Solar Thermochemical Hydrogen (STCH) Production – H2A Analysis

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Timeline

- Start: January, 2007
- Finish: March, 2008
- 100% complete

Budget

- Total budget: $70,725
  - –DOE Share: $70,725
  - –Contractor Share: $0
- Funding for FY08: $75,000

*Project Collaborator

Barriers

- High-Temperature Thermochemical Technology
- Concentrated Solar Energy Capital Cost
- Coupling Concentrated Solar Energy and Thermochemical Cycles

Partners

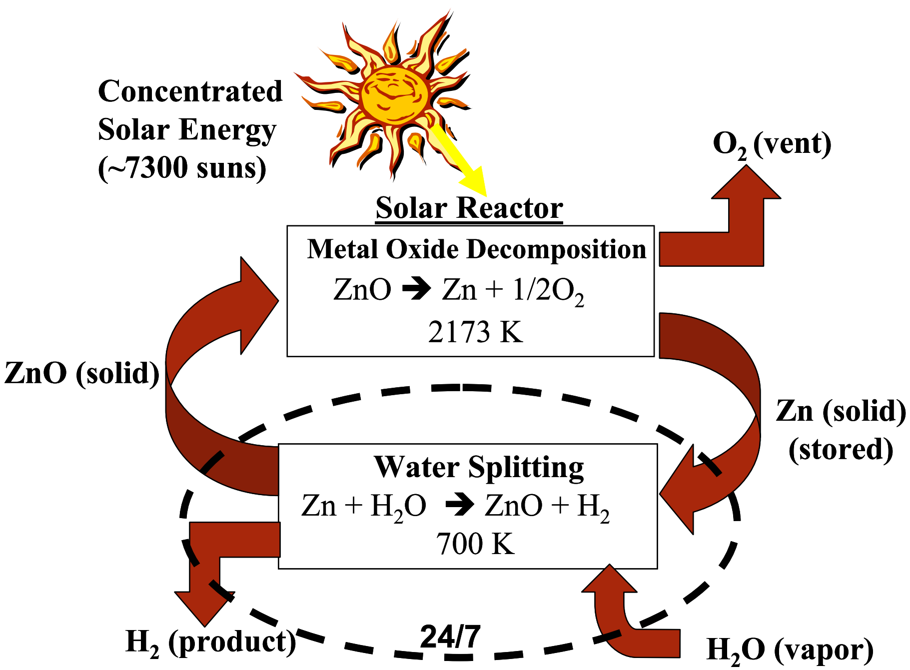
- Argonne National Laboratory
- Deutsches Zentrum für Luft- und Raumfahrt (DLR)*
- General Atomics
- Nevada Technical Services, LLC*
- SAIC/FSEC (beginning in FY08)
- Savannah River National Laboratory*
- U. Colorado, Boulder
- UNLV / UNLV Research Foundation*

Project Objectives/Tasks

- *Objective*: Evaluate which solar-thermochemical hydrogen (STCH) cycles have the potential to meet the DOE central production cost target of $3.00/kg
- *Tasks*
  - Support cost analyses of STCH cycles carried out by STCH Development Teams using H2A
  - Identify key cost drivers to guide research efforts to improve STCH economics
  - Ensure meaningful comparisons of H2 production cost estimates among cycles to enable most effective cycle down-select process

The STCH teams use DOE's H2A Central Production Tool to calculate H_2 production costs consistently and transparently (more at: http://www.hydrogen.energy.gov/h2a_production.html).

Example STCH Cycle: Zn/ZnO



H2A Framework

- **H2A Overview:** Standard approach, format and economic parameters/assumptions
  - Discounted cash flow
- **Years:** 2015 and 2025
- **Capacity:** Average output ~100,000kg/day
- **Guiding Principles for STCH:**
  - Focus on getting variables that have a major impact on production cost right
    - Cycle efficiency
    - Solar field + receiver efficiency
    - Thermochemical plant costs
  - Assume solid – but not overly optimistic – progress for base case
  - Sensitivity cases – 10%/90%
  - Nth plant design

We have worked closely with the teams in a collaborative and iterative process. For each cycle, we:

1. Receive initial H2A spreadsheet analysis and background materials/literature about the cycle from a team
2. Perform thorough review of H2A spreadsheet to critically assess assumptions made and cost values used in the H2A analysis
3. Discuss the review with the team who completed the H2A, focusing on cost values, system design and performance, and economic assumptions that require further explanation, appear questionable, or deviate appreciably from typical H2A values
4. Provide team with a punch list of issues to address/resolve
5. STCH Team revises the H2A analysis
6. Review revised H2A analysis and develops updated list of issues to address/resolve, discusses with team

Iterate As Necessary

Also:

- Evaluate other issues that arise as directed by DOE Program Manager
- Present latest H2A results and issues at STCH Team Meetings

We completed reviews and provided feedback on eleven different H2As using FY2007 funding.

	Lead	Progress	
		2015 H2A	2025 H2A
Ammonium Sulfate	FSEC / SAIC	No H2A received	No H2A received
Cd / CdO	GA	First two iterations completed	No H2A received
CuCl	ANL	First two iterations completed	First iteration completed
Ferrite	SNL	Initial iteration completed	No H2A received
Hybrid Sulfur	SNL	One more iteration completed DLR H2A reviewed	One more iteration completed
Manganese	U. Col.	No H2A received	No H2A received
S-I	TBD	No H2A received	Preliminary H2A completed by TIAX
Zn / ZnO	U. Col.	One more iteration completed	One more iteration completed

For each H2A we reviewed, we identified a range of specific issues to be resolved.

	Key Issues
Cd / CdO	Solar field design and performance, integration of solar energy with thermochemical cycle, Cd handling
CuCl	Electrolyzer design and cost highly uncertain, sensitivity cases
Ferrite	Preliminary design: system performance/efficiency and reliability
Hybrid Sulfur	Electrolyzer capital and replacement costs, integration of cycle with solar thermal heat source (vs. nuclear), backup plan if particle receiver does not work
Zn / ZnO	Solar field design and performance at very high concentration ratios used (>5,000 suns), receiver and reactor costs

We have reviewed and provided input on the hydrogen production cost values for several cycles, including sensitivity ranges. Costs are at the plant gate.

	Latest Estimates Available – *NOT FINAL!!*		Comments
	2015*	2025*	
Cd / CdO	Under revision	Not available	Cycle undergoing major revisions
CuCl	**$4.30** ($3.98 - $5.07)	**$2.82** ($2.65 - $3.35)	Electrolyzer cost highly uncertain
Ferrite	**$5.52** (No sensitivity)	Not available	Very preliminary design and analysis
Hybrid Sulfur	**$4.37** ($3.86 - $4.89)	**$2.91** ($2.46 - $3.21)	Solar electric cost important
Zn / ZnO	**$5.07** ($4.58 - $6.53)	**$3.62** ($3.12 - $4.87)	Solar field + receiver cost, performance questions

** Latest estimates shown (latest sensitivity range in parentheses)*

Based on our reviews, we identified several "lessons learned" that were used to improve all of the H2As.

- Solar Field Annual Efficiency Calculations: Provide detailed breakdown
  - Crucial: Efficiency of solar field, receiver, and thermochemical plant determines total heliostat area, and heliostats dominate capital cost
- General Costing: Use solar costing for solar components (e.g., from Sargent & Lundy) and costs typical of chemical industry for thermochemical plant
- Need to carefully consider and account for planned replacement costs
  - Particularly for electrolyzers, catalysts
- Capital Costs: Carefully review costs from different sources to determine if they include – or omit – line items in the H2A spreadsheets
  - Installation, site preparation, engineering & design, contingency, permitting costs, balance-of-plant, etc.
- General: We are willing to consider cost, performance, etc. values beyond those in general literature, but burden of proof lies with party espousing different value

We have also evaluated several key issues impacting all of the H2As.

- Cost of Thermal vs. Electric Energy Inputs – Noted that current analysis framework biases toward cycles consuming appreciable electricity.
  - H2A thermal inputs capital costs based chemical industry economics
  - Cost of electricity (COE) based lower ROI electric utility economics
  - COE ~50% higher if H2A economics used instead of utility economics
  - Decision: Use H2A-based COE as sensitivity case for all analyses
- Potential Requirement for Level Production Throughout Year – Would have major impact for plants located in U.S.; evaluated in context of annual vehicle fuel demand fluctuations and recommended to not require levelized production.

We also modified several assumptions for the STCH H2As.

- Revised heliostat capital costs based on 2007 SNL Heliostat Cost Reduction study findings
- Electric Power: Cycles using significant quantities of solar thermal energy should also obtain large quantities of electricity from solar sources
  - Use Sargent & Lundy (2003) values, versus H2A industrial electricity
- Recommended revisions to equipment installation factors in thermochemical plant based on review of values used in literature
- Revised guidance thermochemical plant labor force and labor rates based on CuCl H2A
- Eliminated production credit for O2 (negligible value for O2 in very favorable solar thermal locations)

In FY2008, we will continue to work closely with the STCH teams to develop and refine the cost analyses to provide DOE with the best production cost information possible to inform the cycle down-select process.

1. Develop and Complete New Analyses
   – For cycles currently without H2As completed
2. Refine and Complete Existing Analyses
   – Tighten up key assumptions in analysis, namely thermochemical cycle efficiency, solar field efficiency, major thermochemical plant capital costs
   – Refine sensitivity cases
     - Crucial component for cycle down selects
     - Identify high-leverage factors with significant uncertainty
       · Cycle efficiency
       · High capital cost items (usually thermochemical plant components)
     - Truly 10% / 90%: The greater the uncertainty, the greater the range

At present, the STCH project does not have funding in FY2009.

Project Summary

- Relevance: Ensuring high-quality and consistent production cost analyses to enable effective cycle design choices and DOE programmatic decisions, i.e., cycle down select. At present, the analyses suggest that multiple cycles might have a chance of meeting the DOE production cost target circa 2025.
- Approach: Iterative review, feedback, and editing of quantitative H2As of hydrogen production cost, with sensitivity analyses for key variables
- Technical accomplishments and progress: We reviewed and provided feedback on eleven (11) H2As, while also evaluating and resolving a range of common issues that impact all of the analyses
- Technology transfer/collaborations: Worked with several STCH team members on H2As: ANL, General Atomics, SNL, U. Colorado, FSEC/SAIC (in FY08)
- Proposed future research: Continue to work with STCH teams to refine hydrogen cost analyses to provide best information for cycle down select (by end of FY08)

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