Hydrogen Storage Workshop Summary

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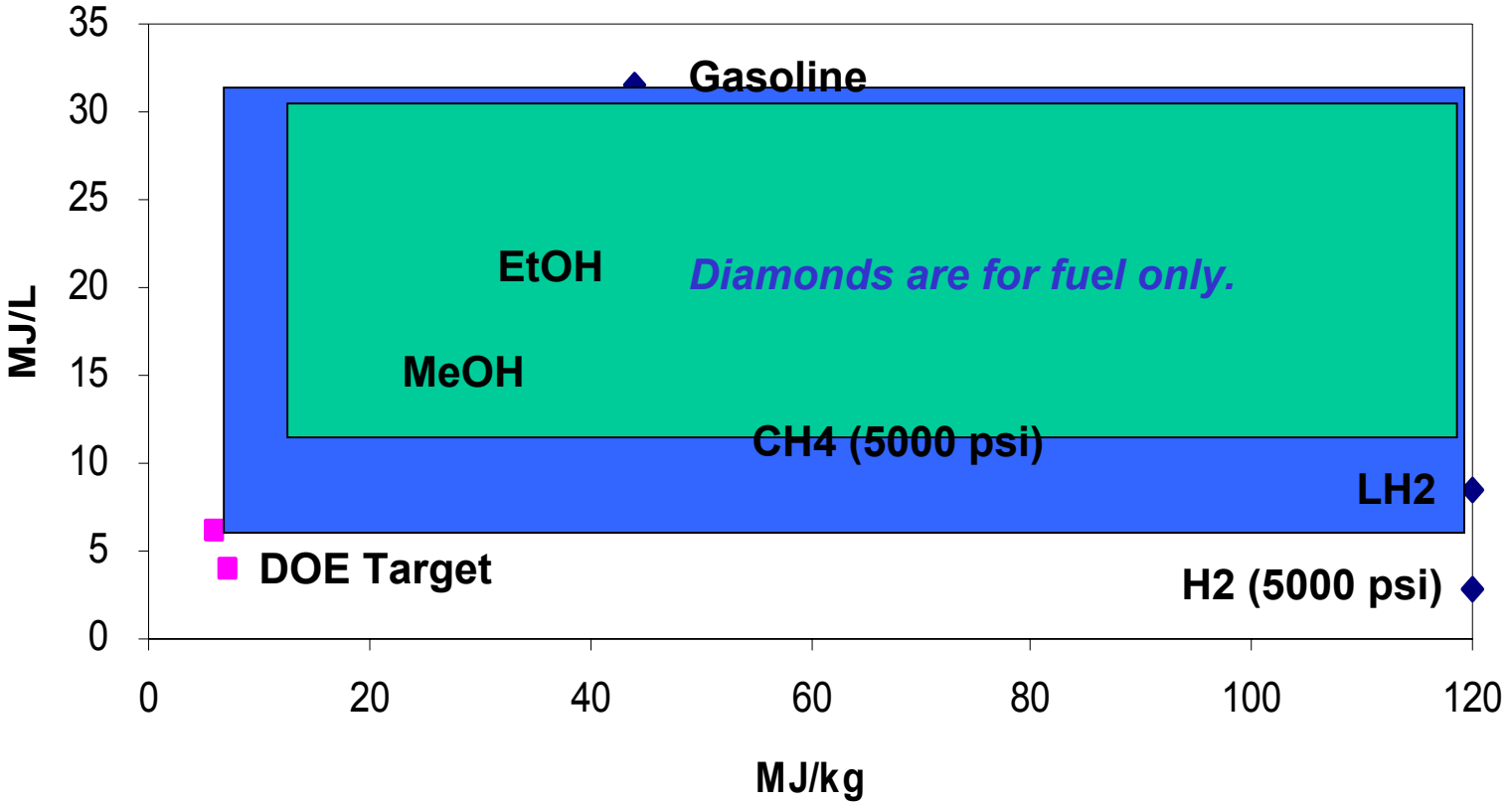
Hydrogen Storage Workshop

- Argonne National Laboratory
  - August 14-15, 2002
  - Attendees
    - 49 DOE/Laboratory
    - 32 Industry
    - 16 University
  - Plenary session
    - Automaker's perspective
    - Five overview presentations
  - Four breakout groups
    - Advanced/complex hydrides
    - Chemical storage
    - Carbon storage
    - Advanced concepts

Energy Storage Perspective



Shaded areas indicate acceptable complete system targets.

DOE target is too low.

Advanced/complex hydrides-targets

- $NaAlH_4$ capacity limited to about 5.6 wt%
  - Interim goal (5-year) of 6 wt%
- Need 8 wt% hydrogen storage capacity for hydride if BOP adds 20 %
- 80% retained capacity after 500 cycles

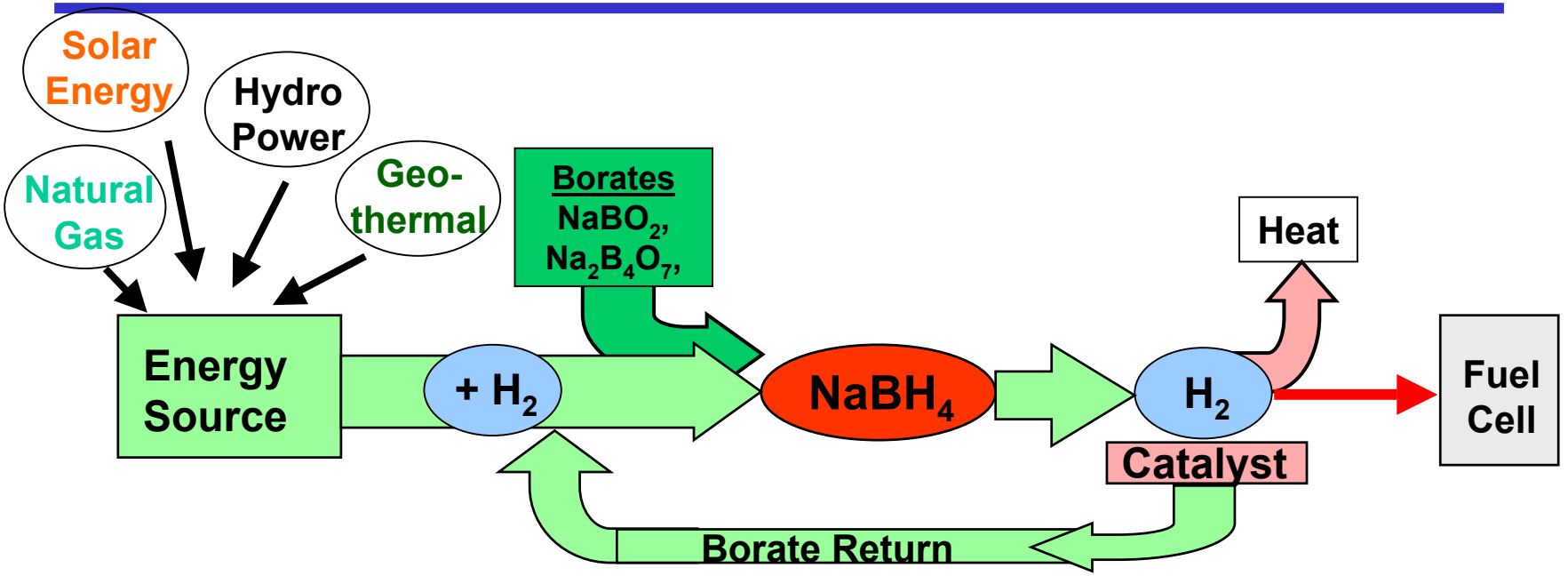
Hydride roadmap recommendations

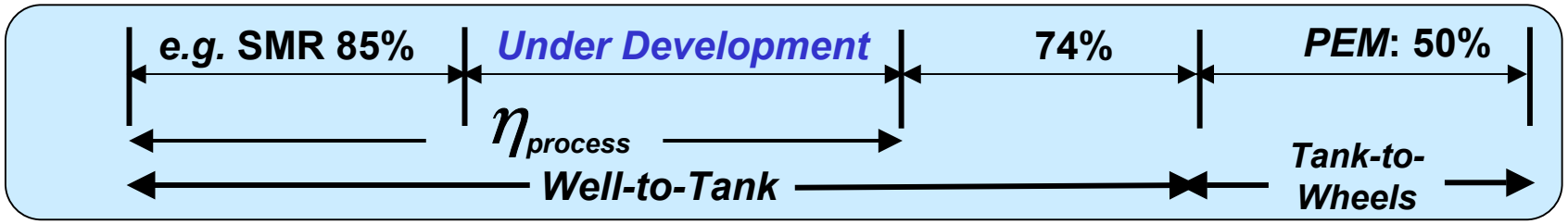
- Continue fundamental studies on $NaAlH_4$ as model system (2005)
- In parallel identify other hydride materials that have storage capacity greater than 6 wt% (2007)
- Develop new materials to achieve 8 wt% (2010)
- Engineering analyses
  - Preliminary system cost analysis
  - Large scale material production
  - Independent safety consultant/laboratory to understand safety and certification issues

Chemical storage roadmap recommendations

- **Screen chemical complexes**
  - Hydrogen storage density potential
  - Thermodynamic energy requirements including regeneration
- **Improved/new process chemistry**
  - Catalysts
  - Operating conditions (temperature, pressure)
- **Well-to-wheels-to-well analysis of top complexes**
  - Primary energy use
  - Cost of delivered fuel
  - Emissions
  - Resource depletion

Complete chemical hydride fuel cycle





Well-to-Wheels Efficiency Targeted At 15 +%

Schematic courtesy of Millenium Cell

Carbon nanotube recommendations

- **Conduct definitive experiments to show where and how hydrogen is stored in SWNT and for various forms of carbon materials**
  - **develop 2-3 pure SWNT standards for synthesis, purification, activation, and hydrogen adsorption/desorption**
  - **conduct round-robin testing**
    - **role of SWRI, other labs, universities, industry**

Carbon storage recommendations

- **Need to understand the science to engineer carbon materials for hydrogen storage**
  - **Baseline theory to elucidate parameters affecting the number and type of binding sites and heat of reaction with for a broad range of (highly) modified carbon materials**
    - **effect of modifying shape, degree of curvature**
    - **chemical/electronic effects of additives and, defects**
  - **Provide "directional" guidance for experiments (and vice-versa)**

Advanced storage approaches identified

1. Crystalline Nanoporous Materials
2. Polymer Microspheres
   Self-Assembled Nanocomposites
3. Advanced Hydrides
4. Metals – Organic
5. BN Nanotubes
   Hydrogenated Amorphous Carbon
6. Mesoporous materials
7. Bulk Amorphous Materials (BAMs)
8. Iron Hydrolysis
9. Nanosize powders
10. Metallic Hydrogen
    Hydride Alcoholysis

Overarching R&D Questions for All Advanced Materials

- Maximum storage capacity – theoretical model
- Energy balance / life cycle analysis
- Hydrogen absorption / desorption kinetics
- Preliminary cost analysis – potential for low cost, high volume
- Safety

Next Steps

- Prepare proceedings, including 5-year R&D plan
- Draft hydrogen storage solicitation
- Discuss advanced storage concepts further to refine recommendations and resolve controversial aspects