



System Design and Media Structuring for On-board Hydrogen Storage Technologies

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General Motors
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Project ID: STP_12_Kumar



Overview

Timeline

Project start – Feb 1, 2009

Phase I end – Jan 31, 2011

Phase II end – Jan 31, 2013

Project end – Jan 31, 2014

Barriers Addressed

- System weight and volume (A)
- Energy efficiency (C)
- Charging/discharging rates (E)
- Thermal management (J)

Budget

DOE: \$2,954,707

GM match : \$738,677

Budget spent: < 5%

Partners

- SRNL
- UTRC
- Ford
- UQTR
- Other HSECoE partners

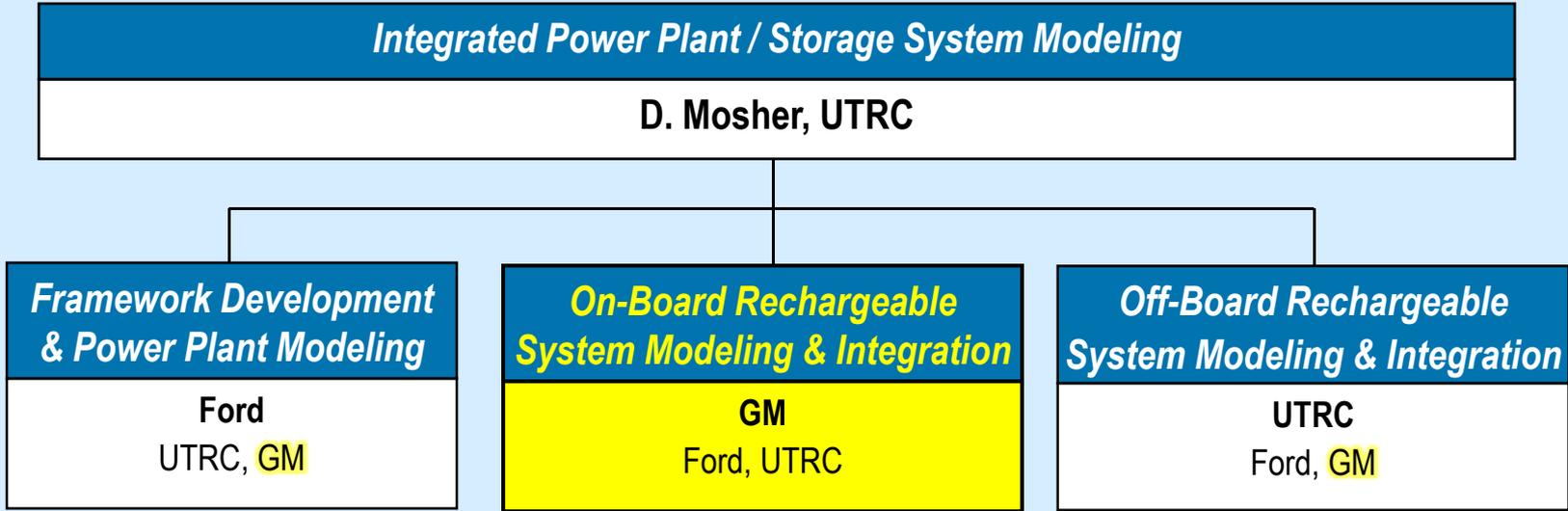


Major Objectives

- Develop system simulation models for on-board rechargeable (metal hydride and adsorbent) hydrogen storage systems
- Develop models for mass and energy transport in metal hydride and adsorbent beds
- Optimize mechanical stability, thermal properties, and hydrogen uptake of metal hydride and adsorbent media
- Design and build a vessel for adsorbent bed model validation and determination of fast-fill and discharge characteristics of an adsorption system
- Participate in prototype designs, data analysis and model validation



Systems Engineering



Objectives:

- Develop representations for on-board rechargeable adsorbent and hydride storage systems consistent with a common simulation platform and power plant model.
- Determine storage system baseline requirements.
- Establish representations consistent with the modeling strategy for vehicle level optimization studies.
- Develop system simulation models for the prime material candidates and system configurations.
- Conduct simulations of integrated power plant / storage system performance for key operational conditions.

Accomplishments:

- Identified MATLAB/Simulink as the common platform for building FC and storage system simulation models

Key Milestones:

1. Identify materials and baseline configurations for hydrogen storage system simulation. *(6/09, GM/Ford)*
2. Develop initial representations of system models. *(9/09, GM)*
3. Identify baseline hydrogen storage system requirements. *(12/09, All)*
4. Develop detailed representation consistent with power-plant and vehicle level models. *(3/10, GM)*
5. Establish generic operating profiles and conduct interaction evaluation of models. *(6/10, Ford/GM)*
6. Provide initial model method and results for Phase 1 Go/No-Go deliverables. *(10/10, All)*

Issues:

- Objectives requires close cooperation with FC modeling team and vehicle level modeling team to identify appropriate interactions with their modeling efforts



On-Board Rechargeable Systems

Compressed H₂ Storage

T ~ 25 °C
P ~ 350-700 bar

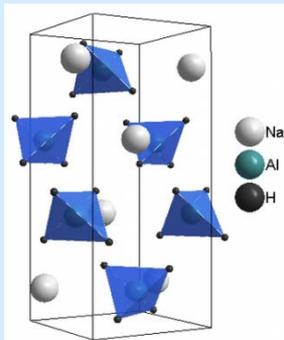
Storage as compressed gas
or cryogenic liquid

Liquid H₂ Storage

T ~ -253 °C
P ~ 1-2 Bar

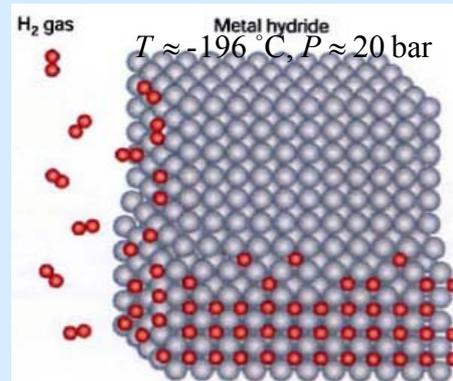
Solid State Storage

Complex metal hydrides
(reaction)



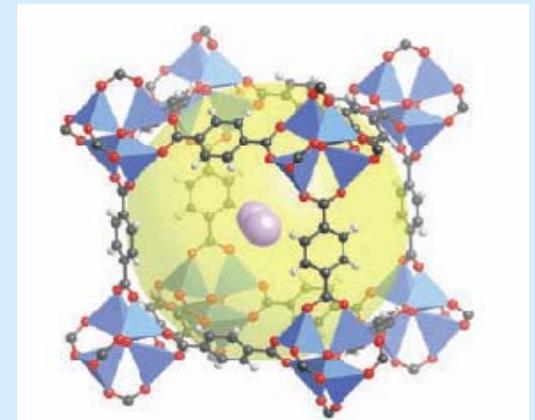
T ≈ 200 °C, P ≈ 125 bar

Interstitial metal hydrides
(absorption)



T ≈ 85 °C, P ≈ 350 bar

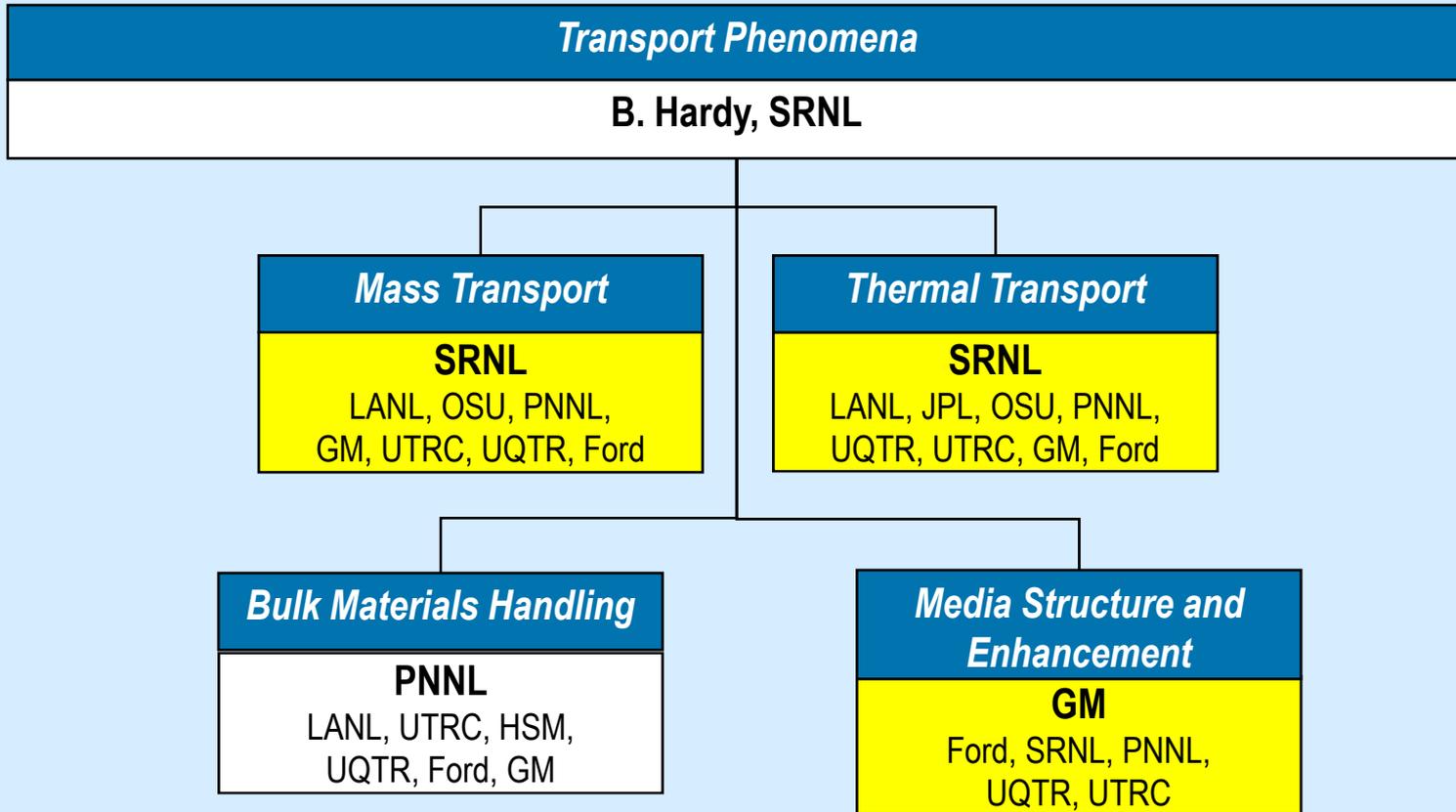
Cryo-adsorption



MOFs, ACs



Transport Phenomena



Technology Area: Transport Phenomena
Technology Team: Media Structuring & Enhancement
Date: March 17, 2009

Technology Team Lead: S. Kumar
Team Members: GM, Ford, UTRC, UQTR,
SRNL

Objectives:

- Select metal hydride (MH), activated carbon (AC) and framework materials (FM) for structured material studies
- Test binders, additives, and processing schemes for enhanced mechanical stability, thermal properties and kinetics
- Optimize composition and processing methods for thermal properties and H₂ uptake/discharge rates
- Measure engineering properties and durability of optimized structural materials

Accomplishments:

Key Milestones:

- Literature review of metal hydride, AC and FM for structured material studies (All) (5/01/09)
- Select metal hydride (GM, UTRC), AC (GM, UQTR) and FM (Ford, GM) materials for experimental investigation (07/01/09)
- Coordinate characterizing powder MH, AC, and FM materials for thermal properties and hydrogen uptake with materials requirements team(08/01/09)
- Preliminary experiments with respective binders, additives, and processing schemes for enhanced mechanical stability, thermal properties, and hydrogen uptake (GM, Ford, UTRC) (11/01/09)

Issues:

- **Coordinate efforts with bulk transport Tech Team**

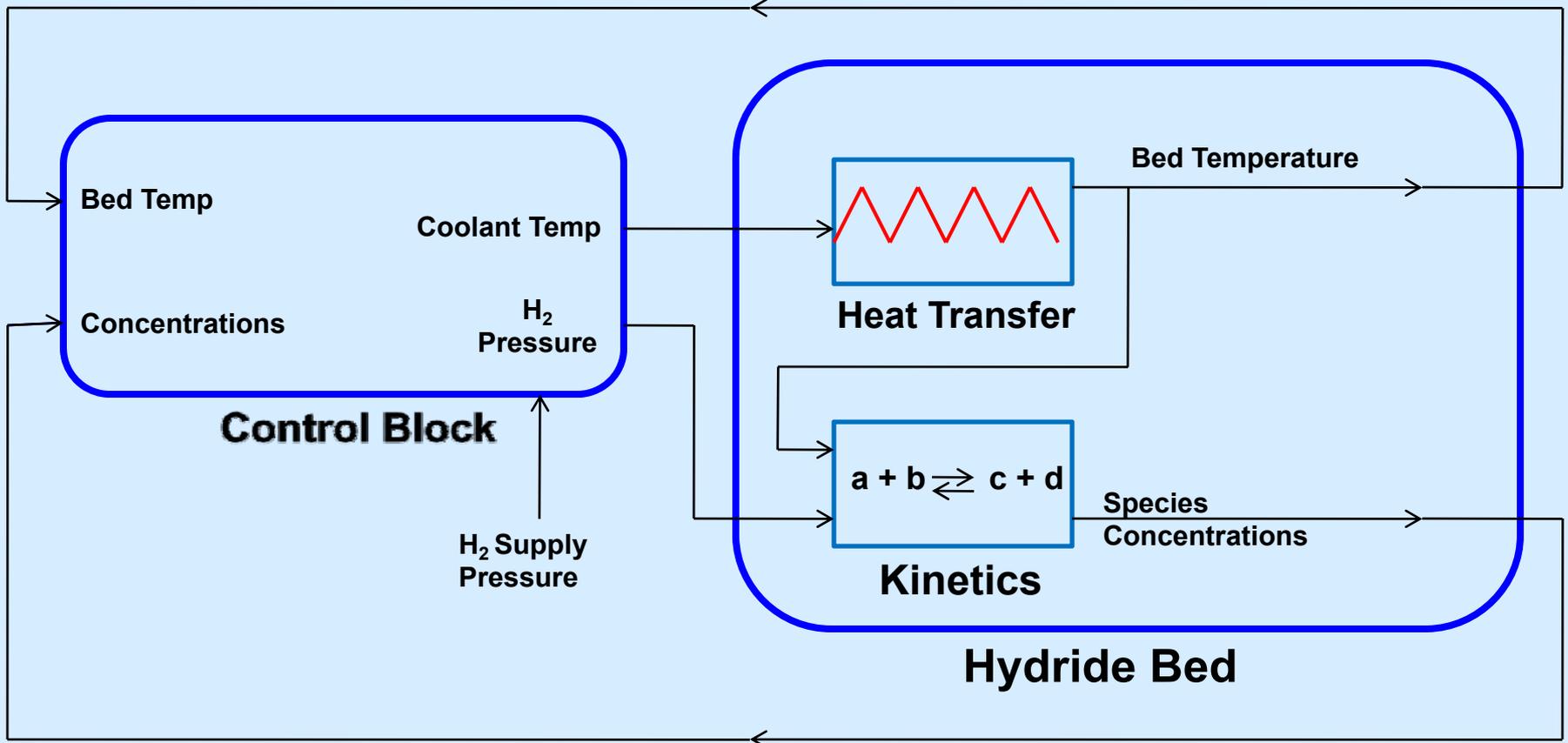


Phase I – Storage System Simulation Models

- Identify common modeling framework and develop initial representation of hydrogen storage system models
- Develop preliminary simulation models
- System integration with generic FC model
- Analysis of storage system ability to meet fuel cell hydrogen flow requirements
 - Adsorption system
 - Metal hydride system
- Use of realistic fuel cell drive cycles
 - Typical urban drive cycle
 - Extreme drive cycle

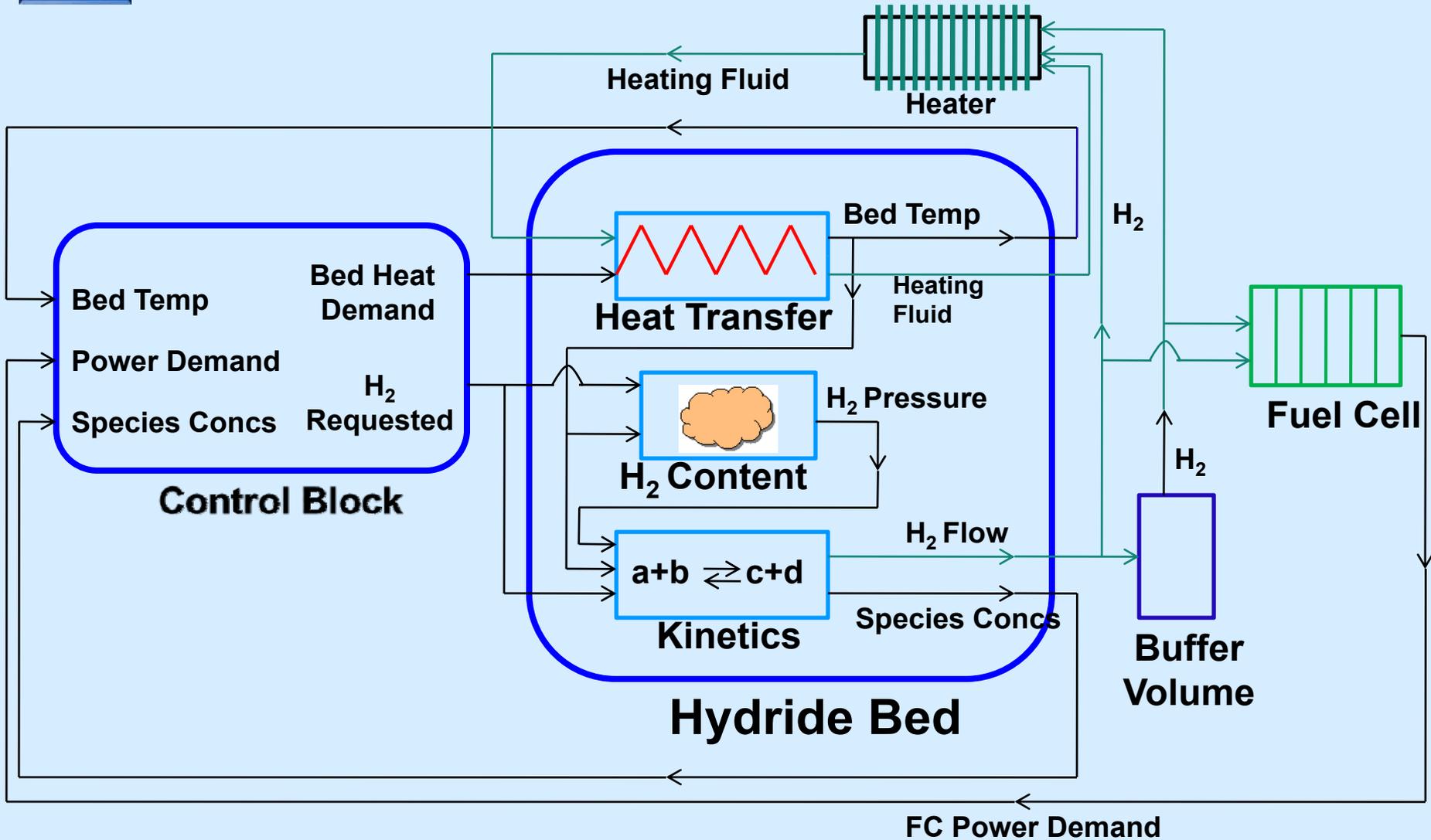


MH System – H₂ Absorption Schematic





MH System – H₂ Desorption Schematic



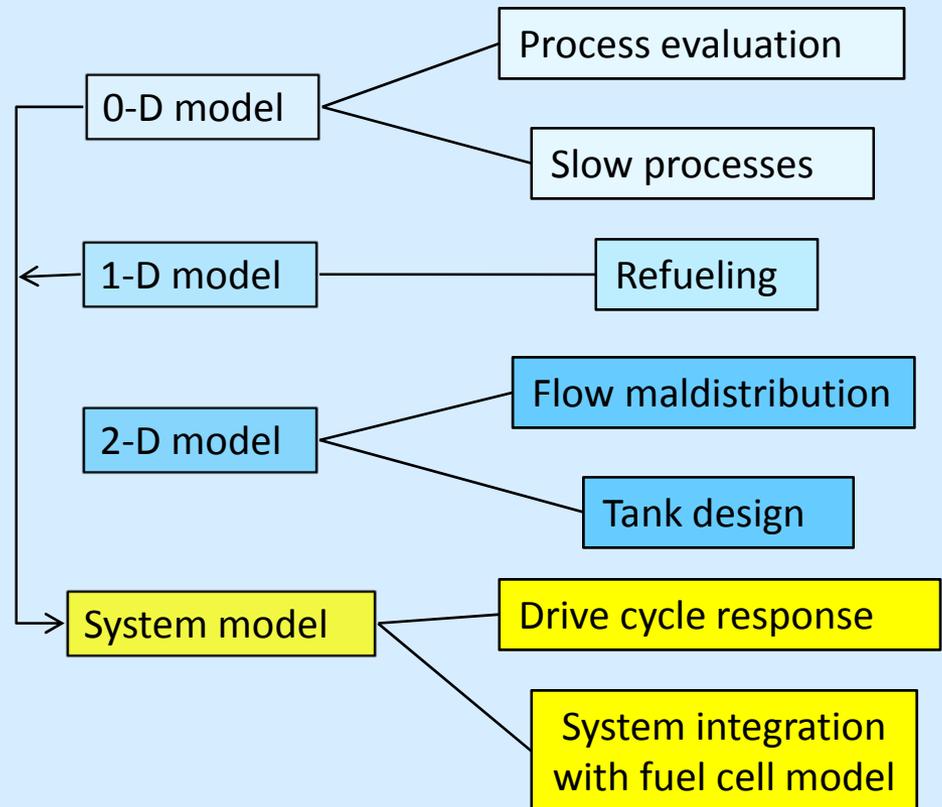
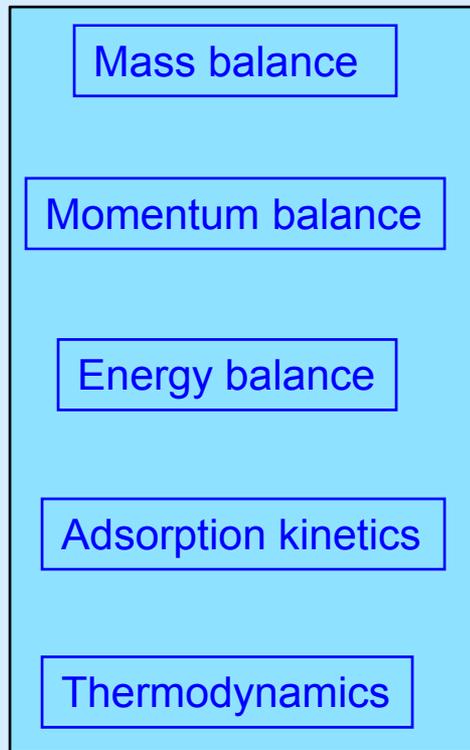


Adsorption System - Modeling Approach & Hierarchy

Refueling << Discharge << Dormancy << Venting
minutes << hours << days << weeks

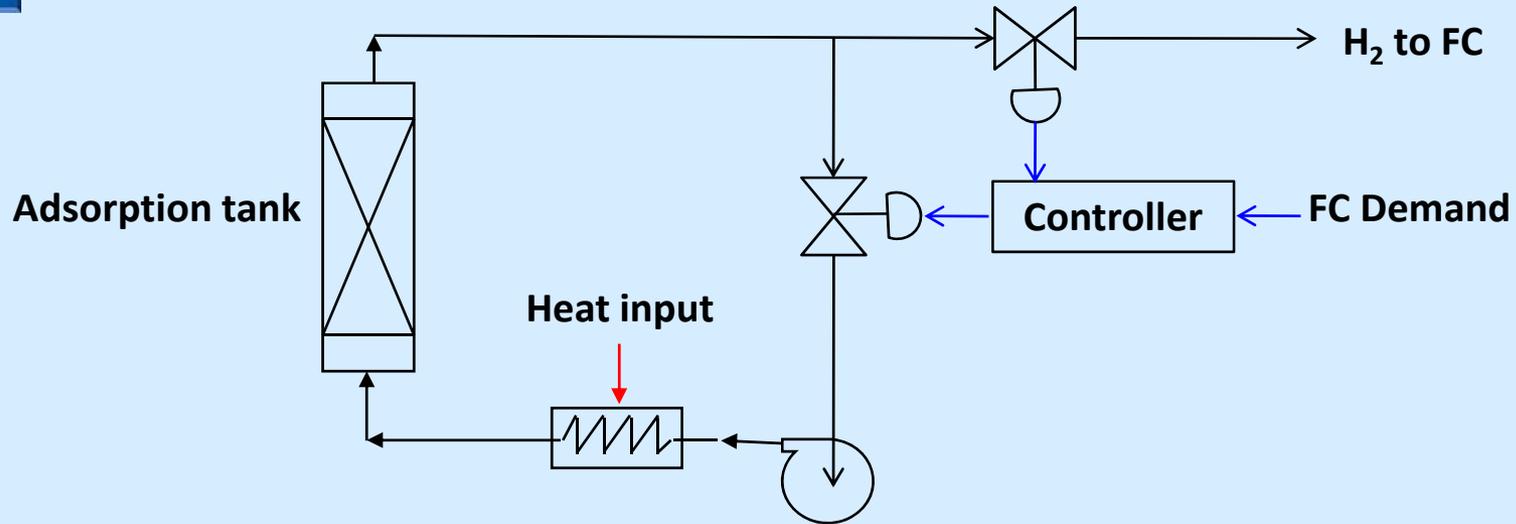
Fast process

Slow processes





System Modeling - Adsorption System



A lumped parameter model will be used to study the system dynamics during discharge and to:

- Identify the operating regimes where hot gas recirculation is necessary
- For a typical drive cycle hydrogen demand, study the storage system response and identify the optimal control strategy.



Status of Adsorption Bed Simulations

- A lumped parameter model for simulation of all four tank processes has been developed
- For the slower processes (discharge, dormancy and venting) a lumped parameter model is expected to be sufficient
- For refueling - the fastest process - higher dimensional models may be required because of significant temperature gradients expected in the tank
- Storage system model will be developed using the lumped parameter model for the adsorption system tank as well as the balance of plant components (pump, heater and controller)
- A hierarchy of models will be developed to study refueling and other issues associated with the adsorption system storage tank



Phase I – Mass and Energy Transport in Storage Beds

- Assessment of the ability of existing metal hydrides and adsorbents to meet DOE technical targets
- Initial models of storage system designs with generic materials; Lumped parameter and 1-D models for
 - Adsorbent material systems (AM)
 - Metal hydride systems (MH)
- Performance sensitivity studies
- Refueling studies
- Dormancy and boil-off analysis for adsorption system
- Select designs that hold promise to meet DOE 2015 goals for further analysis



Phase I – Media Structuring and Enhancement

- Develop MH and adsorbent material composites with enhanced thermal properties
 - Pellets, disks, and similar shapes
 - Metal hydride/adsorbent material, heat transfer enhancing materials, and binders
 - Goal of increasing thermal conductivity by 10 X with minimal impact on hydrogen absorption/adsorption characteristics
- Measure hydrogen uptake and engineering properties as a function of H₂ content for metal hydrides and adsorbent materials



Planned Milestones

- Sep '09 Identify materials and develop initial representations of system simulation models
- Sep '09 Preliminary assessment of the ability of existing media to meet 2010 and 2015 DOE targets
- Nov '09 Preliminary experiments to develop structured media with enhanced thermal properties
- Nov '09 Lumped parameter models suitable for MH and AM system simulations
- Nov '09 Design of a small cryogenic adsorbent material vessel for model validation studies
- Mar '10 System simulation model studies



Phase II – System Simulation Models

- Refine storage systems models for metal hydride and adsorbent material systems
- Integration with fuel cell model to meet requirements
- Forecourt requirements determination through modeling and analysis for energy efficient refueling
- Participate in subscale prototype designs for metal hydride and adsorbent bed technologies



Phase II: Mass and Energy Transport in Storage Beds

- Refine 2-D storage system models for MH and adsorbent bed technologies
 - Include specific geometry
 - Enhanced mass, energy, and momentum transfer as appropriate
 - Refueling and discharge studies
 - Dormancy and boil-off studies for adsorbent bed systems
- Simulations and validation of selected systems
- Evaluation of systems with potential future materials and compare to DOE goals



Phase II: Adsorbent Materials Systems Kinetics, Refueling and Discharge Characteristics

- Validate mass and energy transport models and study adsorption characteristics of various cryoadsorbents in a cryoadsorbent vessel
- Measure axial and radial temperature profiles in the bed
- Pressure drop across bed
- Vessel capable of material exchange to test various materials



Phase III

- Design of experiments for subscale prototype tests
- Analysis and evaluation of data from subscale tests
- Storage system model validation and refinement based on test data



Collaborations

- System simulation models – UTRC, Ford
- Media structuring and enhancement – UTRC, Ford, UQTR
- Mass and thermal energy transport – SRNL

GM Team

- Darsh Kumar – Principal Investigator
- Senthil Kumar V.
- Michael Herrmann
- Jerry Ortmann
- Mei Cai
- Scott Jorgensen