2005 DOE Hydrogen Program: NHI System Interface and Support Systems

Steven R. Sherman, Ph.D.

Idaho National Laboratory

May 25, 2005

Project ID #PD31

Overview

Timeline

- Start: Jan 2004
- End: 2017+
- Project provides ongoing support to DOE NHI

Budget

- Total project funding
  - Projected DOE funding is $37M through 2014
  - Cost sharing may be pursued by 2010
- FY04: $1.86M
- FY05: $2.79M

Barriers

- High temperature structural materials identification & development
- High temperature heat transfer fluids
- High temperature heat exchanger designs and components
- System modeling
- Reactor/process interaction analysis
- Codes, standards, safety

Partners

- Currently INL, ORNL, SNL, UNLV RF (Ceramatec, GA, MIT, UCB, others)

Objectives

- Project Objectives
  - To assist DOE in the development of a high-temperature heat transfer network to enable the linkage of a high temperature nuclear reactor to a nuclear hydrogen production plant (System Interface)
  - Support development of hydrogen plant ancillary systems and infrastructure for pilot-scale and engineering-scale nuclear hydrogen production plants (Support Systems)
- FY 2005 Objectives
  - Determine regulatory/safety factors relevant to determining nuclear plant/hydrogen plant spacing
  - Perform analysis of heat transfer fluids and system characteristics
  - Determine specific heat exchanger requirements, determine candidate materials, and develop preliminary concepts for system interface heat exchangers

Approach (1)

- Materials
- HX Concepts
- Modeling
- Codes/Safety

→

- HX Designs
- System models

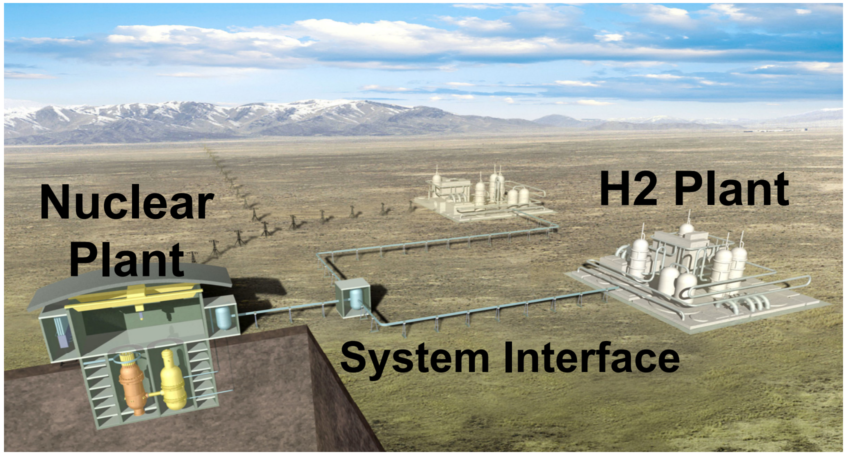
→

- Lab Testing
- System designs
- Improved models

→

- Support pilot-scale and engineering-scale decisions

- Initially, parallel paths
  - Materials and heat transfer fluid analysis
  - Conceptual designs
  - Modeling
  - Codes/safety
- Narrowed focus as project advances
  - Development and testing of hardware
- Ultimately, project must support pilot-scale and engineering-scale design decisions



Approach (2)

- Multi-laboratory effort involving national laboratories, universities, and private companies
  - INL, ORNL, Sandia
  - UNLV Research Foundation
    - Ceramatec
    - General Atomics
    - MIT
    - UC-Berkeley
  - Expansion to other laboratories in future as needed to support the project

Technical Accomplishments (1)

- Infrastructure
  - Defined infrastructure requirements for pilot-scale hydrogen production plants (Mar 2004)
- Balance of Plant
  - Defined initial balance-of-plant requirements for nuclear hydrogen plants (Jun 2004)
- System Interface – most efforts concentrated here
  - Identification of technical requirements and relevant technical issues
  - High temperature materials investigations and development
  - Heat transfer fluid and systems effects investigations
  - High temperature heat exchanger development

Technical Accomplishments (2)

- System Interface technical requirements and issues identified (INL, MIT, UC-Berkeley, MIT, Sept 2004)
  - Broadly covers materials, mechanical construction, operation, and safety needs and issues
- Initial study of nuclear plant/hydrogen plant spacing requirements performed (INL, Mar 2005)
  - Probabilistic Safety Assessment (PSA) tools used
    - ALOHA code for chemical dispersion events
    - SAPHIRE code to perform probabilistic risk analyses
  - Factors considered
    - Probability of nuclear core damage less than 10^{-6}
    - Past history of hydrogen events at commercial BWR's, PWR's
    - Possible effects of hydrogen explosions, chemical leaks on nuclear plant
  - Results
    - Spacing between 60 m and 120 m is possible, depending upon placement of blast barriers, control room placement, etc.

Technical Accomplishments (3)

- Initiated study of the influence of heat transfer fluid choice (helium, molten salt) and nuclear reactor power conversion configuration (direct, indirect, variations) on thermal-hydraulics, mechanical stresses, structural materials choices for system interface (INL)
- Study of nickel-based high temperature alloys for application to heat exchangers (UNLV, MIT, UC-Berkeley, GA)
  - Initiated SCC testing of Waspaloy under slow-strain-rate conditions in presence of S-I fluids and cathodic and anodic potential fields
  - Preparing to test Incoloy 800H, Zr-705, Nb-1Zr, Nb-7.5Ta under constant load conditions
- High temperature heat exchanger design modeling for secondary and process heat exchangers (UNLV)
  - Performed CFD modeling of compact design involving grid spacing studies, channel dimension parametrics, mechanical stress analysis, temperature profile analysis (FLUENT)
  - Incorporating H_2SO_4 decomposition behavior into process heat exchanger modeling to monitor effects on temperature and stress.

Technical Accomplishments (4)

- **Development of Incoloy 800H + Pt and Inconel 617 + Pt added alloys for catalytic heat exchangers (MIT)**
  - Created buttons of 800H and 617 + Pt added material and converting buttons to wrought shapes for testing
  - Constructed catalyst test system to test catalytic activity
- **Corrosion studies of materials in liquid HI-I_2-H_2O at 400-450 °C for application to S-I process (GA)**
  - 22 metallic and non-metallic materials tested using exposed coupons (Nb and SiC-C composites among clear winners)
  - Test apparatus installed to study effects of materials processing on corrosion rates
- **Identification of non-metallic materials, manufacturing techniques, and heat exchanger designs for high-temp operation (Ceramatec)**
  - Non-metallic material choices identified
    - SiC, $MoSi_2$, Ti_3SiC_2, Si_3N_4, Al_2O_3, SiAlON, Cordierite ($Mg_2Al_4Si_5O_{18}$)
  - Identification of critical issues performed
    - Manufacturability/cost, corrosion and thermal shock resistance, thermal conductivity, reliability, strength, creep resistance

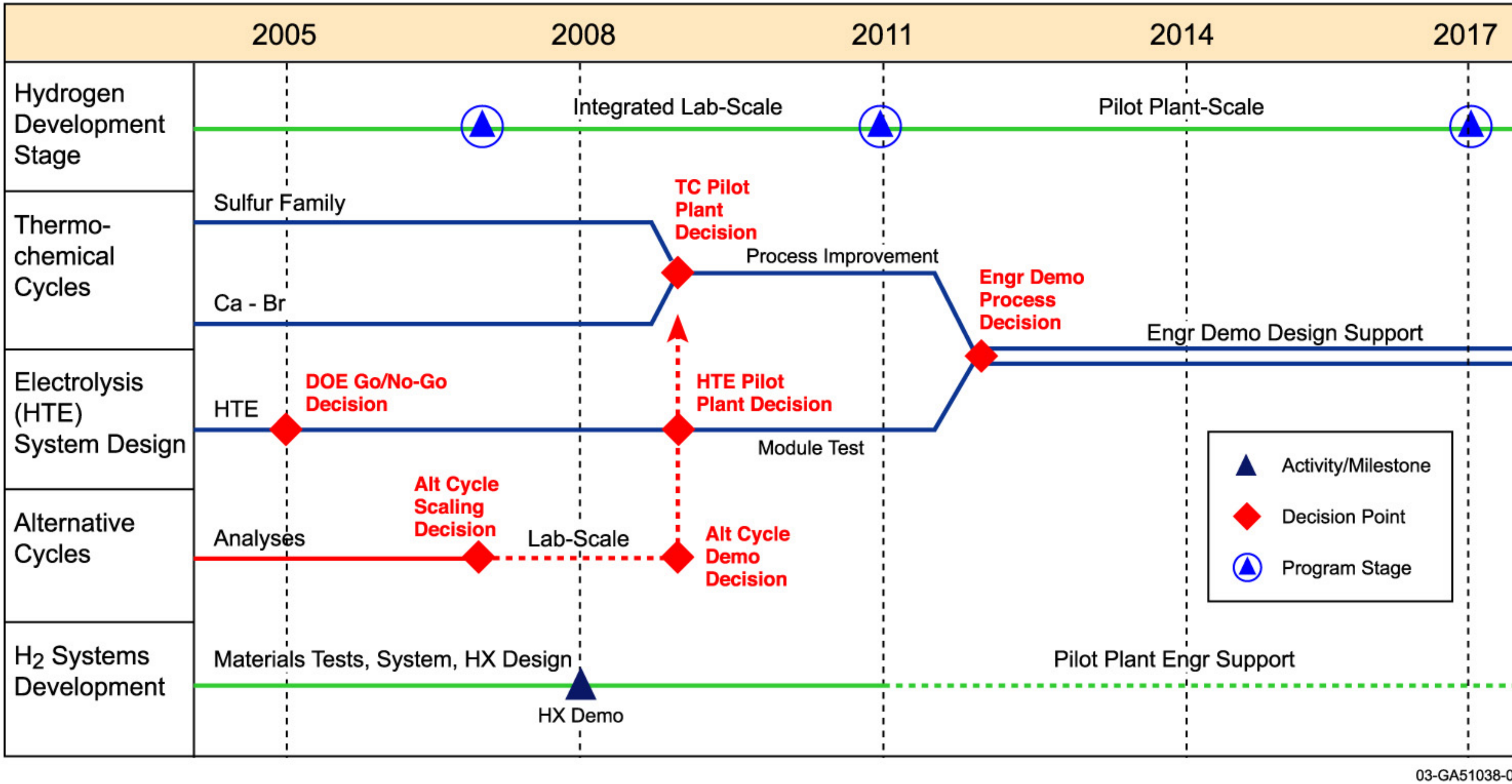
Future Work (1)

- Remainder of FY05
  - Materials & Heat Transfer Fluids
    - Complete thermal-hydraulic analysis of heat transfer fluids and effects on materials choices, temperature profiles, etc.
    - Analysis of hydrogen plant heat exchanger and heat transfer loop requirements, including materials needs
    - Continue corrosion testing of materials candidates for S-I process
    - Continue mechanical properties measurements of metallic alloys
    - Complete work on non-metallic materials, manufacturing methods
  - HX Concepts
    - Complete initial design of sulfuric acid decomposition heat exchanger
    - Perform catalyst testing of Alloy 617/800+Pt catalyst
  - Modeling
    - Continued modeling work on baseline heat exchangers

Future Work (2)

- **FY06**
  - Complete interface heat exchanger design and high temperature materials testing for baseline processes
  - Construct and initiate testing of lab-scale high temperature hydrogen process materials and test loops
  - Complete initial design studies for H_2-plant BOP
  - Complete initial reactor-process isolation assessment
  - Complete assessment of applicable codes and standards
- **FY07**
  - Coordinate pilot-scale component designs and testing
  - Perform lab-scale experiments on heat exchangers & components
  - Complete pilot-scale BOP design for baseline H_2 processes
  - Initiate permitting activities for pilot-scale experiments
- **FY08**
  - Complete design and testing activities to support pilot-scale decisions
  - Complete design and testing for required BOP components and system
  - Complete documentation of systems interface and BOP technologies for pilot-scale experiment decisions

Future Work (3)



Supplemental Slides

Publications and Presentations

- **R.P. Anderson, C.V. Park, W.D. Ridgeway, D.M. Ginosar, J.C. Perkowski, R.A. Carrington, S.R. Sherman, M.R. Anderson, J.S. Herring, P.S. Pickard, R.D. Doctor, R.A. Montgomery, M.D. Sandvig, *Infrastructure Requirements for a Nuclear Hydrogen Pilot Plant*, INEEL/EXT-04-01791, Rev. 0, March 2004**
- **S.R. Sherman, D.B. Barber, J.H. Kolts, *Reactor/Process Interface Requirements*, ANL W7500-0001-ES-00, Rev. 0, July 2004**
- **D. Vaden, M.F. Simpson, S.R. Sherman, J.H. Kolts, *Balance of Plant Requirements for a Nuclear Hydrogen Production Plant*, ANL W7500-0003-ES-00, Rev. 0, September 2004**
- **S.R. Sherman, M.F. Simpson, D. Ginosar, T. Lillo, P. Peterson, R. Ballinger, A. Roy, T. Hechanova, J.H. Kolts, *Reactor/Process Interface Heat Exchanger and Intermediate Loop Technical Issues*, ANL W7500-0002-ES-00, Rev. 0, September 2004**
- **T. Hechanova, *High Temperature Heat Exchanger Project: Quarterly Progress Report, October 1, 2004 through December 31, 2004*, University of Nevada Las Vegas Research Foundation, funded under Financial Assistance DE-FG-04-01AL67358, Amendment 007, U.S. Department of Energy**
- **C. Smith, S. Beck, B. Galyean, *An Engineering Analysis for Separation Requirements of a Hydrogen Production Plant and a High-Temperature Nuclear Reactor*, INL/EXT-05-00137, Rev. 0, March 2005.**

Hydrogen Safety (1)

The most significant hydrogen hazard associated with this project is:

- Through 2006
  - Most significant hydrogen hazard will be associated with handling pressurized cylinders of hydrogen for the purposes of testing materials for hydrogen embrittlement and hydrogen permeability. There is a risk of hydrogen fire in the case of a leak, since these tests may occur at temperatures that are above the auto-ignition temperature of hydrogen in air (571 °C).
- From 2007 through 2009
  - Most significant hazard will be associated with the production of hydrogen in laboratory-scale hydrogen production facilities at volumes reaching 1000 liters/hour. If leaks or equipment failures occur, there is a risk of hydrogen fire, since some of these tests may occur at temperatures that are above the auto-ignition temperature of hydrogen in air (571 °C).

Hydrogen Safety (2)

Our approach to deal with this hazard is:

- Procedural Controls
  - Procedures and experimental practices will conform to all institution-specific safety requirements and guidelines at the location where the experiment or test is being carried out
  - Thorough hazard assessments (and corrective actions) will be conducted for all experiments
  - Experimenters and technicians will have Stop-Work Authority
    - Persons performing the experiment have right to stop the conduct of any experiment if they believe a situation, procedural step, etc. is unsafe
- Engineering Controls
  - Experiments will be performed behind engineering barriers (fume hood sash, ventilated enclosure, etc.)
  - Areas around experimental equipment will be well ventilated to disperse hydrogen leaks, and the areas will be monitored for significant hydrogen concentrations
  - All equipment will be leak-tested to prevent air in-leakage
  - Fail-safe control schemes will be used to shut down equipment or experiments under potentially hazardous conditions.