... FROM CONCEPT TO PRODUCTION

Low Cost, High Efficiency, High Pressure Hydrogen Storage

DOE Hydrogen, Fuel Cells & Infrastructure Technologies Program Review

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Project ID# ST15

Advanced Concepts for High Pressure Tanks

- Optimization and validation to achieve 2010 targets
  - Lower weight and cost of storage system
    - Material optimization
    - Process evaluation
    - Use of lower cost carbon fiber with advanced tank design
  - Reduce amount of material required through use of sensor technology to monitor storage system health
    - Replace tank over-design with sensors
- Investigate methods to improve the density of hydrogen gas storage through thermal management of the system
  - Investigate potential approaches relevant to heat rejection for solid-state systems

Project Overview

Phase 1
Trade Studies
FY 2004 - 2005
$537,257

<u>Track 1</u>
Composite Optimization

<u>Track 2</u>
Sensor Integration

<u>Track 3</u>
CoolFuel™ Study

80% Complete

Phase 2
System Validation
FY 2005 - 2006
$520,000

Combine best of Tracks 1-2 into an optimized 5kg storage tank and validate the tank to ECE/EIHP draft requirements

Initial Demonstration and Testing

Phase 3
System Demonstration
FY 2006+

Vehicle level demonstration of validated system

Evaluation and integration

Quantum cost share portion is approximately 60% of total project costs.

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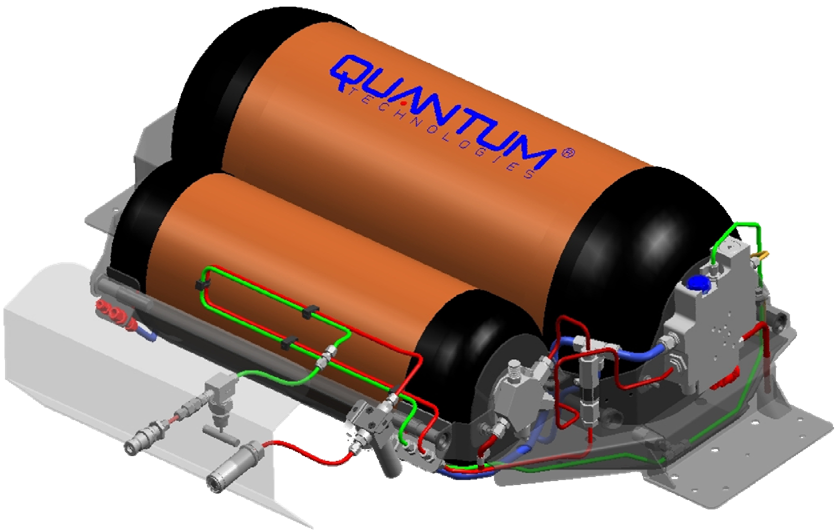
Project Overview

- Technical barriers
  - Cost
    - System level cost reduction (including balance of plant)
    - Minimize use of carbon fiber
  - Weight
    - Minimize use of carbon fiber
    - Investigate opportunities to reduce weight through system design
      - Regulator(s) and valve(s)
      - Plumbing
      - Miscellaneous
  - Volume
    - Increase energy density
- Collaborations
  - System analysis
    - FEA Technologies
    - General Motors



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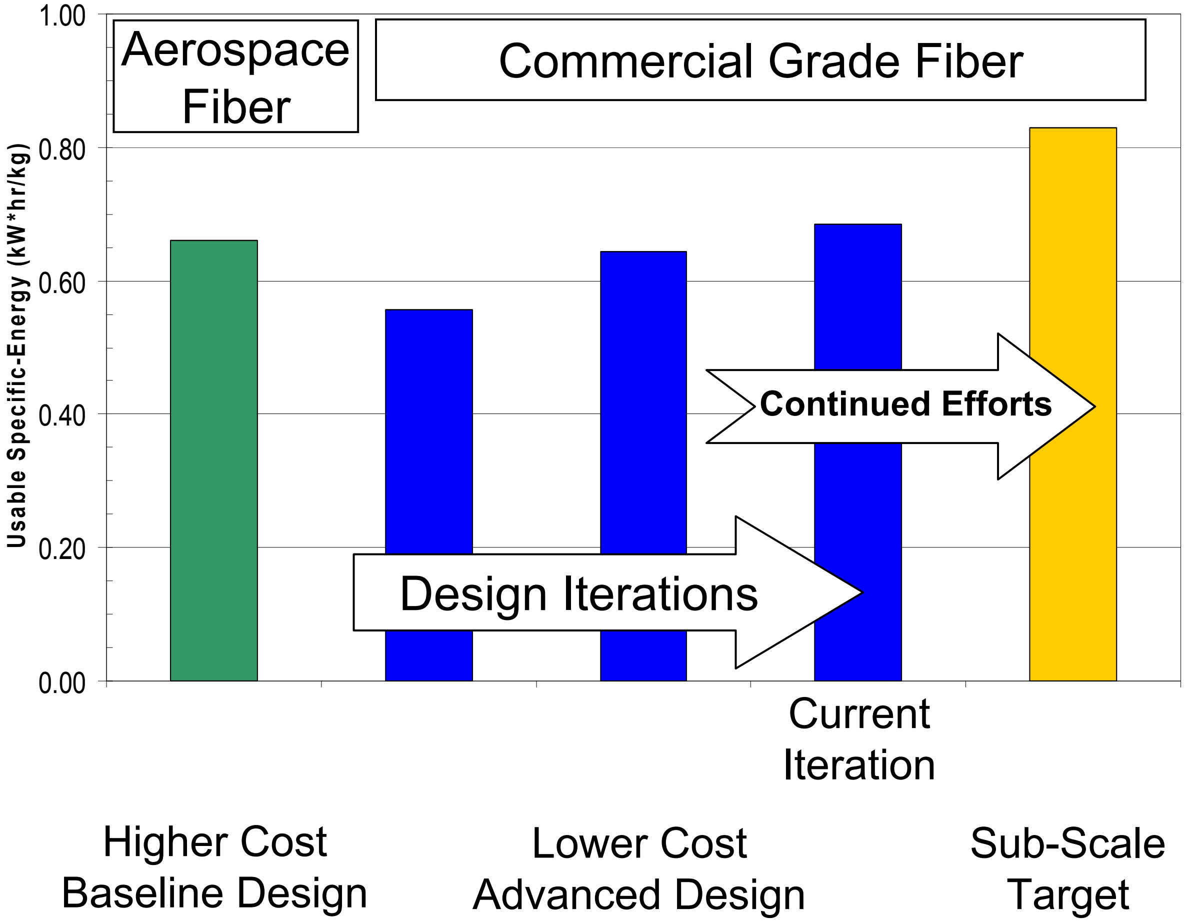
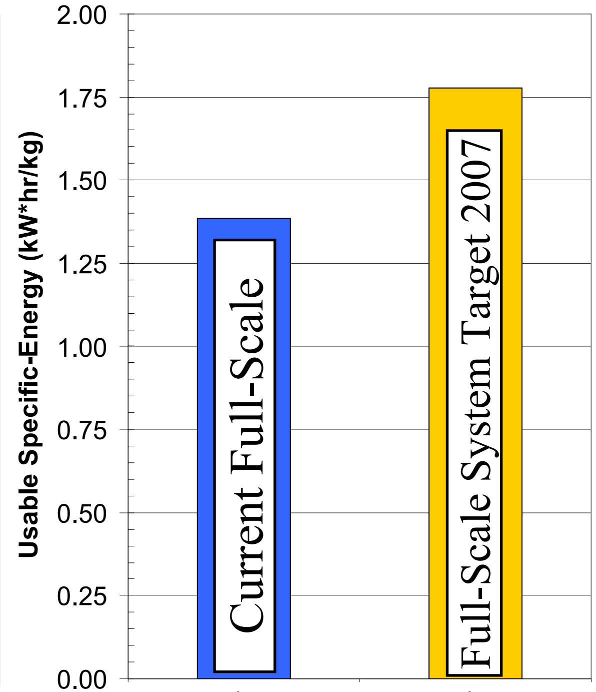
Track 1: Accomplishments

Sub-Scale Tank System
28-liter at 70 MPa (10,000 psi)
Hydrogen Storage



Full-Scale Tank System
160-liter at 70 MPa
Hydrogen Storage



Transfer Sub-Scale Lessons to Full-Scale

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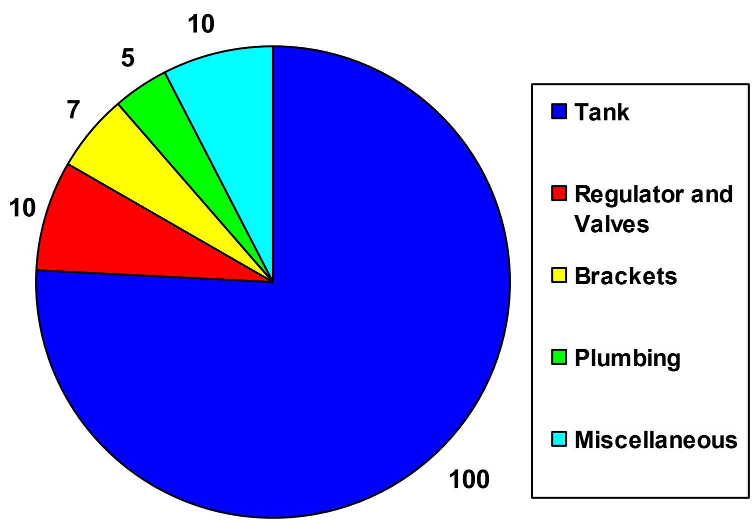
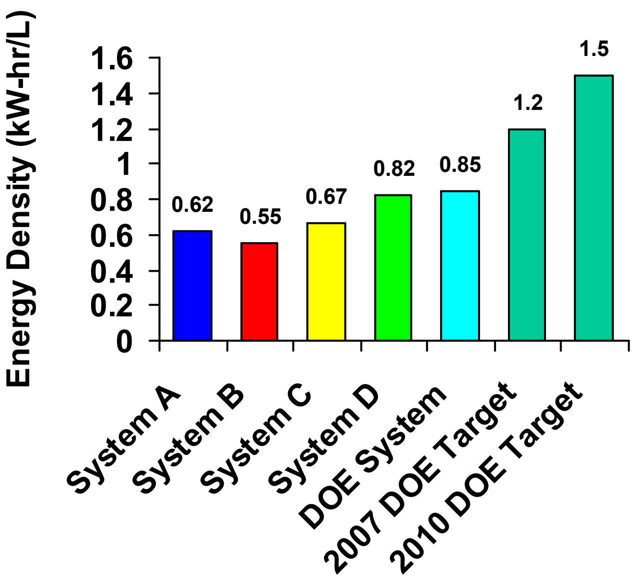
Track 1: Accomplishments

- 20 Tanks built and tested
- Optimization of composite structures is achievable
  - Projected storage efficiency of the sub-scale tank is 55% of the goal (0.83 kW-hr/kg)
- Full scale tank storage efficiency has high potential of meeting the 2007 goal of 1.5 kW-hr/kg
- Volumetric efficiency status is 0.8 kW-hr/L with current 70 MPa compressed gas technology





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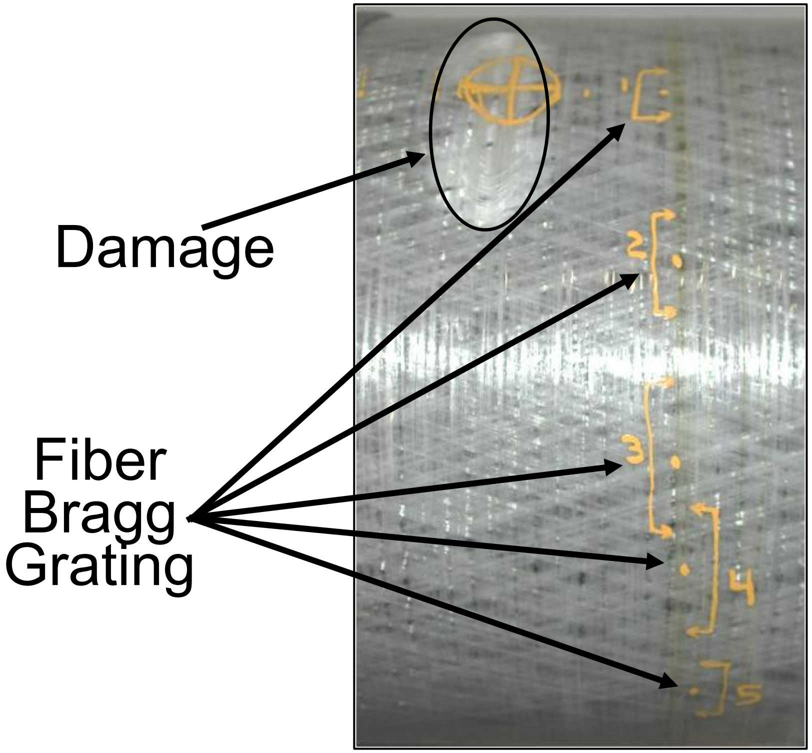
Track 2: Sensor System

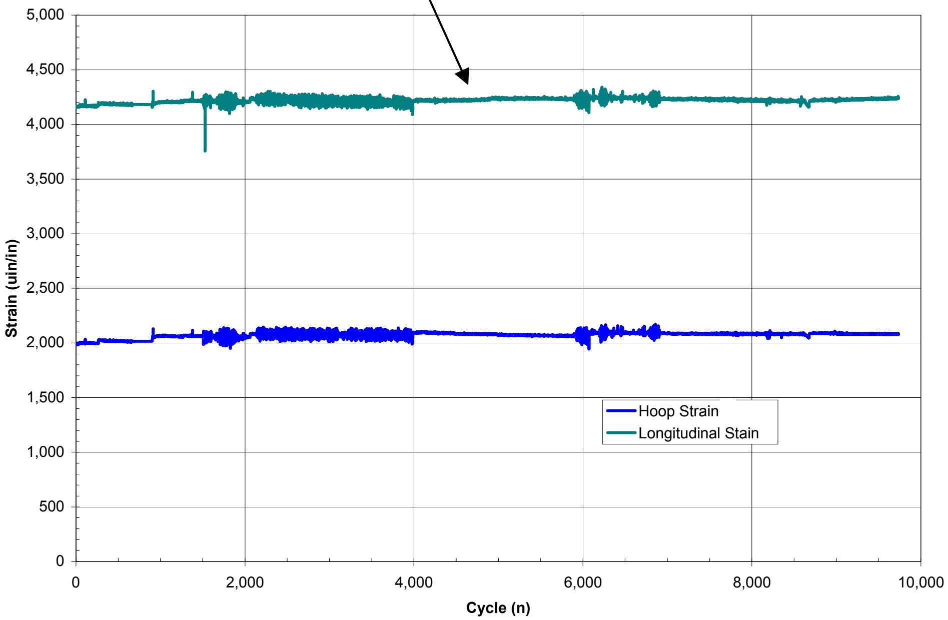


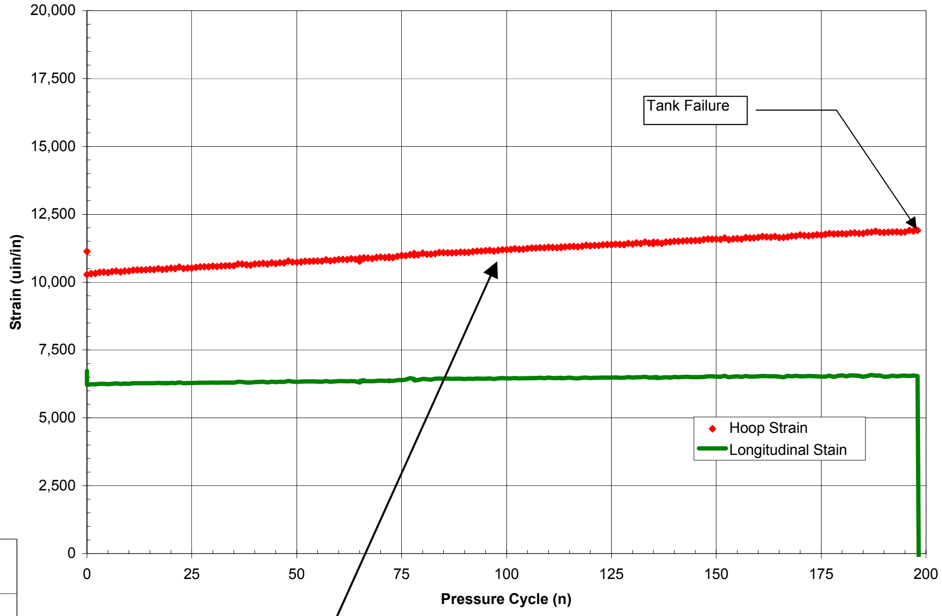
Example of Fiber Optic Strain Measurement

- Sensor Types:
  - Fiber Optic
  - Resistance, Analog
- Benefits
  - Lower weight and cost
    - ECE/EIHP draft regulations allow a lower safety factor if active sensors are used
    - Potentially save 30kg of carbon fiber (26% less carbon fiber)
  - Enhanced safety and reliability
- Approach
  - Introduce damage to composite tank to invoke a fatigue failure
  - Define the sensor density required
  - Calibrate sensor system

Fatigue Test – Strain Sensors

Strain for a healthy tank is constant over the life of the tank



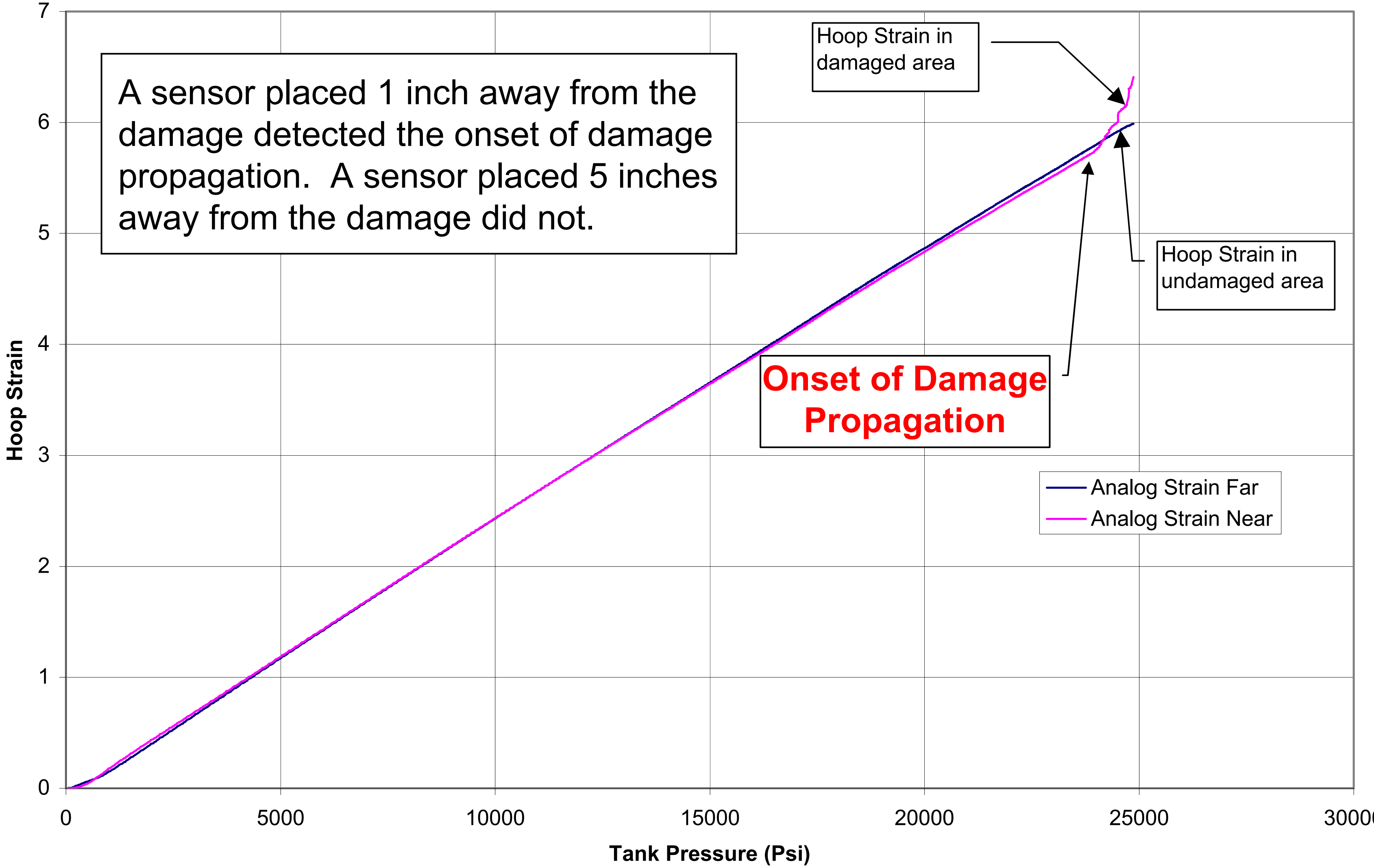


Strain levels increase every cycle for an unhealthy tank

Major question to answer is how many sensors are required to sufficiently detect health

Track 2: Accomplishments

Burst Test – Strain Sensors



Strain Levels on an Impacted Tank During Burst Test

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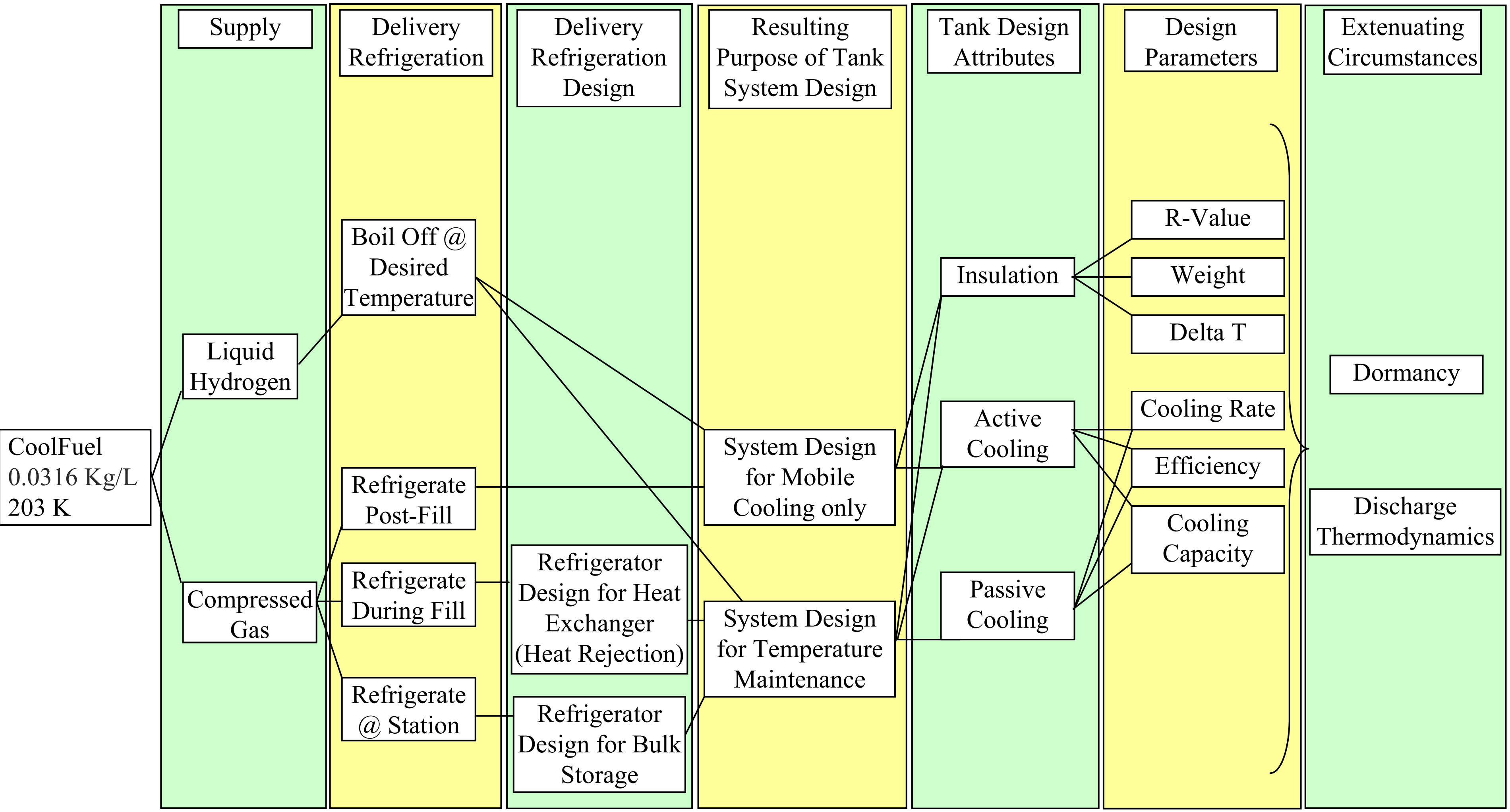
Track 3: CoolFuel™ System Overview



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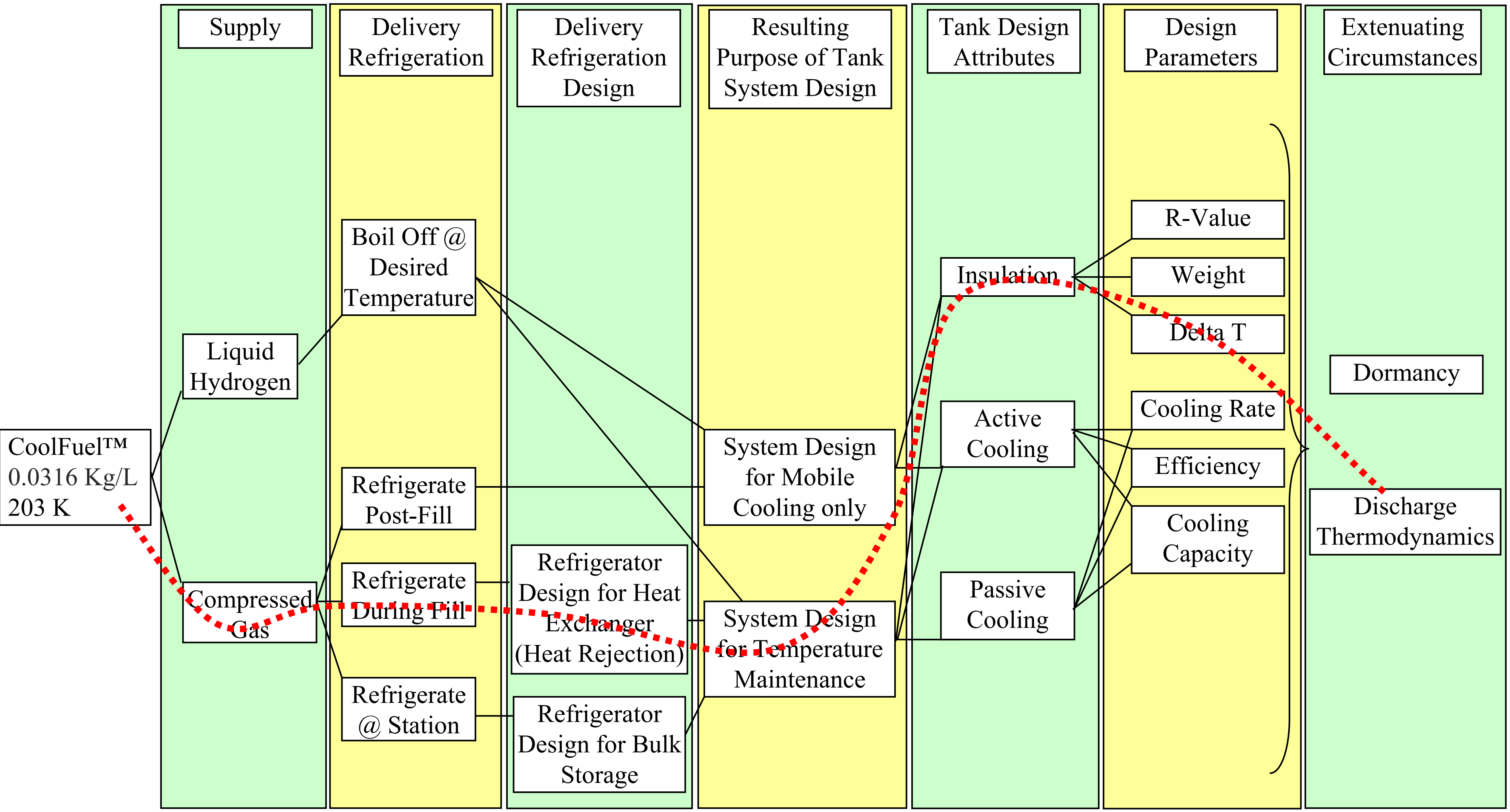
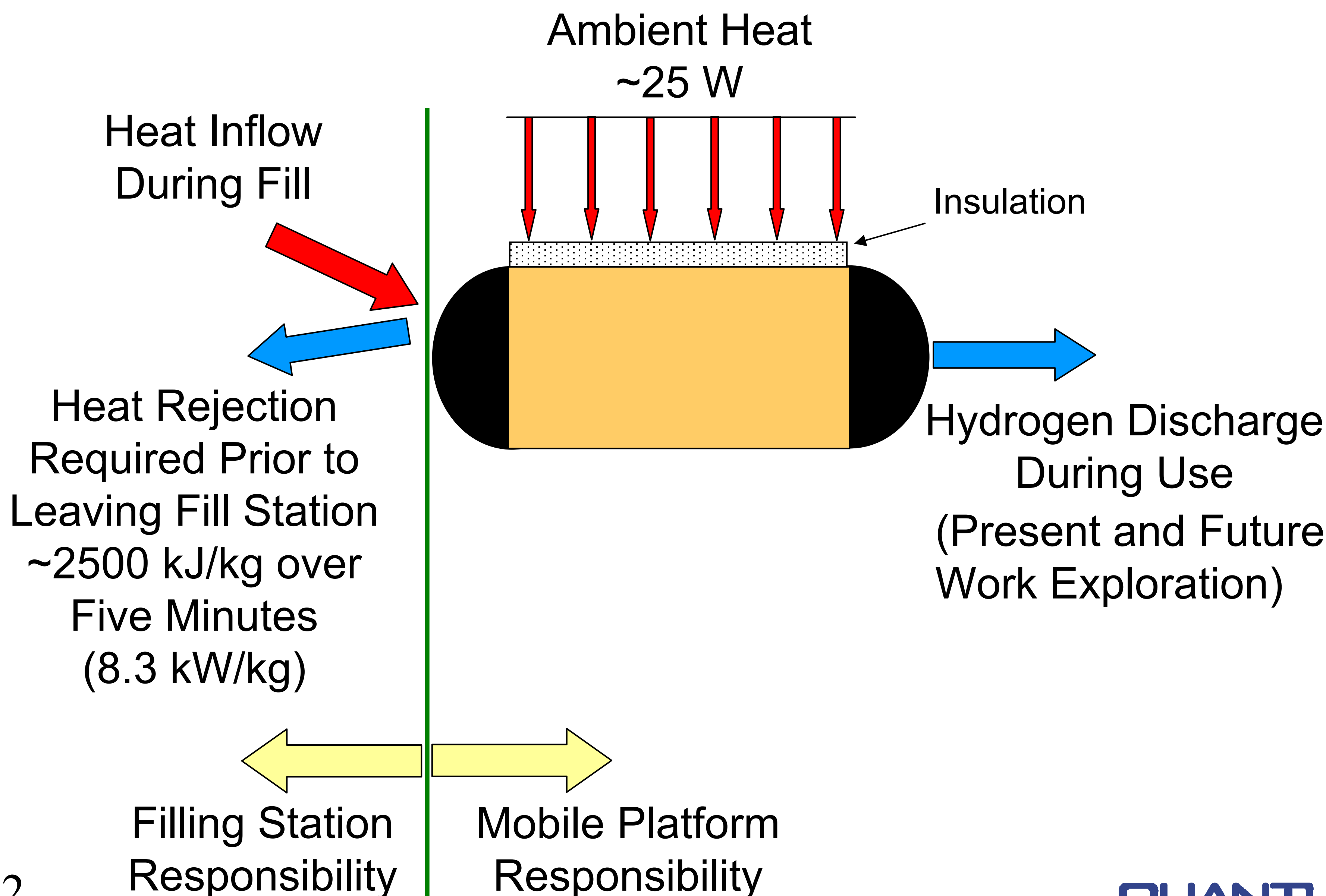
Track 3: CoolFuel™ System Overview



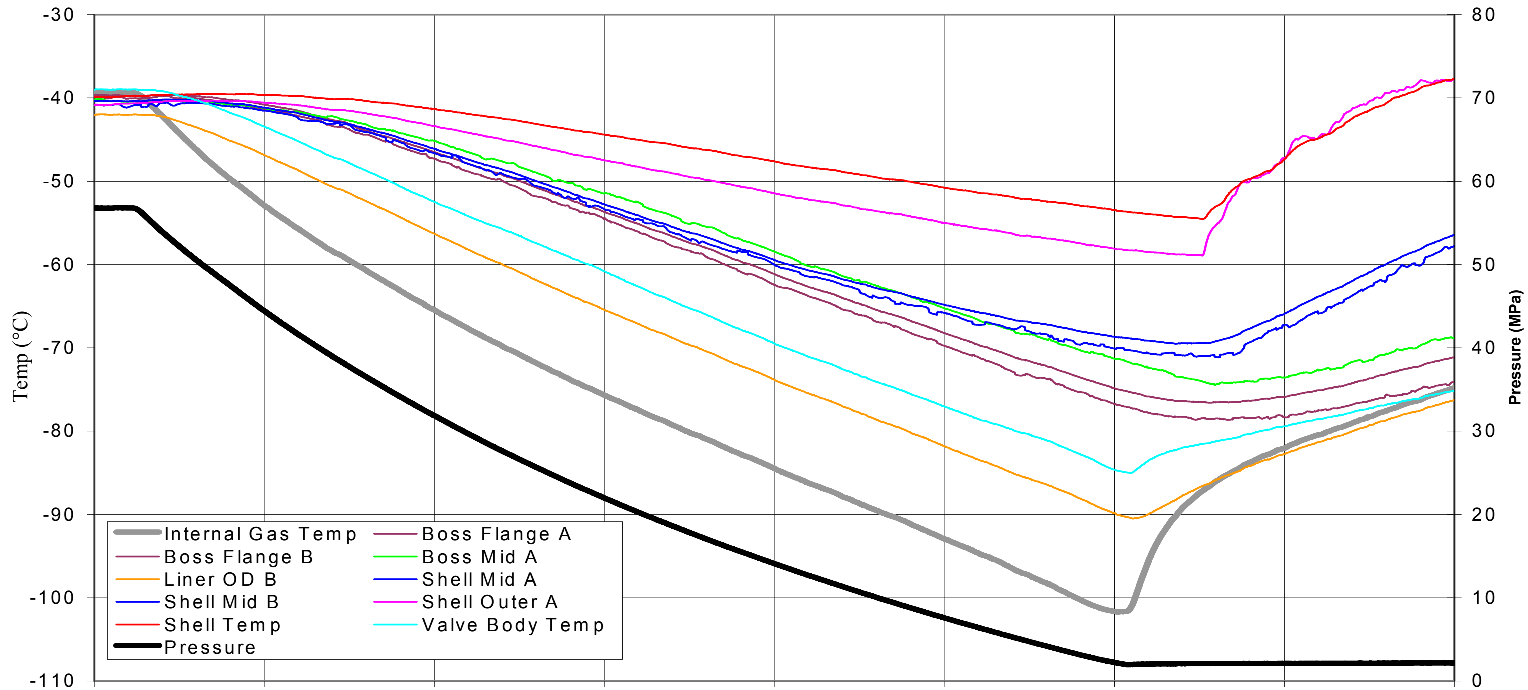
Near-term strategy involves rejecting heat at the filling Station, heavily insulating the tank and relying on discharge thermodynamics to counteract excess heat flow

Track 3: System Energy Balance



Track 3: Discharge Thermodynamics

Typical Hydrogen Discharge – 0.6 g/s @ -40 °C

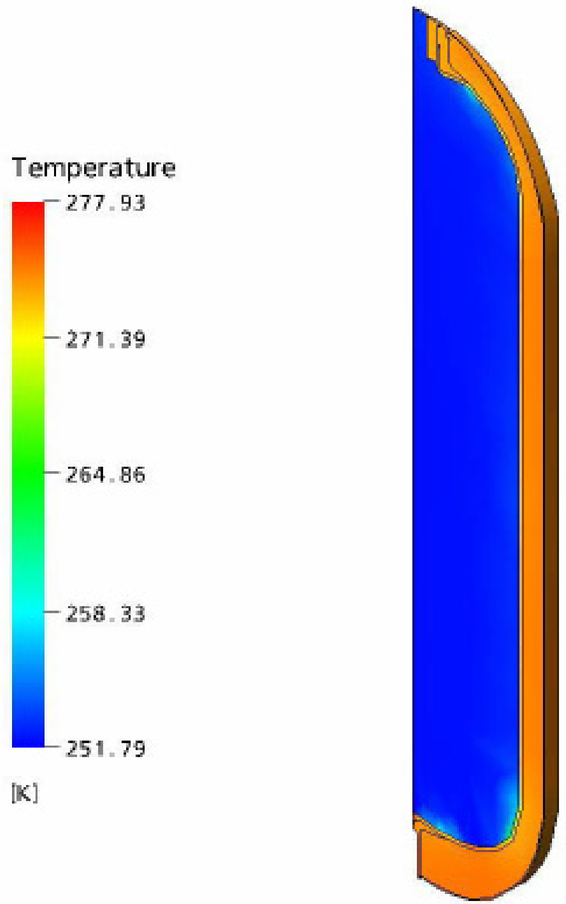


Example of current work on discharge thermodynamics

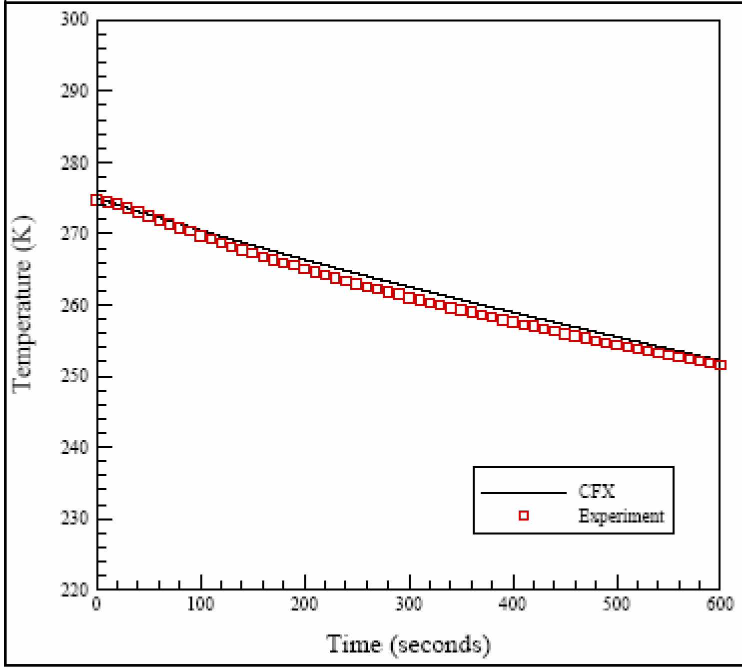
The cooling capacity from gas discharge may be used to keep the system cold until the temperature compensated operating pressure has been reached

Track 3: Finite Element Analysis

FEA Model below shows the temperature distribution throughout the tank 10 minutes after start of discharge



FEA model has shown correlation with experimental data. Next step is to model performance under drive conditions



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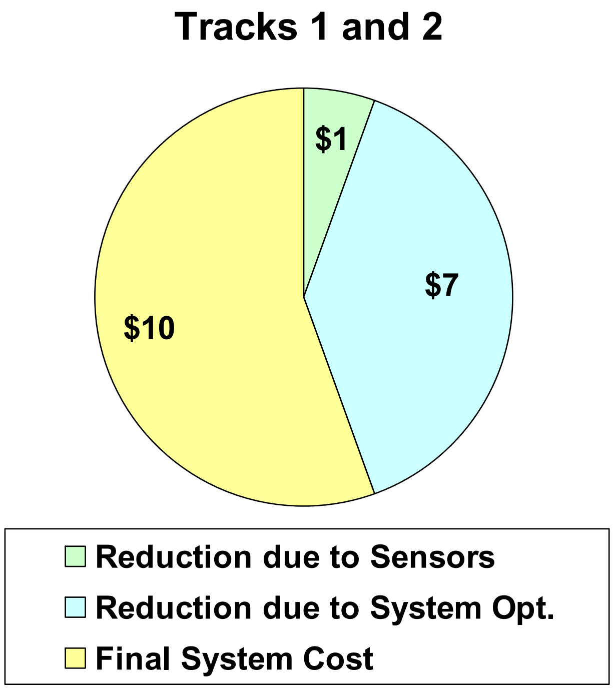
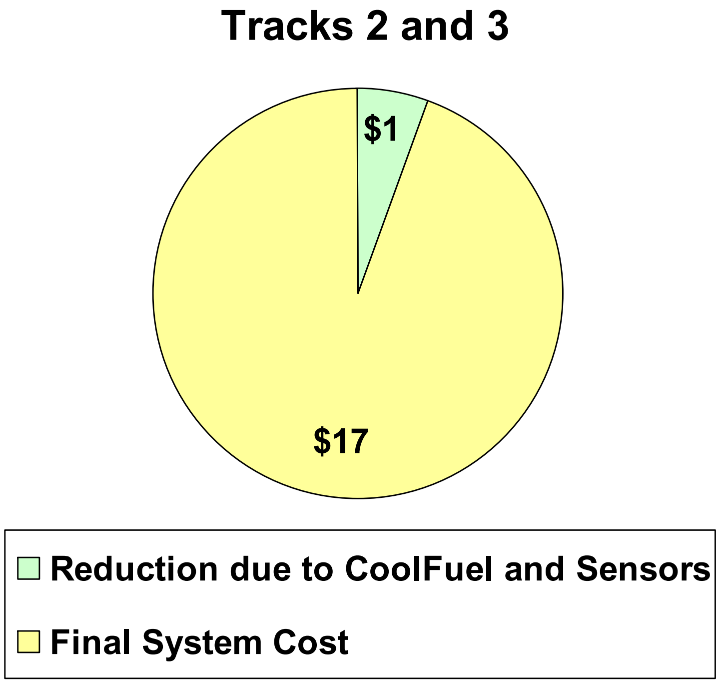
Cost Target ($/kW-hr)





- System cost can reduce to $10/kW-hr through optimization and use of sensors
- Optimization focuses on system cost reductions such as external regulator components that allow a smaller polar boss
- Assumptions
  - No significant carbon fiber reductions due to economies of scale
  - Hardware costs estimated for 500,000 per year production volume

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Response to Last Year's Reviewer Comments

"Status was reported for the tank itself but not for the entire system"

- Balance of plant has now been defined and is included in all calculations

"Good fit for near term goals for storage"

- All storage technologies are likely to require some form of pressurized containment

"EIHP is okay, but what about US-DOT?"

- European agencies have been taking a lead role in developing hydrogen codes and standards

"Limited collaborations"

- Quantum works with major automotive OEMs and utilizes knowledge gained from this work to develop a realistic DOE-defined system

"Break out system volume into components (e.g. pie chart)"

- Component volume is too small compared to tank volume for this chart to have relevance

Future Plans

- Track 1 and 2
  - Combine Track 1 and 2 results into a full scale, optimized tank system
    - Commercial grade carbon fiber
    - Improved manufacturing process
    - Optimized composite lay-up
    - Integrated sensor system to support lower burst ratio
  - Fabricate and validate full scale storage vessel to ECE/EIHP draft requirements
- Track 3
  - Finish theoretical study and choose system strategy
  - Initial prototype fabrication and demonstration of CoolFuel™

Backup Slides

Publications and Presentations

None at this point.

Hydrogen Safety

The most significant hydrogen hazard associated with this project is:

There is no significant hydrogen hazard associated with this project since helium is usually used in pneumatic tests and all destructive tests are performed using hydraulic methods.

Please list pertinent safety measures you are implementing and/or plan to implement.

Quantum Technologies has built test facilities to ensure the safety of its employees and the surrounding area. The facilities are either at a remote location or heavily reinforced to ensure containment of the energy release. All test equipment are designed to withstand the high pressures involved with this project.