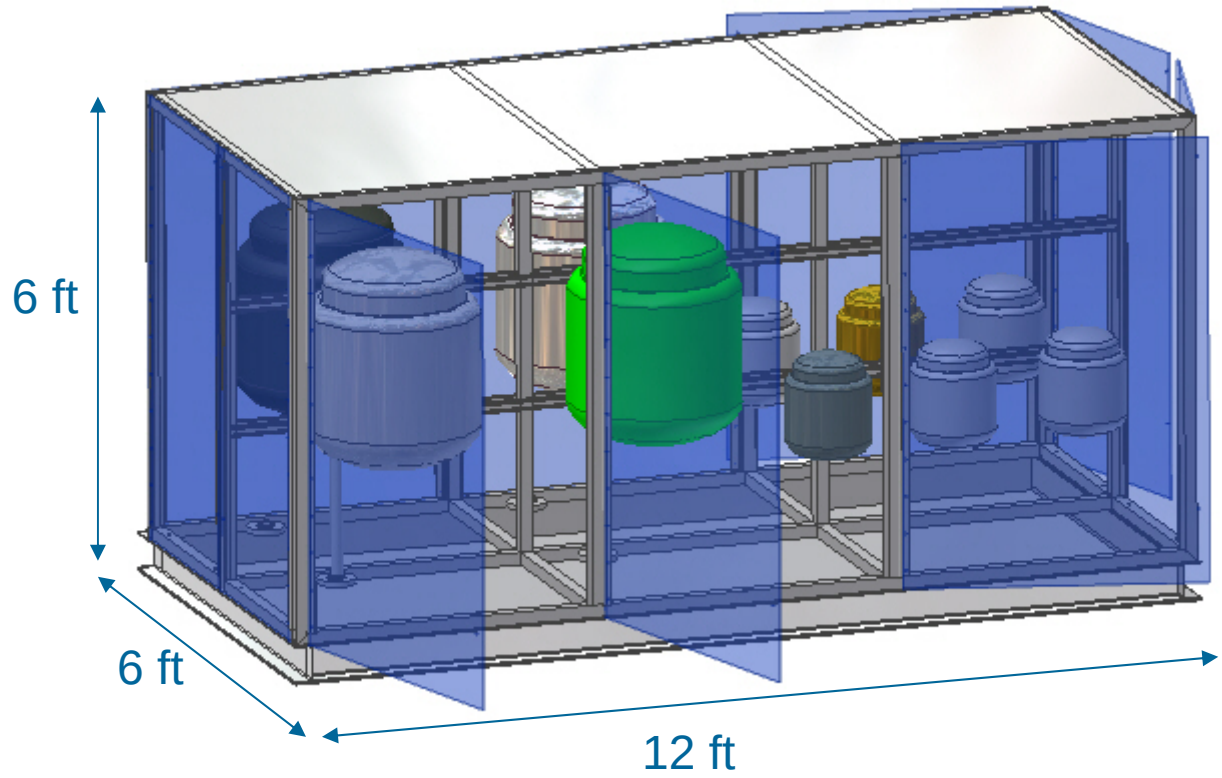
- Equipment assembly is complete in San Diego
- Testing with water and air is underway
- Testing with chemicals is scheduled for May, 2007
- Equipment will be integrated with other sections starting June, 2007

An Interface skid will allow for independent operation during start-up and troubleshooting



Interface Skid puts fluid transfer and storage capability into one location …

- **Components:**
  - 2 HIx tanks
  - 2 I2 tanks
  - 4 water tanks
  - 2 H2SO4 tanks
- HIx and I2 tanks are glass lined steel 90 L vessels
- Water and H2SO4 tanks are plastic 20 L vessels
- Process skids are linked through the interface skid
- Allows independent skid operation during startup
- Buffer between sections will ease integration



GA is constructing the interface skid in California …

- Equipment assembly is underway in San Diego
- Leak testing with water and air scheduled for early May, 2007
- Operation with chemicals is scheduled for late May, 2007
- Equipment will be integrated with other sections starting June, 2007

GA is preparing the facility for the ILS …

- Separate ventilation systems for each skid
- Integrated safety plan
- All liquid waste captured for disposal, with scrubbers for gas streams
- Wet chemistry labs for analysis
- Control room for system operation

In summary …

- The Sulfur-Iodine Engineering Demonstration Loop construction is in work and on schedule
- Individual skid testing and initial integration work through 2007
- Fully integrated experimentation and operation through 2008
- Potential scaleup to 1000 liters per hour in 2009
- Representatives from CEA and SNL will work long-term at the GA site on the project
- Organizations from other countries interested in participating