Overview

Timeline
- Project start: July 1, 2005
- Project end: June 30, 2009
- Percent complete: 15%

Budget
- Total project funding
  - DOE share: $1,562K
  - Contractor share: $390K
- Funding received in FY05: $110K
- Funding for FY06: $150K

Barriers
- Cost: use inexpensive graphite
- Weight and volume: use high density graphite, maximizing capacity
- Efficiency: add electron charge to increase storage rate
- Durability: use electron charge to control cycles
- Refueling Time: use electron charge to increase fueling rate
- Codes and Standards
- System Life-Cycle Assessments

Partners
Superior Graphite Co.
Chicago, Illinois
## Objectives

### Overall
Development of a hydrogen storage device for hydrogen quick charge and discharge, high wt% and vol% storage capacity, durability over many cycles, and safe handling and transport.

<table>
<thead>
<tr>
<th>Year</th>
<th>Activities</th>
</tr>
</thead>
</table>
| 2006 | - Select materials and conduct graphite-processing steps  
      - Test and evaluation cycles for hydrogen storage  
      - Construct an electron charge device and evaluate the concept with the modified graphite materials. |
| 2007 | - Prepare samples for independent evaluation  
      - Investigate performance optimization and prototype container systems. |
Plan and Approach

Task 1. Proof of Feasibility
1. Select materials for intercalation
2. Test and evaluate hydrogen storage cycles
3. Theoretical calculation

Task 2. Hydrogen Storage Optimization
1. Prepare samples for independent evaluation
2. Performance optimization
3. Investigate process steps

Task 3. Prototype Development and Process Scale Up
1. Pilot evaluation of production steps
2. Production cost and market potential

Task 4. Production and Market Assessments
1. Build prototype systems
2. Analysis of market
Technical Accomplishments/Progress/Results

- Achieved 4.5Å space between graphite flakes. This 4.5Å can allow hydrogen molecules to enter.
- Intercalated different metals to change the graphite electronic configuration: Mg, Li, Al, and Ti etc.
- Achieved 1% hydrogen storage with graphite based materials in early-stage tests.
- Built an electron-charge device for hydrogen storage and observed the effect of external charges on the hydrogen storage.
Accomplishments/Progress/ Results

Hydrogen Storage Material Development

- Graphite expansion and oxidation
- SEM and TEM analysis of the expansion
- Expanded graphite reduction and mechano-chemical intercalation
- Structure reorganization under heat treatment
- Hydrogen uptake and release using high temperature, high pressure TGA as well as Sievert devices
# Graphite Samples for Hydrogen Storage Materials

<table>
<thead>
<tr>
<th>Superior Batch</th>
<th>Sample Name</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO-4-40-05</td>
<td>GTI Compacted Worms</td>
<td>Worm structure</td>
</tr>
<tr>
<td>SO-4-40-08</td>
<td>GTI SLC 1520</td>
<td>High bulk density, spherical</td>
</tr>
<tr>
<td>SO-4-40-09</td>
<td>GTI SLA 1518</td>
<td>High bulk density, spherical</td>
</tr>
<tr>
<td>SO-4-40-07</td>
<td>GTI SCD310</td>
<td>Purified carbon black with graphite</td>
</tr>
<tr>
<td>SO-4-40-03</td>
<td>GTI 2935 GRAPH</td>
<td>Flat flakes</td>
</tr>
<tr>
<td>SO-4-40-04</td>
<td>GTI Fullerine</td>
<td>Fullerine graphite</td>
</tr>
<tr>
<td>SO-4-40-01</td>
<td>GTI 9039 RG</td>
<td>Boron graphite</td>
</tr>
<tr>
<td>SO-4-40-06</td>
<td>GTI SR11993</td>
<td>Unique SGCo</td>
</tr>
<tr>
<td>SO-4-40-02</td>
<td>GTI 2926 RGAPH</td>
<td>Flake graphite for plates</td>
</tr>
<tr>
<td>Batch 73703</td>
<td>GTI 4926</td>
<td>Flake graphite for plates</td>
</tr>
</tbody>
</table>
Accomplishments

Different Graphite Shapes Fabricated and Tested

Graphite shape modification, metal intercalation, and coating for hydrogen storage
Accomplishments

Graphite Expansion

Thermally Purified natural crystalline flake graphite G2900G8

2939APH
(D50~10um; BET surface area: 9 m2/g)
Accomplishments

Aggressive intercalation + oxidation

Step 2
Accomplishments

Enlarged SEM showing high surface area

BET surface area: 700 m²/g
The space between graphite layers is more than 4.5 Å
TGA of the Expanded Graphite for Hydrogen Storage

![Graphite SO#4-49-18 and Temp vs. Time (sec.) plot]

- Graphite SO#4-49-18
- Temp

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Wgt (%) vs. Time (sec.)

- 100.05
- 100
- 99.95
- 99.9
- 99.85
- 99.8
- 1000
- 2000
- 3000

Temp (°C)

- 0
- 50
- 100
- 150
- 200
- 250
High temperature, high pressure thermo gravimetric analysis (TGA) is used to test the hydrogen storage and cycle lifetime.

- Look for the storage capacity decay under different pressures.
- Screen material modification to increase the hydrogen storage capacity and decrease hydrogen charge/discharge decay rate.
Hydrogen Uptake/Release Cycle on Graphite-based Material

Hydrogen storage capacity increases while the hydrogen release decreases.
Hydrogen Storage Capacity Decays with Cycles under Different Pressures

- H2 Storage at ambient pressure
- H2 Storage at 136 KPa
- H2 Storage at 340 KPa
Sievert Method to Test Hydrogen Storage Capacities

- Measure the hydrogen storage and release capacity at steady state under different temperatures.

- Calculate the enthalpy ($\Delta H$) of the hydrogen adsorption
Pressure/Composition Isotherm Curves of the Graphite-based Hydrogen Storage Material

Storage capacity: 0.8 ~ 1.0 wt%
The heat release ($\Delta H$) of the metal modified graphite material for hydrogen adsorption is $-22.7$ kJ/mol. The theoretical calculation of pure metal alloy for hydrogen adsorption is approximately $-33$ kJ/mol. The metal modified graphite has low heat produced in the hydrogen adsorption.
Electron-charged Device for Hydrogen Storage
Electron-charge Effect on Hydrogen Storage

![Graph showing the effect of electron charge on hydrogen storage with pressure (MPa) on the y-axis and hydrogen content (mole/gram) on the x-axis. The graph includes lines for different voltages: 0V, -5V, and +5V, and indicates the room temperature.](image-url)
Electron-Charge Effect on Hydrogen Storage

- The PCT shift is related to the electronic structure of the substrate. Electron-rich material needs positive charges and electron-poor material needs negative charges.

- External charge shifts the chemi-sorption to physi-sorption and shifts physi-sorption to chemi-sorption with different charges.

- Exploring benefits in conventional metal hydride and newer materials
Future Work

- Test and evaluation cycle for hydrogen storage
  1. Modify testing apparatus
  2. Test the expanded and intercalated graphite materials
  3. Investigate the electron charge effect on different hydrogen storage substrates.

- Calculate and compare the theoretical charge sufficient for the hydrogen storage target
Future Work

- Prepare samples for independent evaluation
- Investigate performance optimization and prototype container system
- Investigate process steps for production
- Preliminary analysis of production costs
- Pilot-evaluation of key production steps
- Prepare samples and prototype containers for independent evaluation
Summary

> Demonstrated the hydrogen storage capacity 0.8~1.0 Wt% of graphite-based materials.

> Achieved 4.5Å space between graphite flakes

> Demonstrated the external electron charges affect the hydrogen storage. The PCT curves of the graphite-based materials show that the positive charges reduce the hydrogen storage and negative charges increase the hydrogen storage.
Acknowledgements

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