# Nuclear Hydrogen Initiative

*Programmatic Overview*

**Office of Advanced Nuclear Research**
**Office of Nuclear Energy, Science and Technology**

FY 2003

# Nuclear Hydrogen Initiative

## Program Goal

- Demonstrate the economic commercial-scale production of hydrogen using nuclear energy by 2015

## Need for Nuclear Hydrogen

- Hydrogen offers significant promise for reduced environmental impact of energy use, specifically in the transportation sector
- The use of domestic energy sources to produce hydrogen reduces U.S. dependence on foreign oil and enhances national security
- Existing hydrogen production methods are either inefficient or produce greenhouse gases
- As an emission-free source of energy, nuclear energy provides the opportunity to produce very large quantities of hydrogen without emitting greenhouse gases or other harmful air emissions

# Nuclear Hydrogen Initiative

- **Integrate applicable work conducted in programs in the Offices of Nuclear Energy (Gen IV, NERI, I-NERI), Energy Efficiency and Renewable Energy, and Fossil Energy**

- **Program Milestones (may be revised by R&D Plan)**
  - FY 2003: Develop a Nuclear Hydrogen R&D Plan defining the R&D for the Nuclear Hydrogen Initiative
  - FY 2006: Complete a demonstration of a laboratory scale thermochemical hydrogen production system
  - FY 2010: Complete the design of a commercial-scale nuclear hydrogen production system
  - FY 2015: Demonstrate commercial-scale hydrogen production using heat from a nuclear reactor

# Nuclear Hydrogen R&D Plan

- **Purpose -- define the R&D path to develop a viable nuclear hydrogen production capability by 2015 – economics, technology, implementation strategy**
- **Focus – on most promising production methods for nuclear application – not covered in other $H_2$ programs**
- **Approach – define options for production, determine what needs to be known before decisions can be made on the next level of demonstration**
  - Define R&D needed at each level of demonstration (Lab, Pilot, Demo)
  - Develop logic/approach that is robust to budget uncertainties (risk/benefit)
  - Guide the development of technology to support decisions
- **Develop draft by end of FY 2003**

# Nuclear Hydrogen R&D Plan
## *Management/Integration*

- **Develop R&D Plan, identify technical areas, technical area leads, establish R&D plan development schedule**
- **Technical Integrator**
  - Charles Park - INEEL
- **Integration Team**
  - Charles Park (INEEL – Technical Integration)
  - John Kotek (ANL Hydrogen initiative)
  - Paul Pickard (Gen IV Tech Dir for Energy Conversion)
  - David Henderson (DOE-NE)
  - Mark Paster (DOE-EE)
- **Integrate technical inputs, metrics, decision processes, develop draft nuclear hydrogen R&D plan.**

# Nuclear Hydrogen R&D Plan
## *Technical Leads*

- **Technical Leads - evaluation of nuclear hydrogen production methods and system/infrastructure issues:**
  - Thermochemical Cycles - Charles Forsberg (ORNL), Michele Lewis (ANL)
  - Thermally -Assisted Electrolysis - Steve Herring (INEEL)
  - Barrier and alternative production technologies – Tim Armstrong (ORNL), David King (PNNL)
  - Infrastructure, balance of plant issues - Mel Buckner (SRTC), Blaine Grover (INEEL)
- **Technical Leads**
  - Solicit input from technical experts, provide support as available
  - Interface with other hydrogen programs/projects within DOE (NE, EE, FE) where appropriate
  - Integrate inputs for technical areas – descriptions, potential, status, R&D needed

# Nuclear Hydrogen R&D Plan

## *Proposed Timeline*

**3/14 -- Input from Planning Workshop**

**4/4 -- Finalize R&D Plan outline/content, identify Technical Leads**

**-- Technical Leads identify initial list of candidate concepts, contributors**

**4/18 -- Technical Leads solicit input on concepts, process, -- make assignments**

**6/6 -- Technical Leads assembles initial input, arrange telecons/ meetings to review, discuss technical gaps and R&D needs**

**7/11 -- Technical Leads provide draft R&D reports provided for review**

**8/8 -- Final Technical reports provided to Integration Team**

**8/29 -- Draft R&D Plan assembled by Integration Team**

**9/30 -- R&D Plan review complete**

# Nuclear Hydrogen R&D Plan

## *Suggested Outline*

1. **Goals and objectives**

   - Nuclear hydrogen perspective, objectives

2. **R&D Plan Approach**

   - Scope, schedule, economic context / metrics

3. **Description of Candidate Hydrogen Production Cycles**

   - Process, Status, Issues, Benefits, R&D needed
   - Thermochemical, electrolysis, barrier, alternatives

4. **System Issues**

   - Balance of Plant, Safety, Regulatory R&D needs

5. **Detailed R&D Description**

   - Process, system, safety, schedule, costs, metrics

6. **Demonstration/Implementation strategy**

   - Demonstration scale, criteria, metrics, selection process

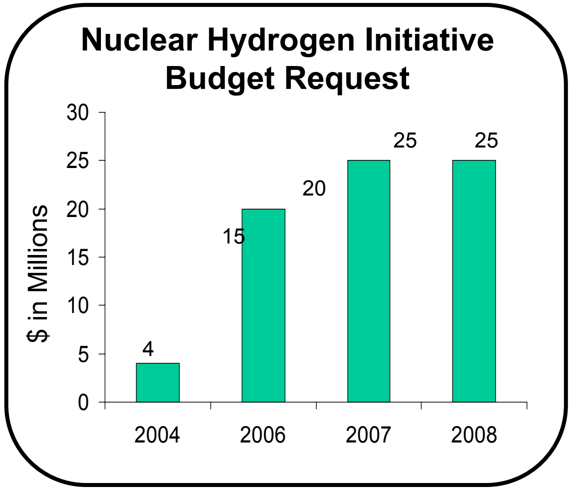
# Nuclear Hydrogen R&D Plan
## *Development Considerations*

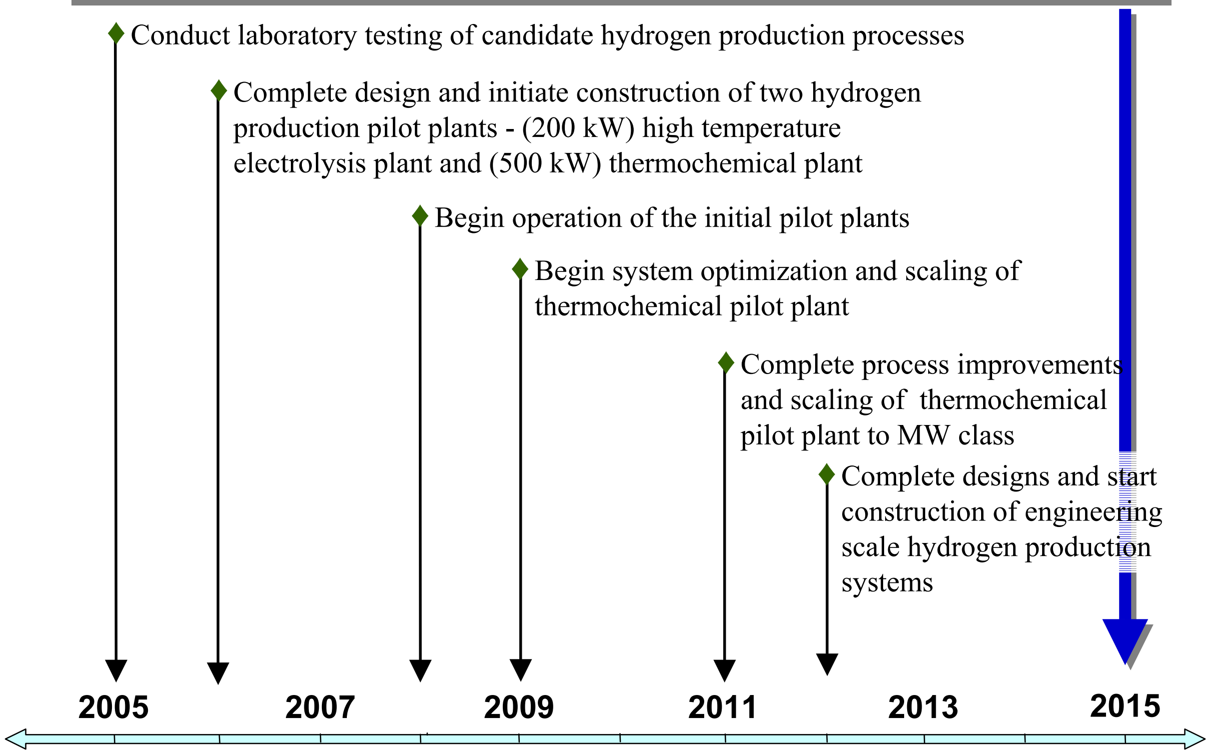
- **Determine Schedule**
  - 2015 – nuclear hydrogen demonstration goal
  - Pilot scale demo for selected technology(s) by 2010?
  - Lab scale evaluation needed by 2006
- **Focus on processes relevant to the 2015 target – longer term research pursued in basic R&D programs (NERI, Office of Science, etc.)**
- **Implementation Approach**
  - Multiple (budget driven) evaluation of candidate technologies at Lab scale
  - Downselect to 1 (or 2) for pilot plant demo (~300 kW class)
  - Identify demonstration H2 system by 2010
  - Integrated nuclear commercial scale demo (5-50 MW) - 2015
  - Industry/International participation where possible

# Nuclear Hydrogen Initiative

## *Preliminary Estimated Funding Requirements*

**Goal:** Couple advanced hydrogen production technology with Next Generation Nuclear Plant (NGNP) demonstration plant to demonstrate economic, commercial-scale hydrogen production by 2015.



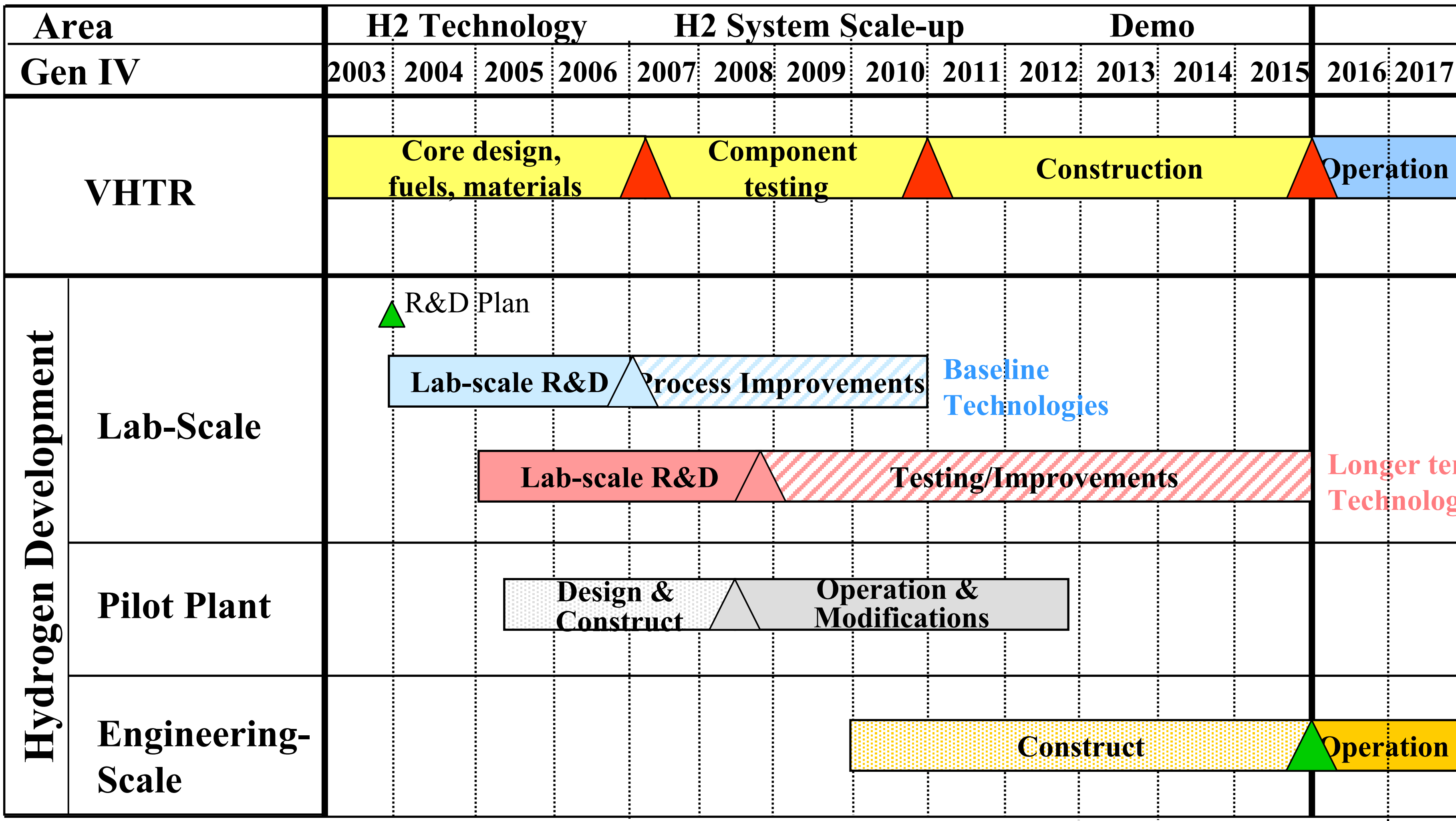

**Significant Accomplishments**

**2002:** Completed DOE *National Hydrogen Energy Roadmap*

**2003:** Complete nuclear hydrogen R&D plan

**2004:** Initiate R&D to develop nuclear hydrogen production capabilities

# Generation IV Hydrogen R&D Plan - Major Milestones




Draft

# BACKUP

# Ongoing Nuclear Hydrogen Research

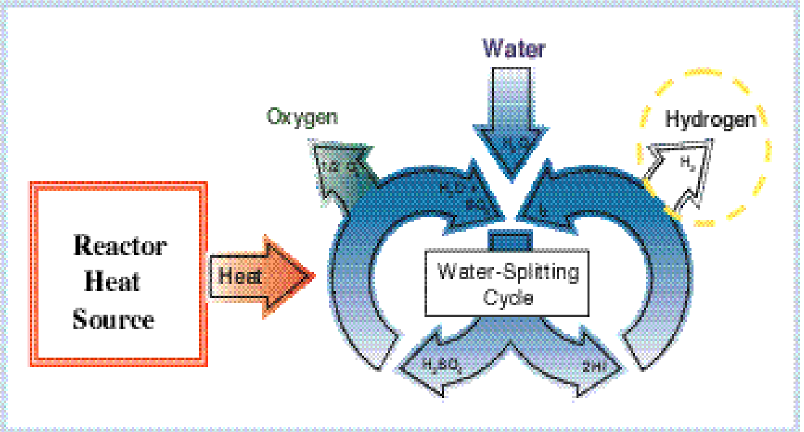
- **Nuclear Energy Research Initiative (NERI) – 1 completed project, 4 ongoing projects**
  - 1999 (completed) -- *High Efficiency Generation of Hydrogen Fuels Using Nuclear Power*
  - 2000 -- *Nuclear Hydrogen Using Thermochemical Cycles including Calcium-Bromine (Ca-Br)*
  - 2002 -- *Nuclear-Energy-Assisted Plasma Technology for Producing Hydrogen*
  - 2002 -- *Hydrogen Production Plant Using the Modular Helium Reactor*
  - 2002 -- *Centralized Hydrogen Production from Nuclear Power: Infrastructure Analysis and Test-Case Design Study*
- **International NERI – 1 project**
  - 2001 -- *High Efficiency Hydrogen Production from Nuclear Energy: Laboratory Demonstration of S-I Water-Splitting*

# NERI Hydrogen Research

## General Atomics (GA)/Sandia National Labs/Univ. of Kentucky

### "High Efficiency Generation of Hydrogen Fuels Using Nuclear Power"

- **GA/SNL/UoK reviewed world literature**
  - 822 references, 115 separate cycles
- **Screened these and selected 25 cycles for detailed evaluation**
- **Identified the S-I cycle as best suited for hydrogen production from a nuclear heat source**
  - Higher efficiency, easier handling
  - France, Japan have also selected the S-I cycle
- **Developed thermodynamic models for H2SO4/H2O and HI/I2/H2O**
- **Developed flowsheet for S-I cycle**

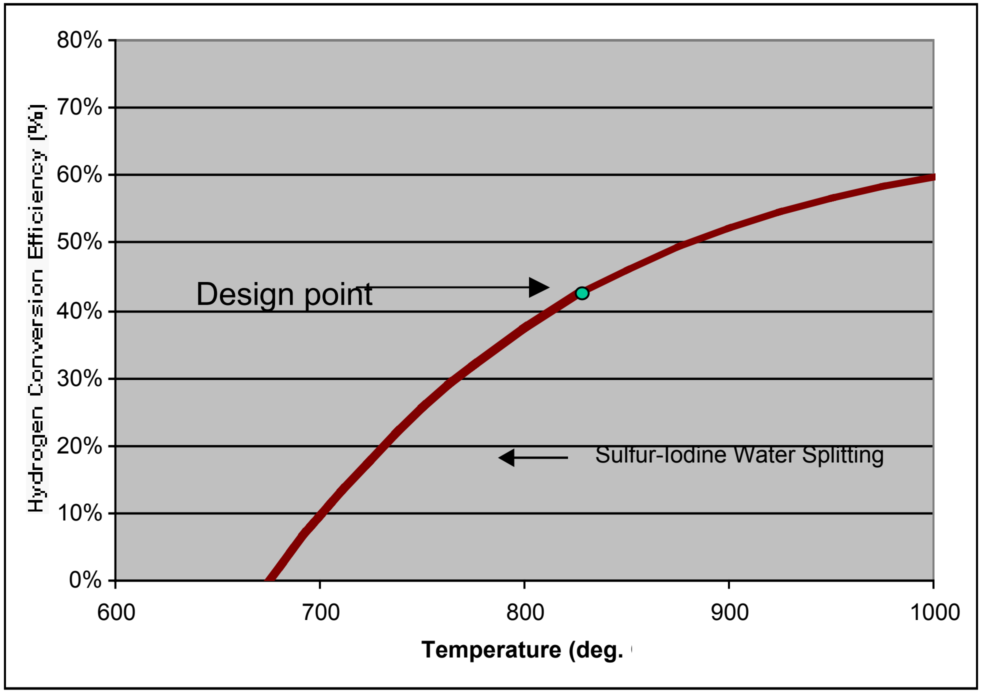


# NERI Hydrogen Research

## *GA/Sandia/Univ. of Kentucky (cont.)*

### Estimated S-I Process Thermal-to-Hydrogen Energy Efficiency (HHV)

- **Process is coupled to nuclear heat source by an intermediate loop with 2 heat exchangers ~50°C ➂T**
- **Earlier studies used 827°C, achieved 42% efficiency**
- **>50% efficiency requires >900°C peak process T**
- **Reactor outlet T >950°C desired**



# NERI Hydrogen Research
## *Argonne National Lab/Texas A&M Univ.*

### "Nuclear Hydrogen Using Thermochemical Cycles including Calcium-Bromine (Ca-Br)"

- A Ca-Br cycle is proposed with a 44 percent efficiency
- Easy solid-gas separations
- Lower Temperature (750°C) – lower materials demands
- Ambient pressure operations
- Calcium and bromine are easily available, there is no chemical use of strategic materials
- The only corrosive agent is hydrogen bromide (HBr)
- Significant opportunities for improvement with higher temperatures
- Need to more fully examine the design details
- Experimental materials development and evaluation needed

# NERI Hydrogen Research

## *Idaho National Engineering & Environmental Lab*

### "Nuclear-Energy-Assisted Plasma Technology for Producing Hydrogen"

- **Initial Status**
  - Sodium-borohydride has the potential to be an excellent carrier of hydrogen, reducing the technical and economic requirements to store and deliver the hydrogen to the end user
  - No technology exists to produce sodium borohydride economically
- **Current Status - relationships between electrode materials, electrode configuration, process temperature, and power requirement on sodium borate to sodium borohydride conversion will be studied**
- **Expected Results**
  - A bench scale research unit for process demonstration
  - Basic R&D data to support the scientific basis of the technical concept

# NERI Hydrogen Research
## *GA, INEEL, Texas A&M University, Energy Nuclear*

### "Hydrogen Production Plant Using the Modular Helium Reactor"

### Initial Status

- The 1999 NERI showed SI process with an MHR to be economically competitive with steam reforming of methane and even stronger with inclusion of CO2 costs and/or modest increases in the price of natural gas
- Detailed flow sheet of SI process developed and analyzed using Aspen simulation software.  Efficiencies calculated as a function of the temperature of the process heat.

### Expected Results

- Develop functions and requirements for a hydrogen production plant using the MHR
- Develop a conceptual design for an MHR/SI hydrogen plant
- Assessments of plant design with respect to performance, safety, economics, and licensing

# NERI Hydrogen Research

## *Savannah River/University SC/GA/Entergy*

### "Centralized Hydrogen Production from Nuclear Power: Infrastructure Analysis and Test-Case Design Study"

- **Project Objectives**
  - Identify, characterize and evaluate the critical technical and economic issues associated with hydrogen production from nuclear power
  - Assess combination of hydrogen infrastructure issues with the latest reactor and thermochemical process concepts
- **Expected Outcomes:**
  - Define physical characteristics and economics of nuclear hydrogen plant
  - Analysis of infrastructure needs and characteristics
  - End-user economics and interface issues
  - Pre-conceptual design for nuclear hydrogen plant supplying regional chemical plant
  - Define needs and path forward for commercialization

# I-NERI Hydrogen Research

## *France (CEA)/General Atomics/Sandia National Labs*

### "High Efficiency Hydrogen Production from Nuclear Energy: Laboratory Demonstration of S-I Water-Splitting"

- **Project Objective**
  - Demonstrate operation of major process components of Sulfur-Iodine (S-I) thermochemical cycle operating at prototypical temperatures and pressures
- **Laboratory Demonstration of S-I Water-Splitting**
  - Sulfur-Iodine Cycle developed in 1970's, lab scale loop built and operated at GA in 1979-1980. (glassware – ambient pressure, open loop operation)
  - Japan has built and operated lab scale system (~1 liter/hr H2) under non-prototypic conditions
  - JNC plans a larger closed loop demonstration (~50 l/hr) under non-prototypic conditions

# I-NERI Hydrogen Research
## *France (CEA) (cont.)*

### Project Approach

- Three year program
  - Develop three independent modules corresponding to major subsystems of S-I Cycle
    - CEA - Bunsen reaction ($SO_2 + xI_2 + 2H_2O \rightarrow H_2SO_4 + 2HIX$)
    - Sandia - Sulfuric acid concentration and decomposition ($H_2SO_4 \rightarrow H_2O + SO_2 + 1/2O_2$)
    - GA - Hydrogen Iodide concentration and decomposition ($2HIX \rightarrow xI_2 + H_2$)
- Next Step – System Integration
  - Integrate three subsystems at a single site
  - Demonstrate integrated hydrogen production at a rate of ~100 liters per hour