Comparison of On-board Hydrogen Storage Options

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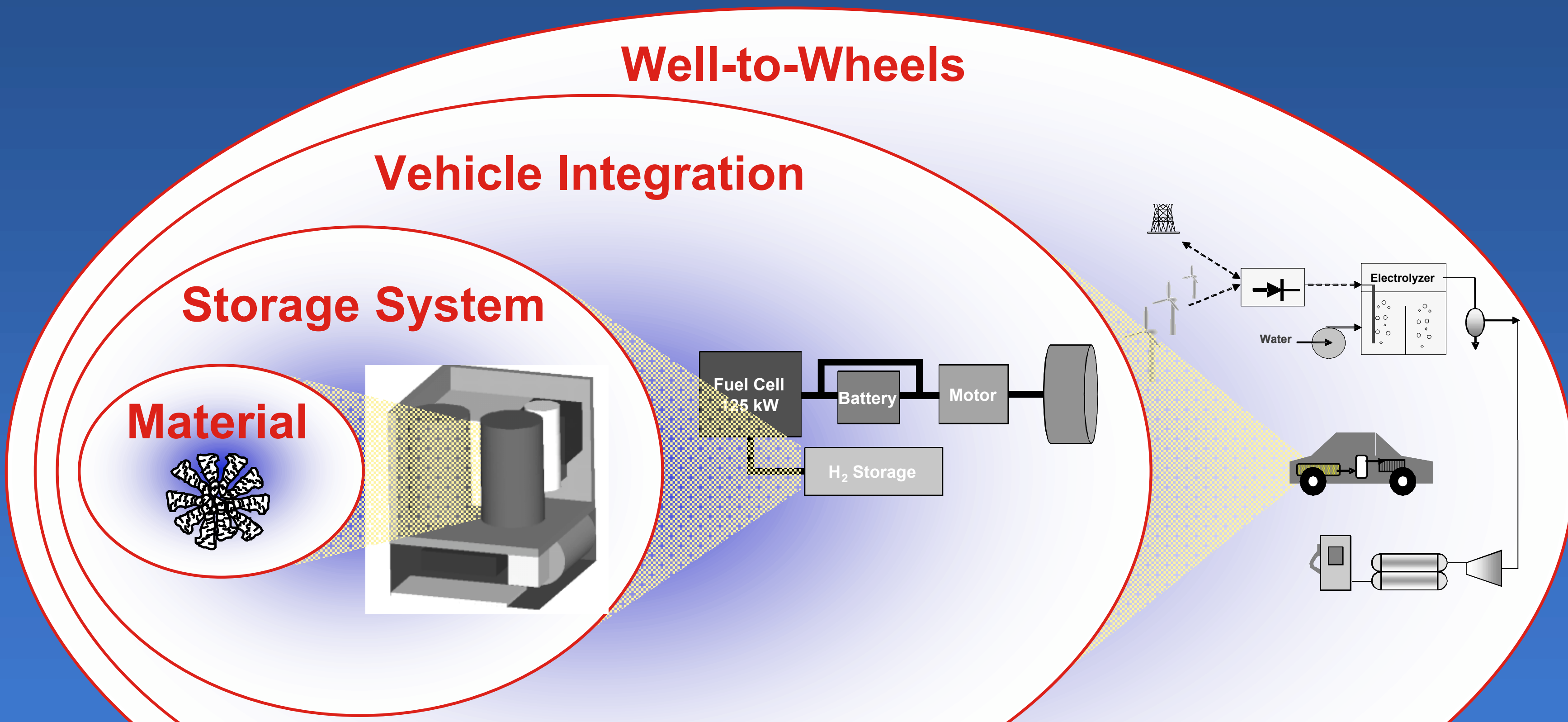
Reference: D0268

Project Overview Background

We are in the process of evaluating the performance and cost of various hydrogen storage options for the DOE.



- Material wt %
- P, T requirement
- Thermo, kinetics

- BOP requirements
- System size, cost
- System issues

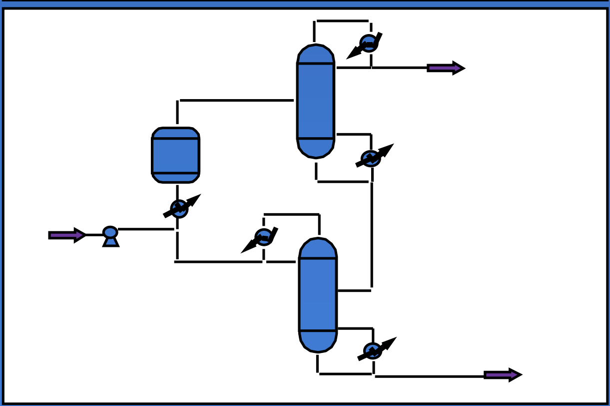
- Power unit and thermal integration
- Vehicle cost, weight
- Fuel economy

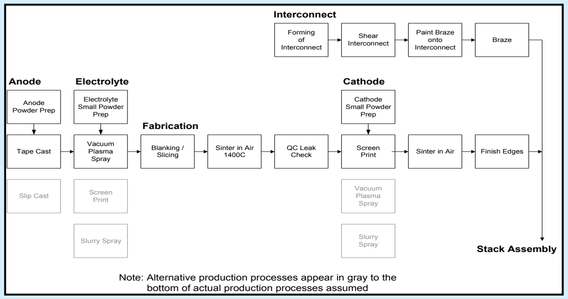
- Fuel chain requirement
- Ownership cost
- WTW energy use, GHG

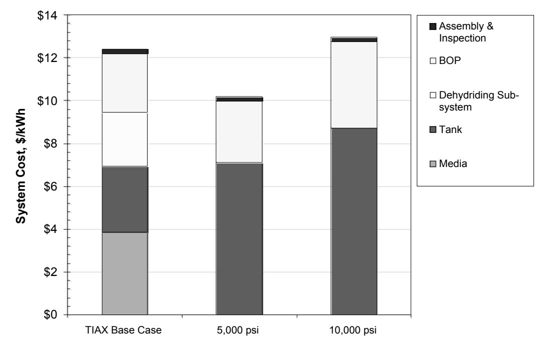
Project Overview Approach

On-board cost and performance estimates are based on detailed technology assessment and cost modeling.

Performance and Tech Assessment	Cost Modeling	Overall Model Refinement
• Literature Review • System Design and Configurations • Process Modeling • Outline Assumptions • Developer Feedback	• Document BOM • Determine Material Costs • Identify Processes and Mnf. Equipment • Sensitivity Analyses	• Developer and Stakeholder Feedback • Revise Assumptions and Model Inputs





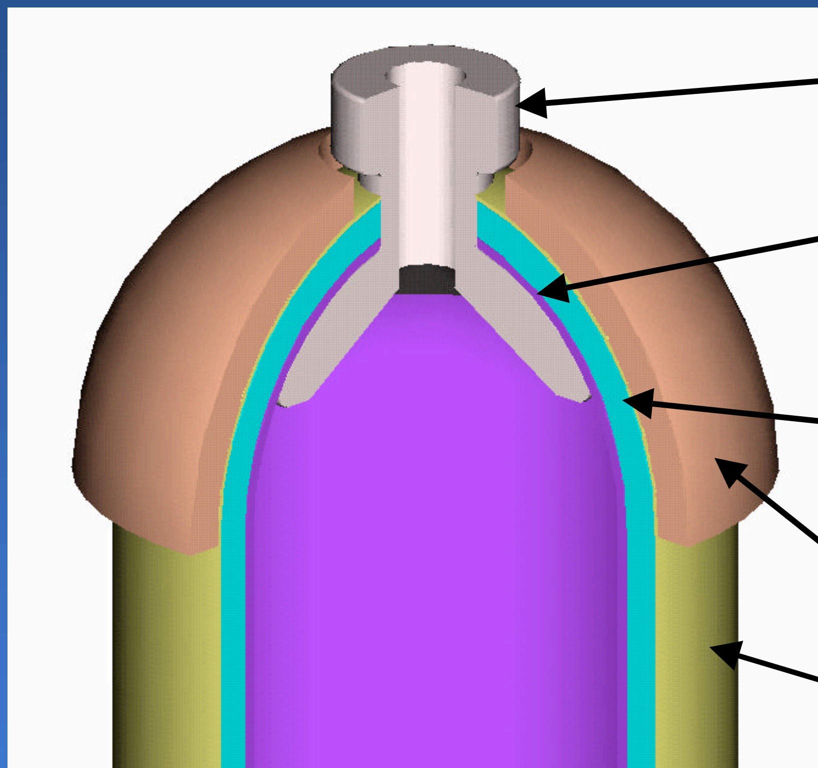


To date, we have evaluated compressed gas tanks, sodium alanate, and sodium borohydride storage technologies.

Category	Initial Cases	Tech Status	Storage State	H_2 Release	Refueling
Compressed and Liquid Hydrogen	5,000 & 10,000 psi	Mature (low volume)	Gas	Pressure regulator	H_2 gas
Reversible On-board: *Metal Hydrides, Alanates*	Sodium Alanate	Proof of Concept	Solid	Endothermic desorption	H_2 gas and HTF loop
Regenerable Off-board: *Chemical Hydrides*	Sodium Borohydride	Early Proto-type	Aqueous solution	Exothermic hydrolysis	Aqueous solution in/out
High Surface Area Sorbents: *Carbon*	TBD	R&D	Solid (low T?)	Endothermic desorption	H_2 gas (low T?)

[1] HTF = Heat Transfer Fluid

Two type III compressed hydrogen tanks were designed to accommodate 5,000 and 10,000 psi storage pressures.



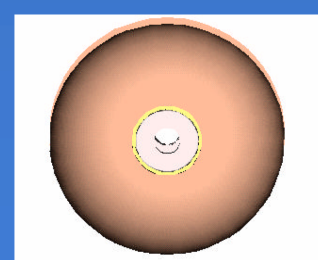
Metal Boss (aluminum) for Tank Access (some constructions may also use a plug on the other end)

Liner (polymer, metal, laminate)
HDPE 6.3 mm thick
Al 2.3 mm thick

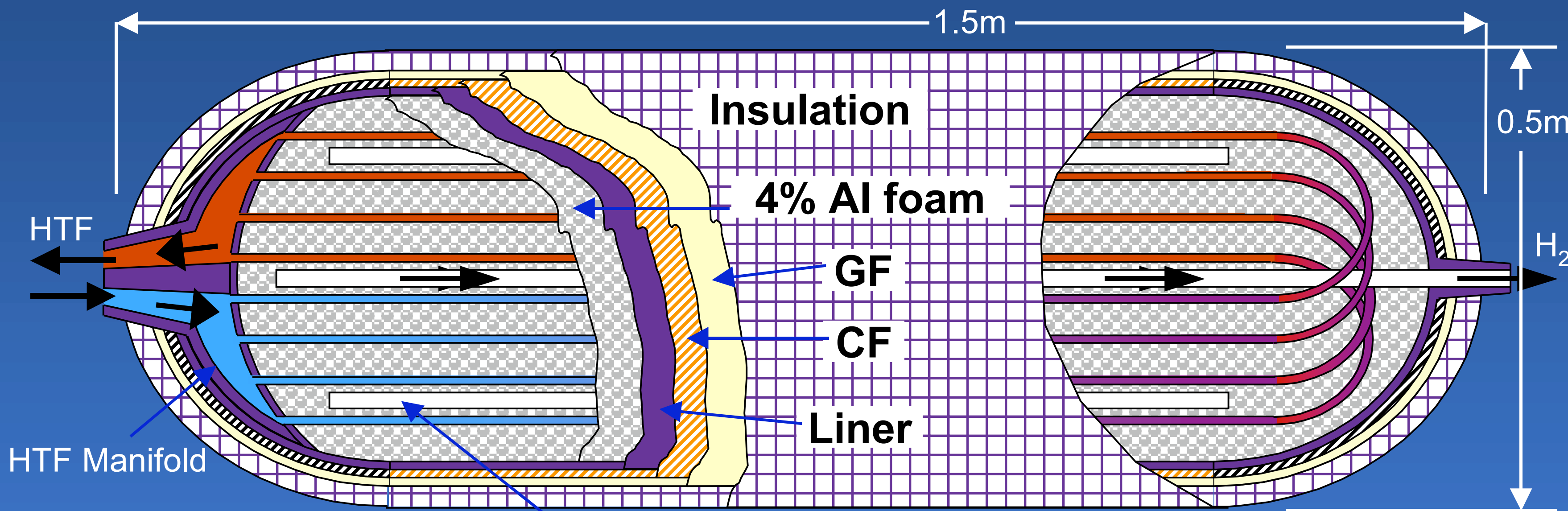
Wound Carbon Fiber Structural Layer with Resin Impregnation (V_f CF:Epoxy 0.6:0.4; W_f 68/32)

Impact Resistant Foam End Dome

Damage Resistant Outer Layer (typically glass fiber wound)



A sodium alanate storage tank was designed to accommodate both high pressure and rapid heat exchange.




Metal Foam

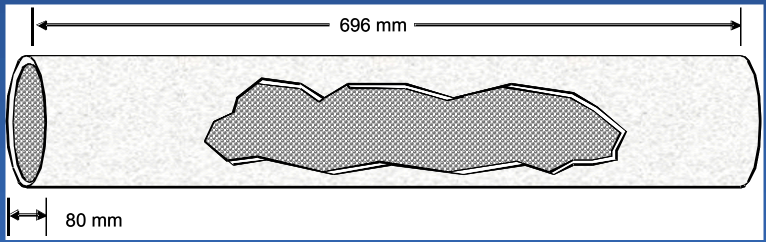
Legend	
Al = Aluminum	HTF = Heat Transfer Fluid
GF = Glass Fiber	HX = Heat Exchanger
CF = Carbon Fiber	SS = Stainless Steel

System Designs Sodium Borohydride Components

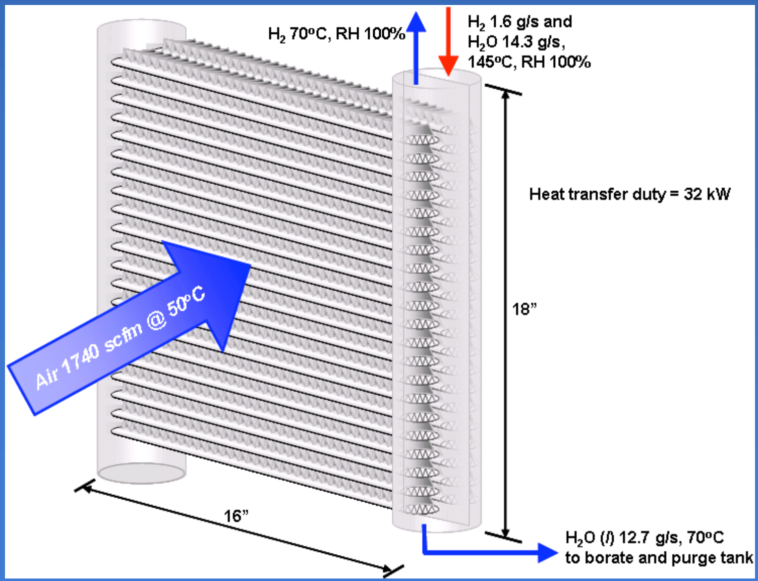
A sodium borohydride storage system was designed to accommodate solution storage and water management.

Storage Tank

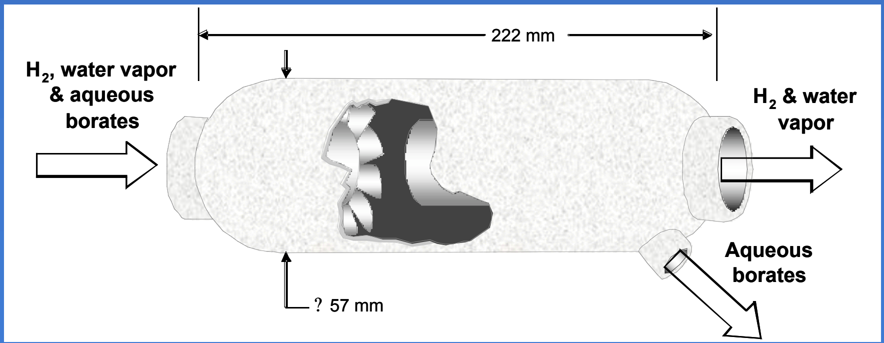
Reactor



Condenser

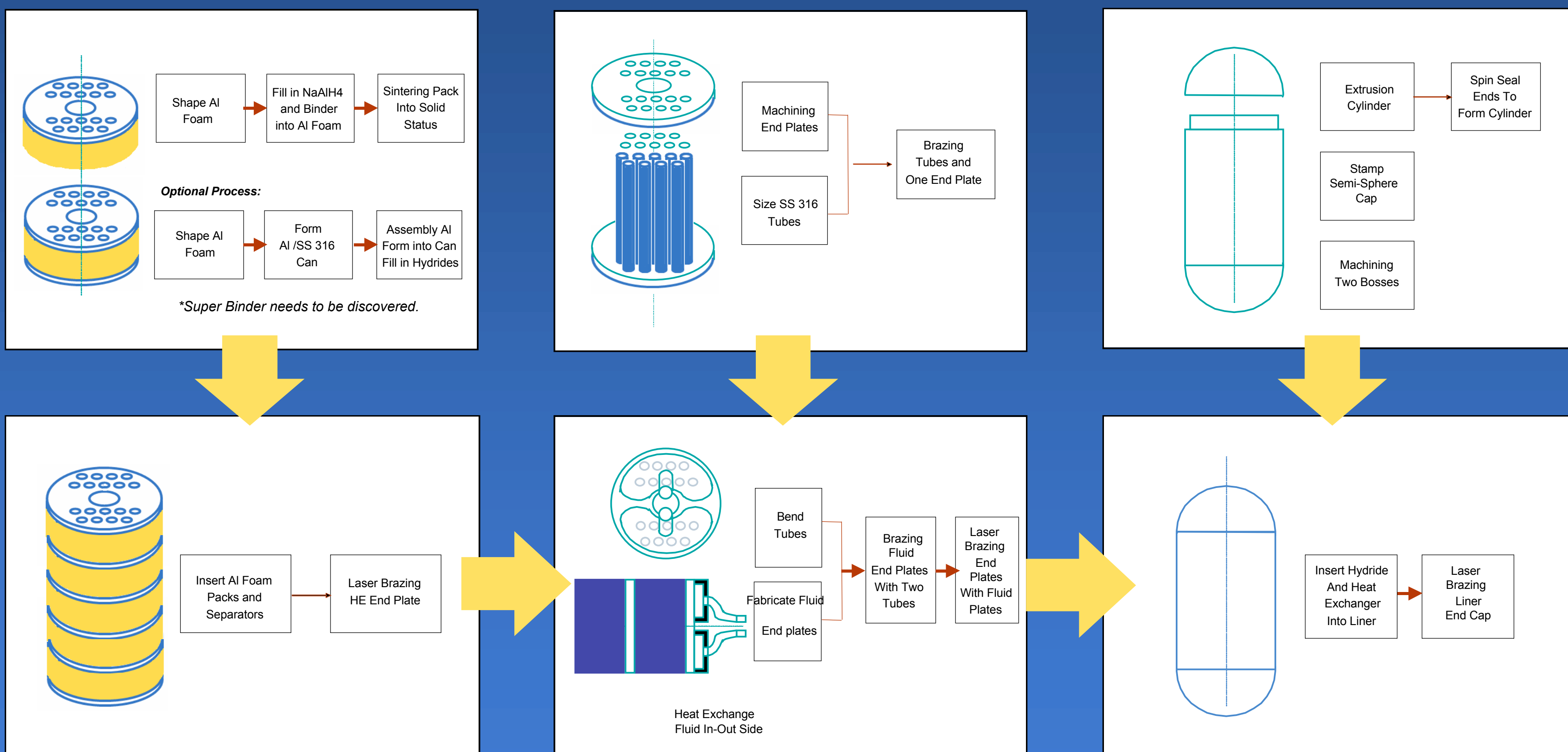


Liquid Separator



System Designs   Sodium Alanate Tank Manufacturing

Manufacturing processes and equipment are determined based on the individual component designs.



In this case, we assume a tank manufacturing process that loads the alanate in automated steps.

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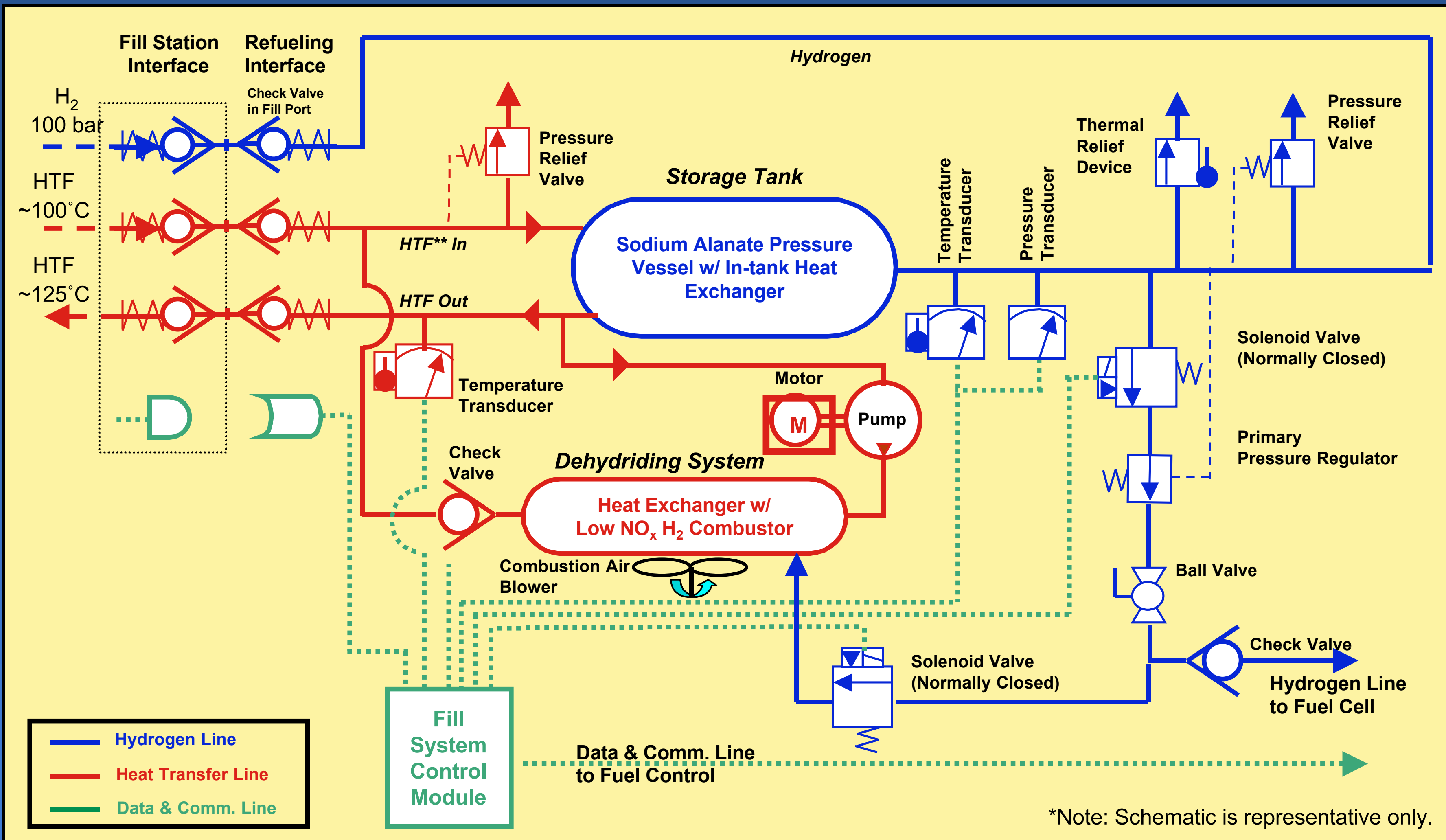
The complete storage systems require significant BOP for overall flow control and thermal management.



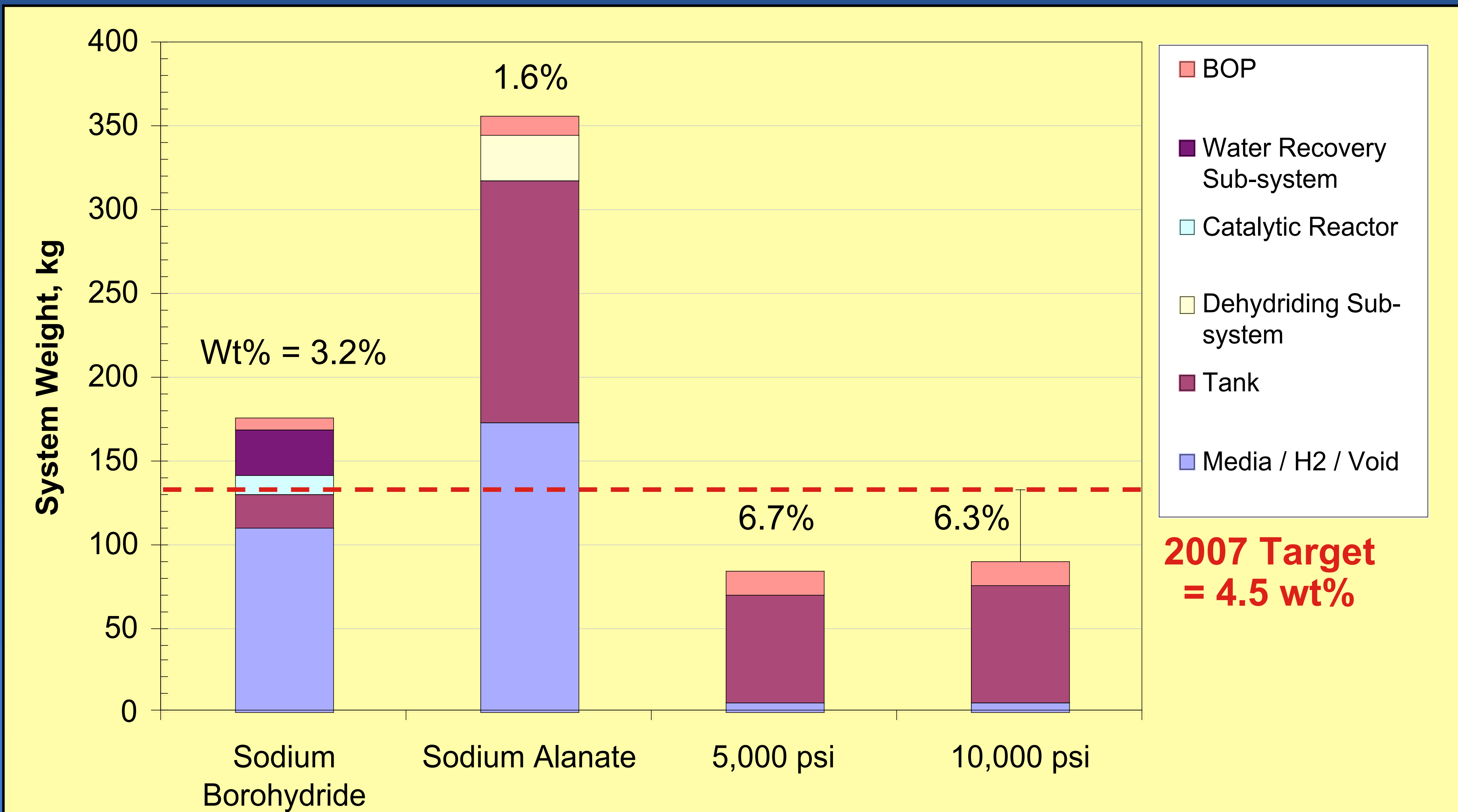
We have evaluated system designs based on the current technology, which does not always meet DOE targets.

Issues	Comments/Impact of Meeting Target
Transient and Start-up	• Additional components or advanced designs may be needed • May impact on-board efficiency and usable hydrogen stored
Material Life	• Limited amount of real-world data • Reformulated materials or advanced designs may be needed • Major impact on life-cycle cost • May impact on-board efficiency and usable hydrogen stored if material performance degrades over time
Safety	• Not all systems will have the same inherent safety • Additional components will be needed
Refueling	• Off-board requirements will be very different • Major impact on life-cycle cost and fuel chain efficiency • May impact on-board efficiency and usable hydrogen stored

Not all systems will perform exactly the same

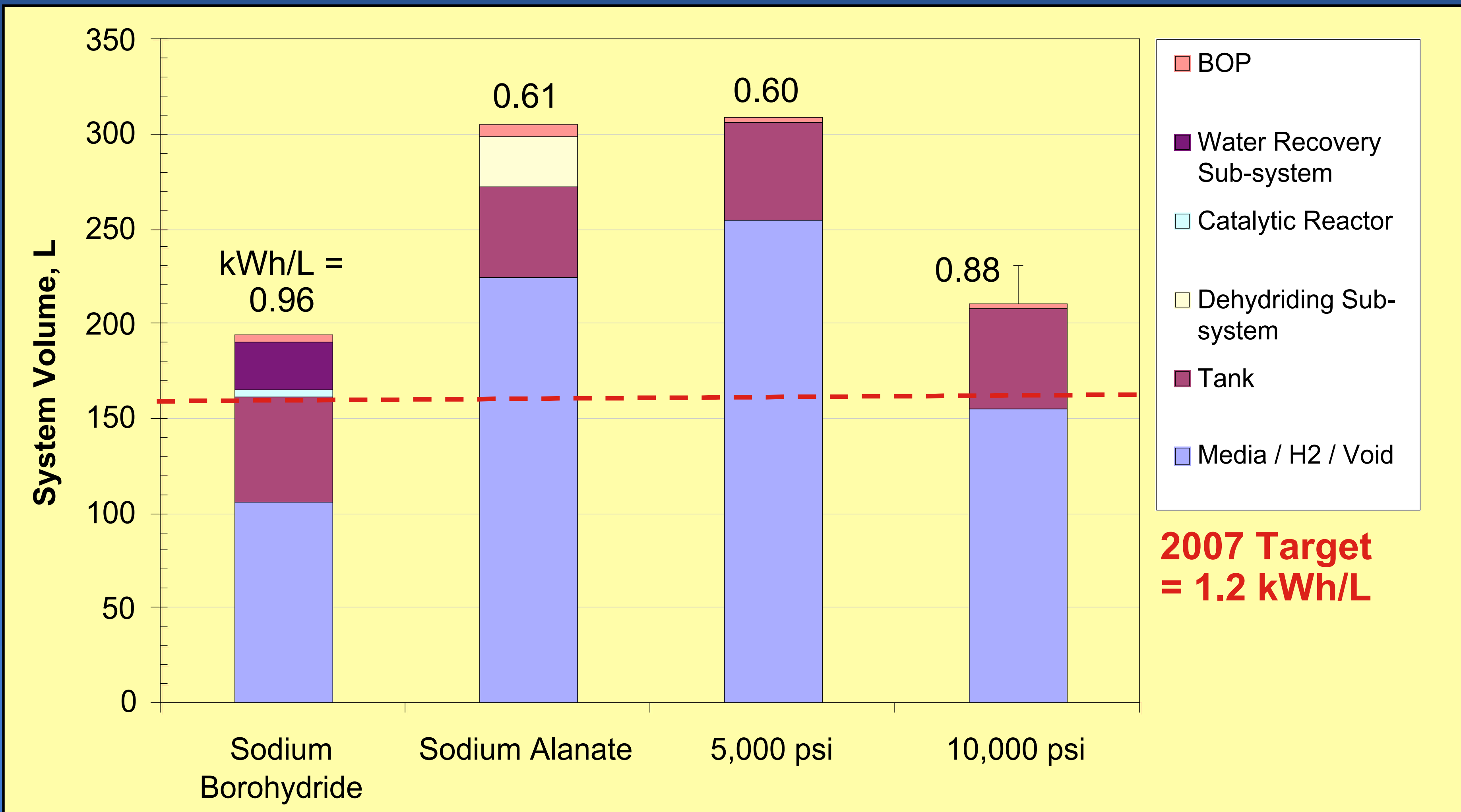
Results Weight Comparison

Compressed hydrogen storage at 5,000 and 10,000 psi resulted in the lowest overall system weight.



Results Volume Comparison

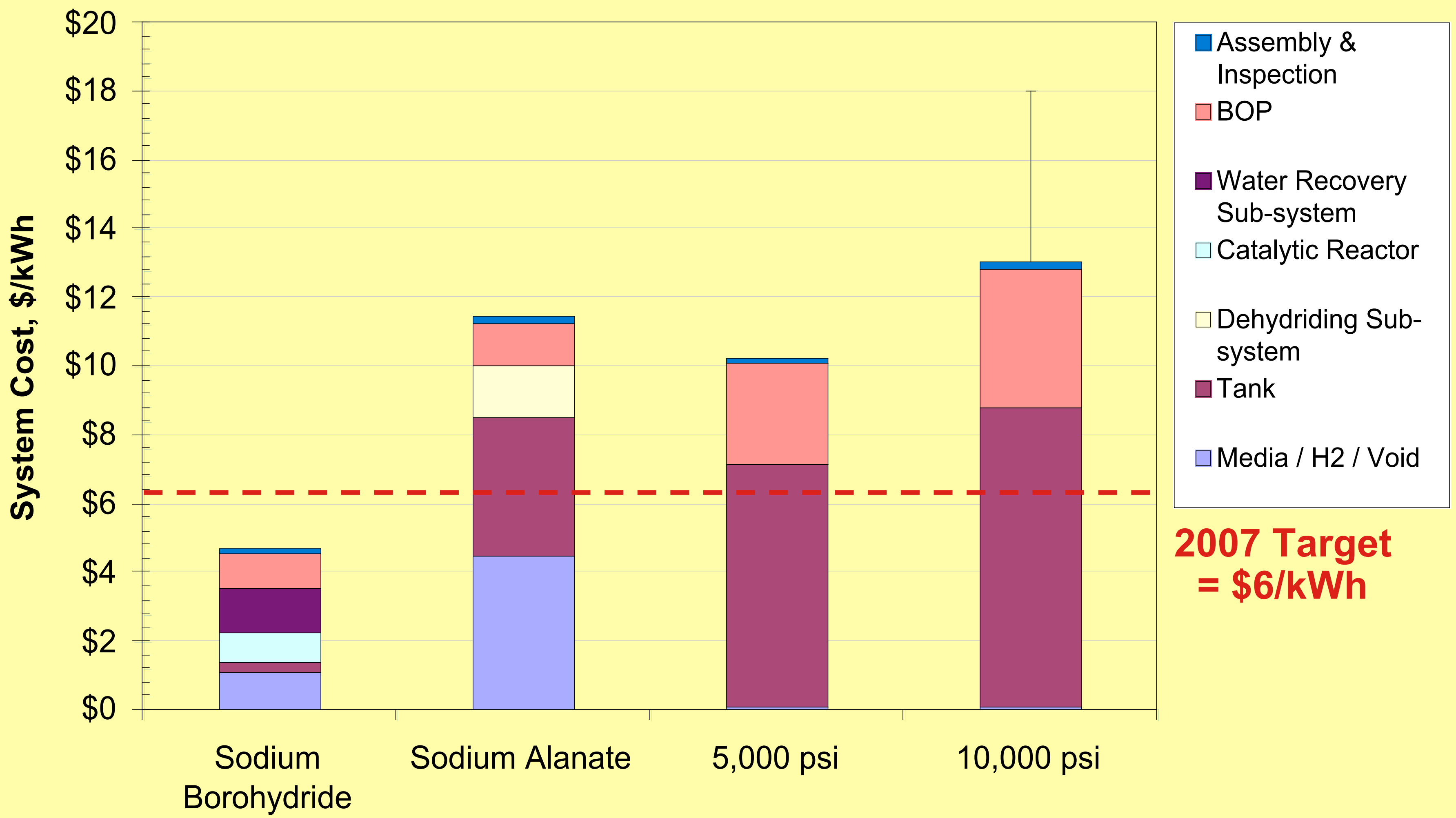
Sodium borohydride system with volume exchange design would be somewhat smaller than a 10,000 psi system.



Note: Volume results do not include void spaces between components (i.e., no packing factor was applied).

Results Cost Comparison

Factory cost of the sodium borohydride system is projected to be lower than the other systems evaluated thus far.



Note: Factory cost results do not include refueling costs over the life of the storage system.

Both basic research and system-level engineering need to continue if a viable storage system is to be developed.

Technology	Potential Advantages	Potential Disadvantages
5,000 & 10,000 psi	• High gravimetric density • Most mature • Relatively low fuel cost • Relatively high fuel chain efficiency	• Will not meet volumetric density target • High factory cost • High-pressure storage
Sodium Alanate	• Lower-pressure storage • Relatively low fuel cost • Relatively high fuel chain efficiency	• Low gravimetric density • High factory cost • High energy, P, T requirements • Slow startup
Sodium Borohydride	• Conformable tank • Low factory cost • Low-pressure storage • “Pumpable”	• One-tank design and water management challenges • Fuel cost and fuel chain efficiency TBD

Conclusions Next Steps

We will continue to support DOE and the Grand Challenge participants as they refine designs, processes, and materials.

- Preliminary results will continue to be refined based on developer/stakeholder feedback and progress
- Off-board (WTT) analysis will begin on the initial cases
- Task 1 report will summarize the results for the initial cases
- Work with DOE, ANL and COEs to select and evaluate new cases

Acknowledgment

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- Rest of the project team
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