Project ID: ST140

Emergency Hydrogen Refueler for Individual Consumer Fuel Cell Vehicles

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DOE SBIR Phase I Contract DE-SC0017695

Overview

Timeline

- Project Start Date: June 12, 2017
- Project End Date: March 11, 2018
- Percent Complete: 100%

Barriers Addressed

- 100% Reaction Conversion of LiH to H_2
- Passively Controlled H_2 Gas Evolution over 15 Minutes
- Reduced cost from $391 to $83

Budget

- Total Project Budget: $149,999
  - Contractor Share: $0
  - Federal Share: $149,999
- Funds Spent: $149,999

Partners

- US DOE: Project Sponsor and Funding
- Skyhaven: Technical R&D
- Champlain College: Financial Modeling and Commercialization Planning

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Market Need

- A common concern for fuel cell vehicle operators is running out of hydrogen fuel
  - Sparse hydrogen filling stations
  - Operators can experience range anxiety
  - This lessens the appeal of these vehicles hindering their commercialization
- To overcome this shortfall, the DOE is interested in developing emergency hydrogen refuelers
  - Similar in concept to keeping a can of gas in the trunk
  - Compact and lightweight H_2 storage unit that can be stored in the vehicle trunk
  - Can be safely and reliably operated by the driver

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Value Proposition

- To meet this market need, a H_2 gas refueler is being developed
- Skyhaven's refueler product goals
  - Provides 0.75 kg (1.7 lb) of hydrogen fuel
  - Refills the vehicle within 15 minutes
  - Is activated with water giving it a long storage lifetime
  - Mass of 10 kg (22.8 lb) that includes the activating water
  - Compact space of 11 liters (0.4 ft^3)
  - No moving parts helping to increase reliability
  - Material cost budget of $391 in low production volumes
- With this product, the average fuel cell vehicle will have a 50 mile range enabling the operator to reach a hydrogen refueling station

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The Innovation

- Store lithium hydride powder in a hermetically sealed vessel
- When this chemical hydride is exposed to water vapor, it releases hydrogen gas instantaneously
  - $LiH + H_2O \rightarrow H_2 + LiOH$
- Use a network of water conduits placed throughout a packed bed of lithium hydride to shuttle liquid water
  - Liquid water pervaporates through the conduits introducing water vapor to the LiH particles
- Use hydrophilic micro-wick additives within the LiH to further disperse water to all LiH particles giving 100% reaction yield

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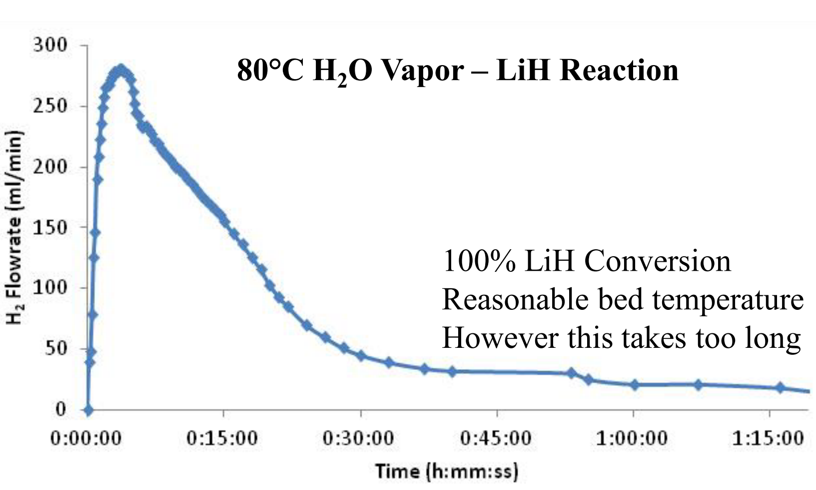
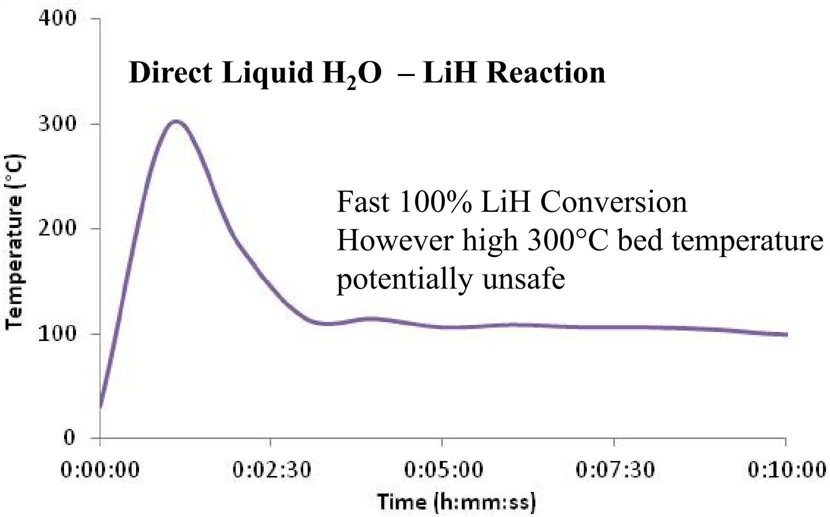
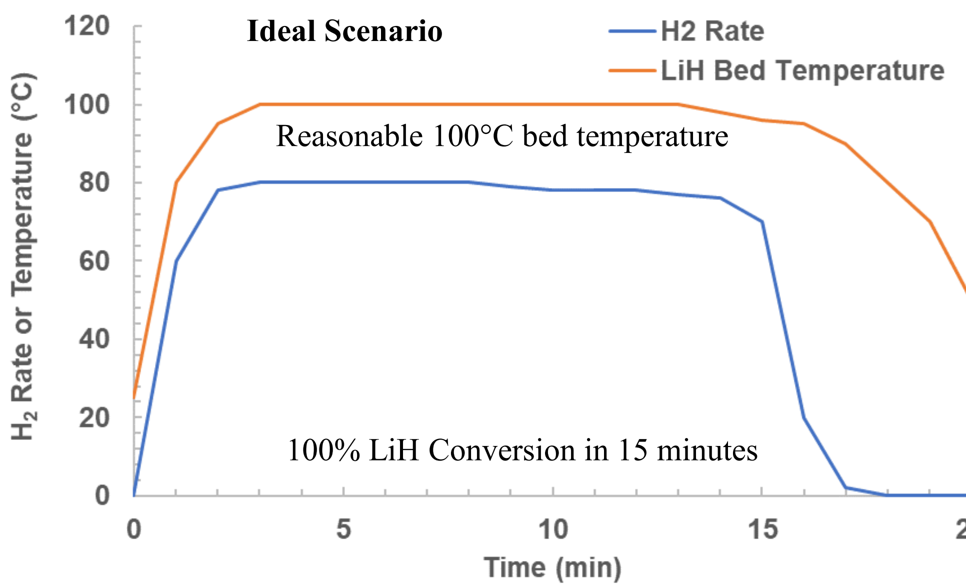
Water Activation of LiH to Release H_2 Gas: Vapor Versus Liquid Feed





- Ideal scenario
  - React all LiH within 10-15 minutes
  - Maintain bed temperature less than 100°C using water vapor feed
  - Liquid water for bootstrapping



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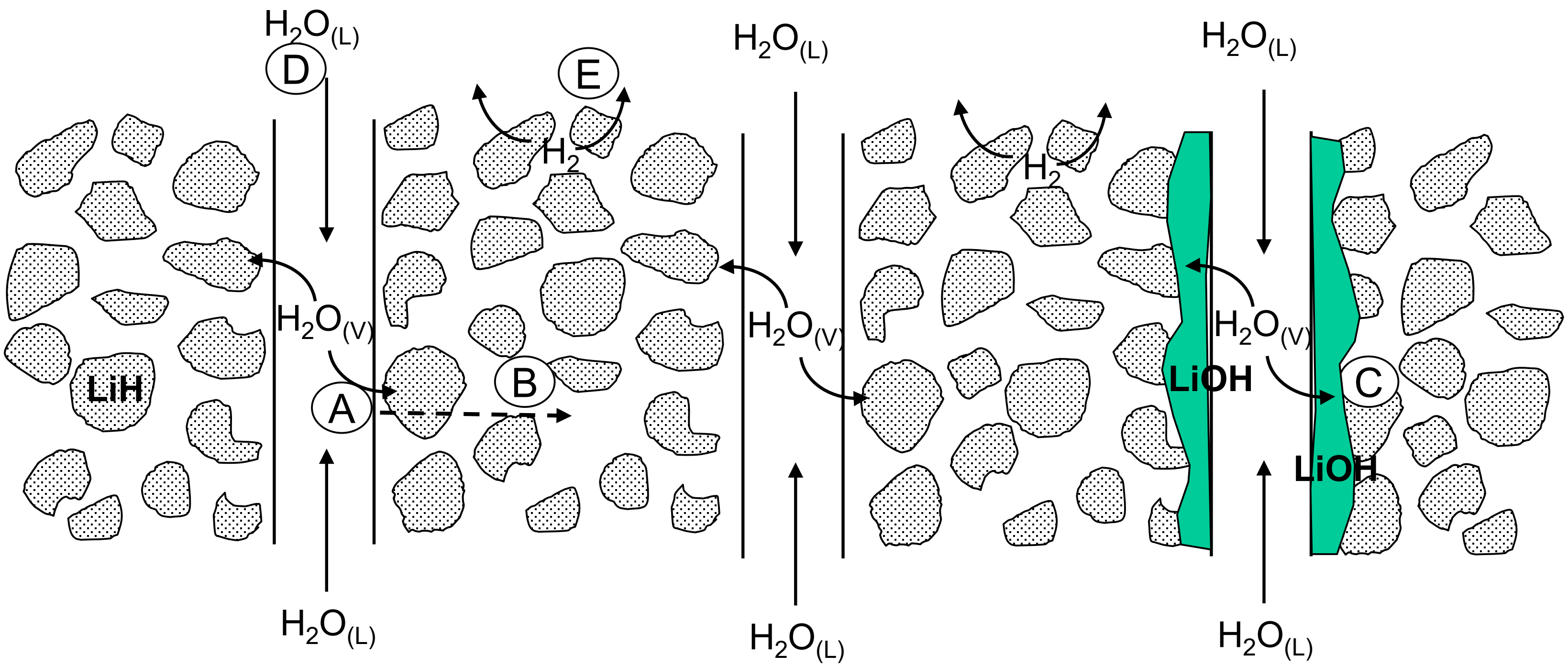
Top Phase I Technical Challenges



A : Maximizing the water vapor transport rate through the conduits

B: Maximizing the distance that water vapor can transport into the LiH bed

C: Overcoming LiOH films that hinder water transport to LiH particles

D: Introducing liquid water into the conduits without pumps

E: System engineering – start up, heat removal, H_2 purity, reliability, refueler design, cost

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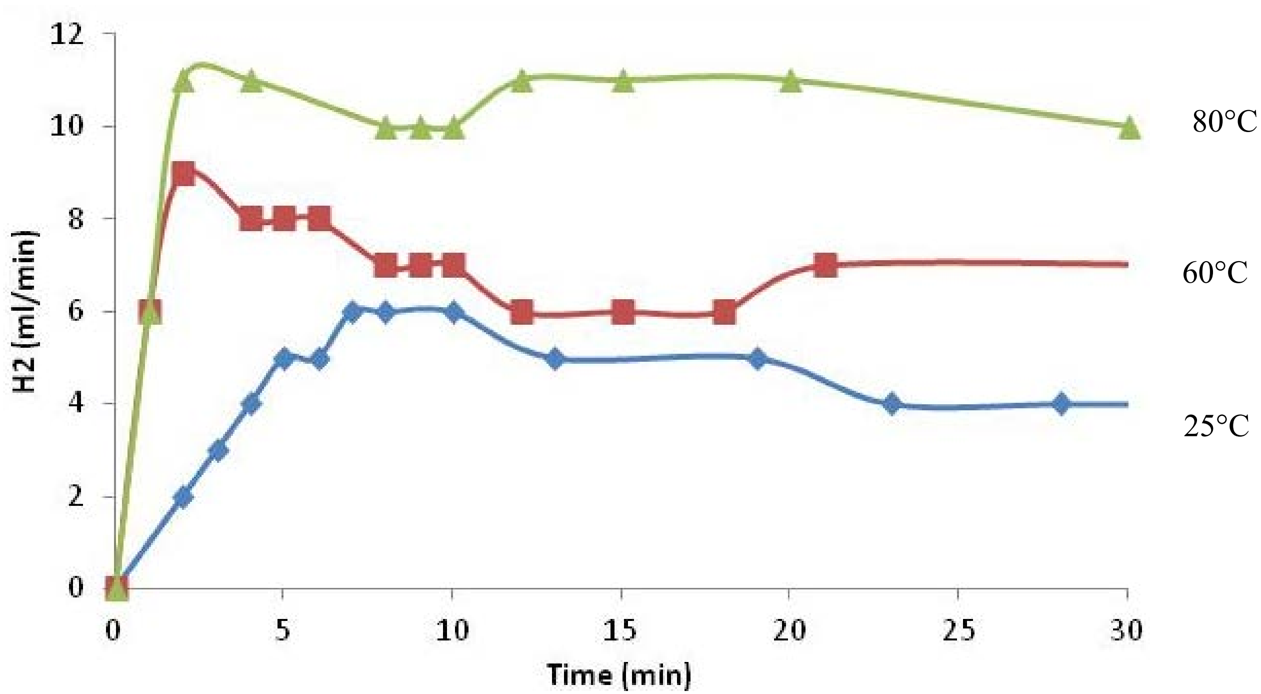
Technical Challenge A: Maximize the Water Vapor Rate Through the Conduits

- Fabricate water feed conduits that are dispersed throughout the LiH packed bed
- Choose conduit materials and design to minimize their size (and cost) while enabling water pervaporation through them



- Miniaturized tubular conduits produced operating at 80-100°C that maximize the water vapor transmission rate into the LiH bed

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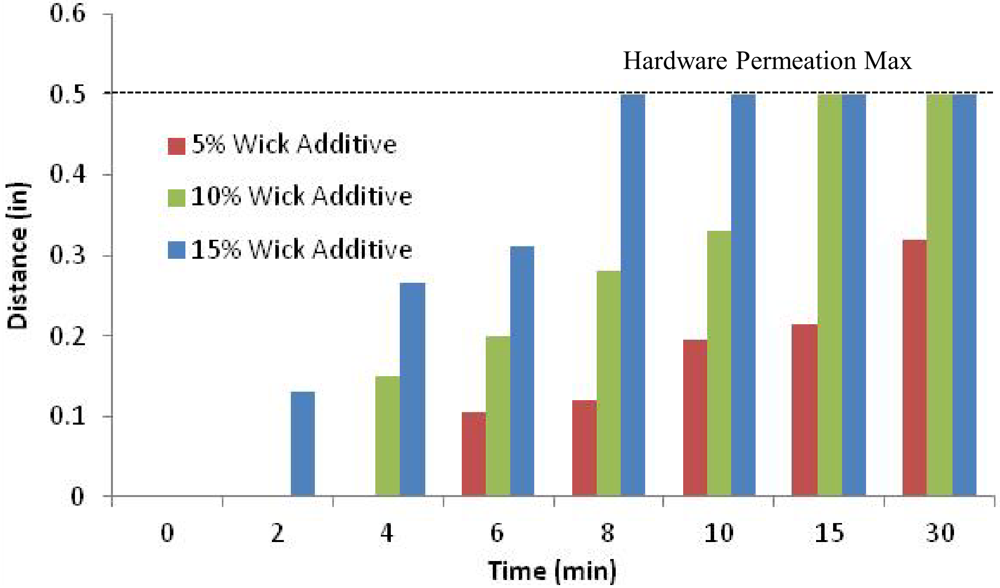
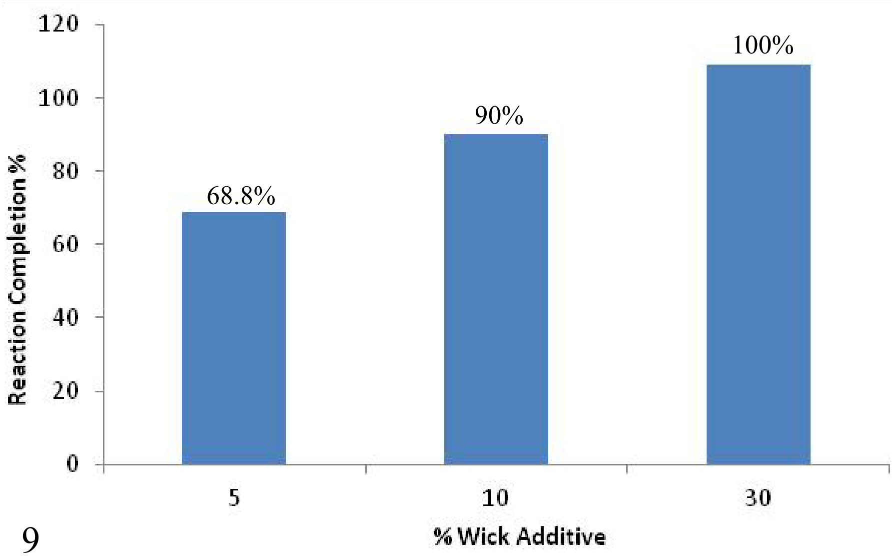
Technical Challenge B&C: Maximize the Water Vapor Distance Through the LiH Bed

- Want water vapor to diffuse through long distances of LiH particles (and through LiOH films)
- This minimizes the number of water conduits and maximizes the amount of LiH
- Incorporate wick additives into LiH to shuttle water





- Increasing percentage of wick additives
  - Enables deeper water penetration into the LiH bed
  - Enables 100% LiH conversion in reasonable time periods (15 min)
  - However, compromises LiH content

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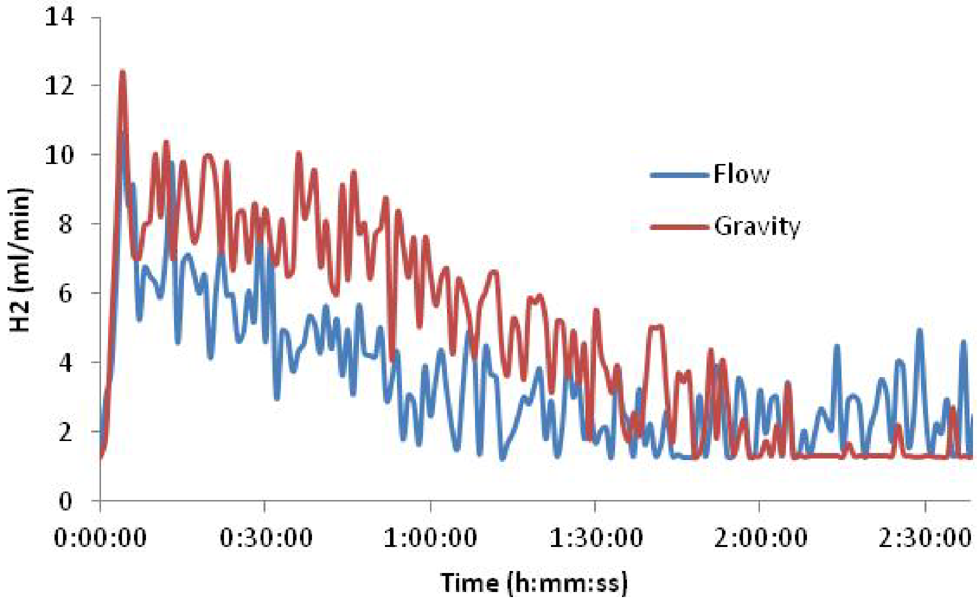
Technical Challenge D:
Introducing Liquid Water into the Conduits

- Hydrogen refueler needs to use a gravity water-fed delivery system (no pumps)
- Challenge is getting liquid water to fill the miniaturized conduits quickly once activated



- Gravity fed operation shows similar behavior to pumping water through the conduits
- Room temperature gravity-fed water supply to a single cell achieved a reaction completion of 79%

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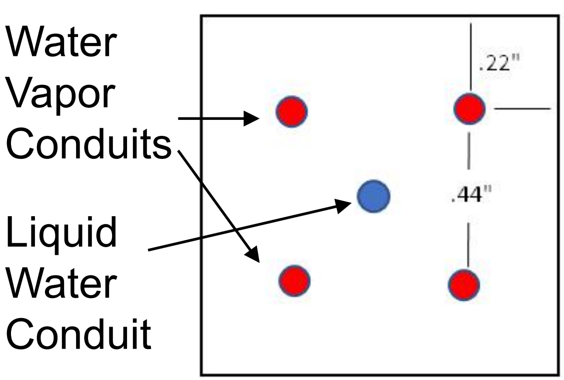
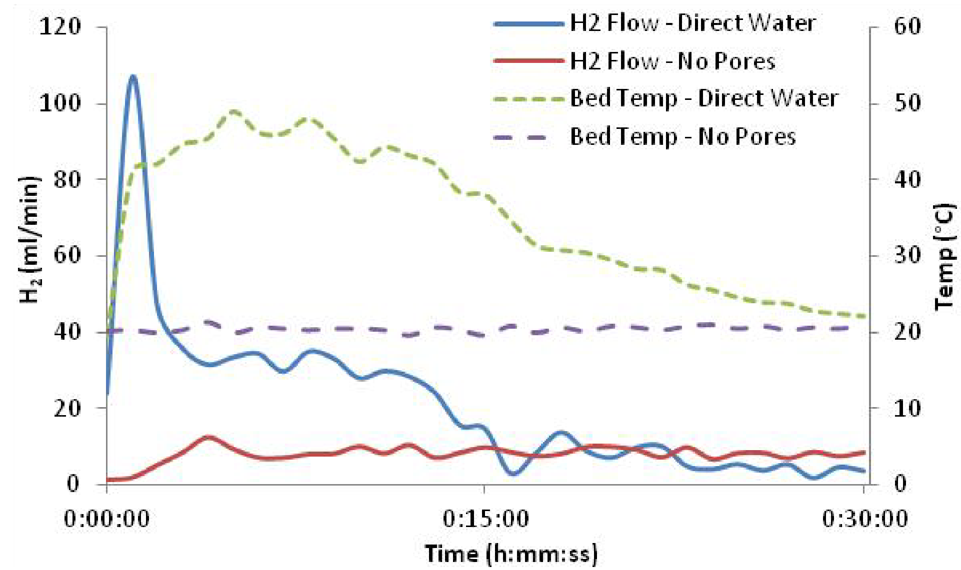
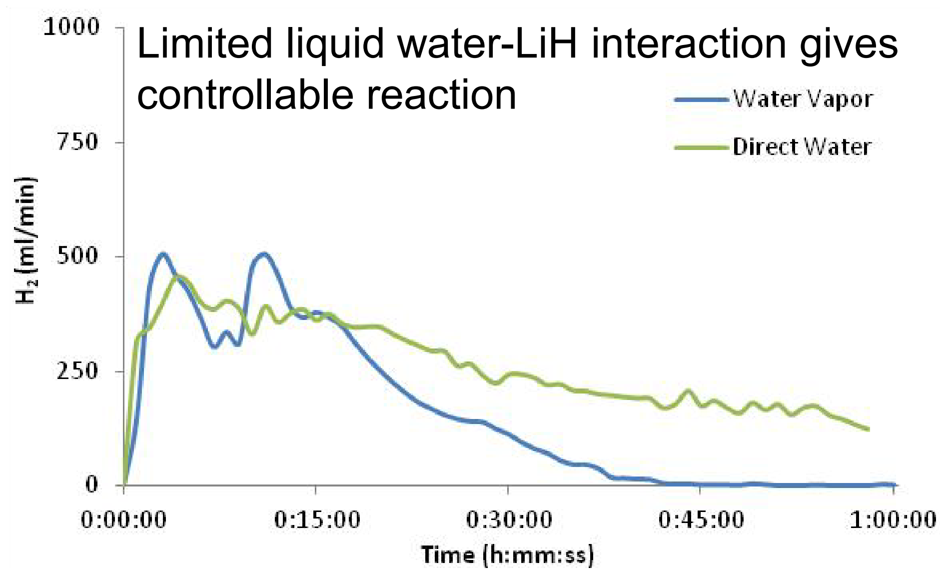
Technical Challenge E: Starting the H_2 Refueler

- User activates refueler via turning a valve that gravity feeds water to the conduits
- Want 80-100 °C internal refueler temperature quickly as possible
  - This significantly increases the water vapor transport rate
- Since direct liquid water-LiH contact immediately releases heat, consider using a limited number of direct liquid water-LiH conduits to bootstrap the reactor







Technical Challenge E: Heat Removal

- Heat of reaction:

$$\Delta H_{Rxn} = \Delta H^{\circ}_{LiOH} + \Delta H^{\circ}_{H_2} - \Delta H^{\circ}_{LiH} - \Delta H^{\circ}_{H_2O}$$

$$\Delta H_{Rxn} = -155.3 \frac{kJ}{mol} LiH$$

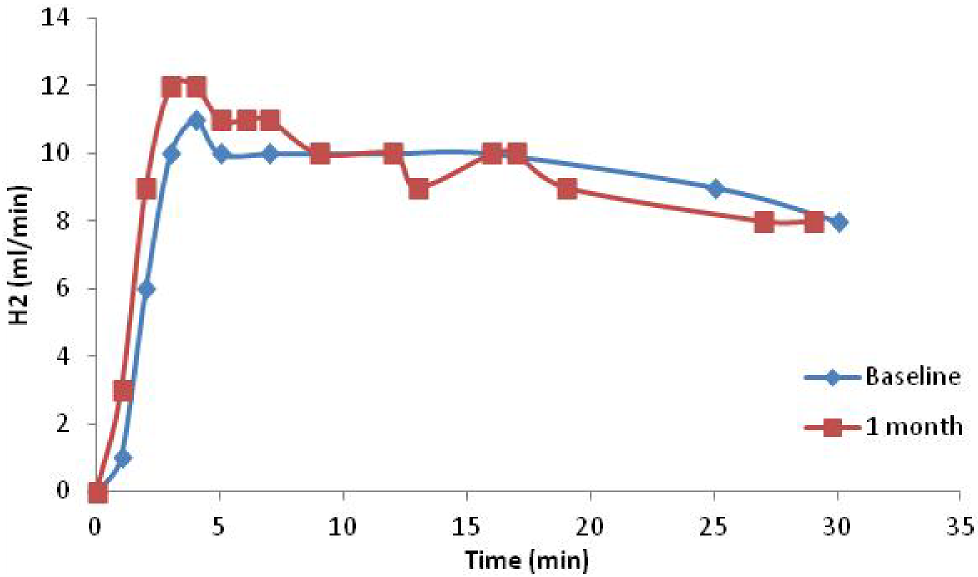
- A refueler with 750 g of H_2 requires 2976 g LiH
- Total energy released: -58,134.6 kJ
- Assume refueler is designed to dispense H_2 over a 10 minute period
  - Total heat released is: -96.9 kW
- Heat release calculations show importance of a controlled water delivery system to minimize heat generation and subsequent heat removal requirements
- Use internal heat transfer fins coupled to external fins for cooling

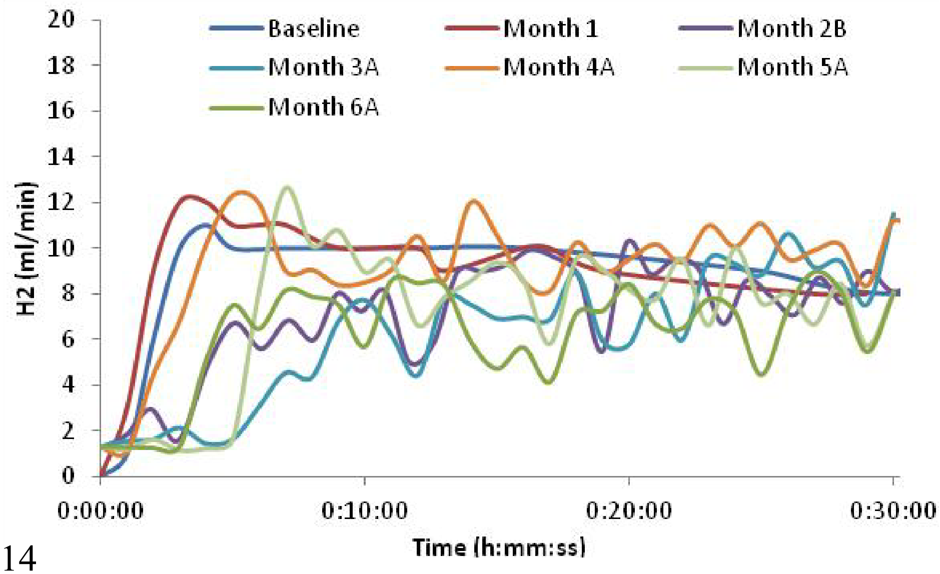
Technical Challenge E: H_2 Purity

- SAE J2719 – Hydrogen Fuel Quality Specification
  - Hydrogen lower limit of 99.97%
  - Water upper limit of 5 ppm
- Refueler will require a bed of silica gel to get below water threshold
- Gas chromatography has shown that no other by-products are produced from the reactor
  - Oxygen and nitrogen presence from fitting leak

Technical Challenge E: Refueler Material Reliability

- Examined material compatibility of LiH, conduits, and wick additives
  - Determine if material interactions degrade the refueler in storage
- 12 reactors initially fabricated with 0.9 grams of LiH containing conduits and wick additives
- 2 reactors activated each month measuring the H_2 flow rate





- Reliability studies have shown that there are no material compatibility issues with the refueler
- H_2 is generated after months of storage proving LiH is maintaining its reactivity during storage
- Differences in performance are attributed to LiH/wick additive packaging

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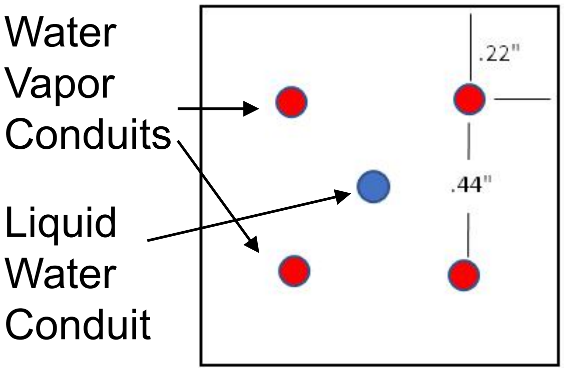
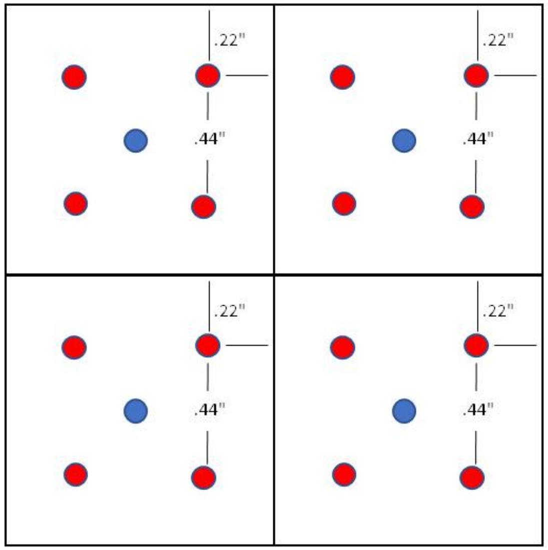
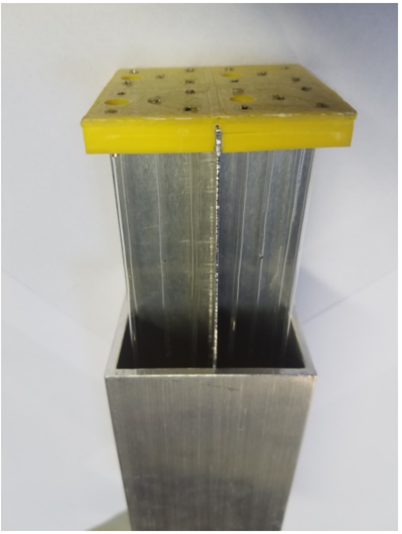
Technical Challenge E:
Refueler Design

- Repeatable units forming individual compartments
  - e.g., compartments comprised of five water delivery conduits with a single direct water feed conduit in the middle to bootstrap
- Compartment walls serve as the internal heat exchanger fins
- External fins for ambient convection thermal management







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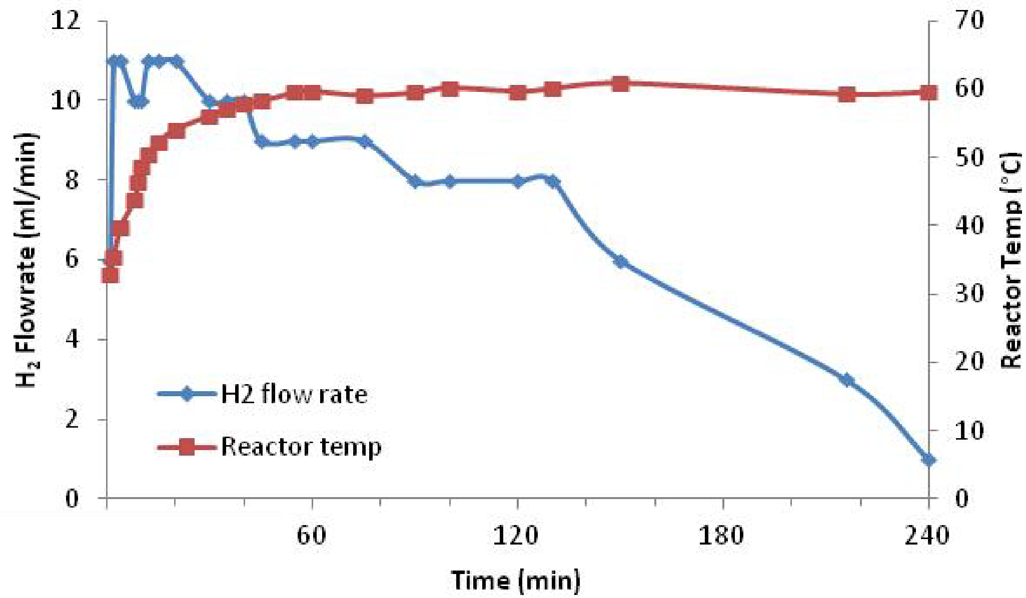
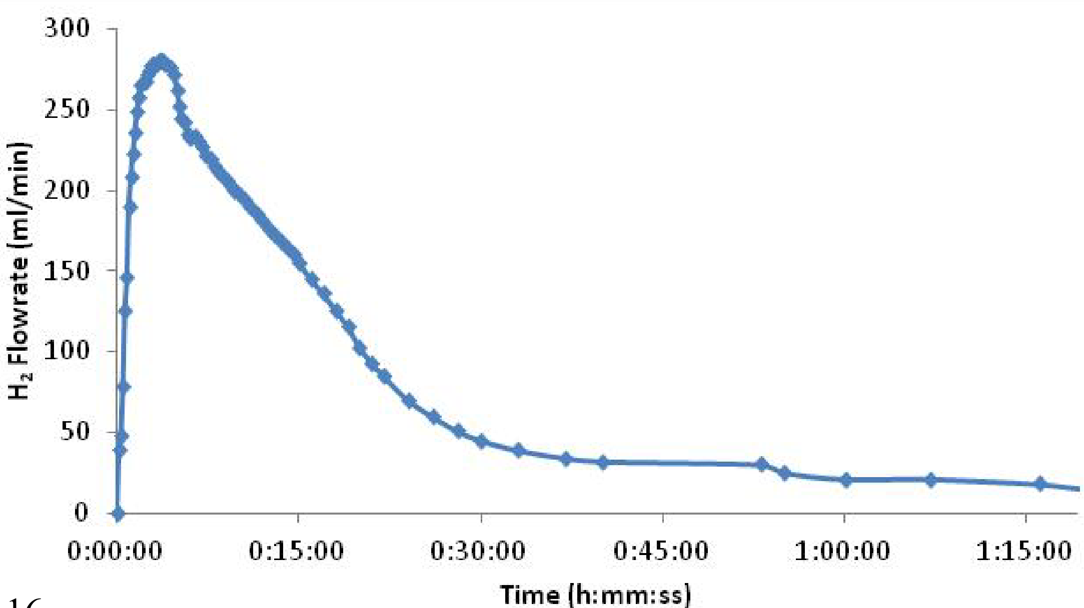
Technical Challenge E:
Refueler Design Shows Scalability

- Single conduit, 1.5” long
- 0.9 g LiH
- 7.3 ml H_2/min/in conduit





- 4 conduits, 6.0” long
- 3.0 g LiH
- 11.7 ml H_2/min/in conduit

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Technical Challenge E:
Refueler Design for a H_2 Fueling Nozzle

- Approach
  - Injection plastic molded nozzle
  - One-time use device
  - Mimic nozzle design from refueler stations
  - 5’ plastic hose from refueler to nozzle
- Phase II design effort

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Technical Challenge E:
Reducing the Material Cost Less than $391

Component	Phase I Pricing				Phase I H_2 Refueler Material Cost		Phase II Expected H_2 Refueler Material Cost		
			Unit Pricing						
	Bulk Price	Qty	Price	Unit	Qty	Cost	Qty	Unit Price	Cost
HX Fins	$77.25	12" x 1000'	$0.00054	in^2	1764	$0.95	1764	$0.00054	$0.95
Housing	$110.71	24" x 50'	$0.0077	in^2	294	$2.26	294	$0.0077	$2.26
Additives	$65.60	500 g	$0.13	g	150	$19.68	150	$0.13	$19.68
Water Conduit	$152.00	1500'	$0.10	ft	1500	$152.00	143	$0.010	$1.45
Lithium Hydride	$16.00	1000 g	$0.016	g	3000	$48.00	3000	$0.016	$48.00
Dessicant	$66.88	230,350 in^3	$0.00029	in^3	5	$0.00	5	$0.00029	$0.00
Plastic Valve	$6.69	1	$6.69		1	$6.69	1	$6.69	$6.69
Plastic Hose	$1.75	1	$1.75		1	$1.75	1	$1.75	$1.75
Plastic Nozzle	$2.00	1	$2.00		1	$2.00	1	$2.00	$2.00
Total						$233.33			$82.78

- Main material cost drivers are the conduits and LiH
- Phase II material cost expectation of $83 in relatively low procurement volumes
- Supports a H_2 refueler sale price of $150-200

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Technology Status Today

- Phase I DOE program has shown the technical feasibility of the hydrogen refueler
  - Demonstrated mechanisms to gravity feed water to the conduits
  - Showed conduits and operational methods that increase the water vapor transport rate through the conduits
  - Showed using wick additives to increase the depth that water can diffuse through LiH and LiOH toward 100% LiH conversion
  - Demonstrated using a limited number of liquid water-LiH cells to bootstrap the reactor to 80 °C
  - Showed that only H_2 and water exit the refueler where a desiccant will adsorb the water before filling the fuel cell vehicle
  - Demonstrated material compatibility over 9 months supporting a long storage shelf life
  - Examined scale up using compartmented zones for heat removal and safe operation
  - Showed low material cost projections of $83

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H_2 Refueler Technology into the Future

- DOE SBIR Phase II Program will be used to focus on further development of technology including:
  - Improving water conduit permeation and cost reduction via investigation into new materials and designs
  - Continued scaling of reactor to higher H_2 flow rates by increasing number of water conduits
  - Optimize design of water delivery system and thermal management
  - Investigate manufacturing requirements of various refueler components
  - Produce and demonstrate a 750 g H_2 refueler
  - Work with DOE/industry partners to obtain refueler specifications

Any Proposed Future Work is Subject to Change Based on Funding Levels

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