Hydrogen Storage for Automotive Vehicles: Challenge and Opportunity

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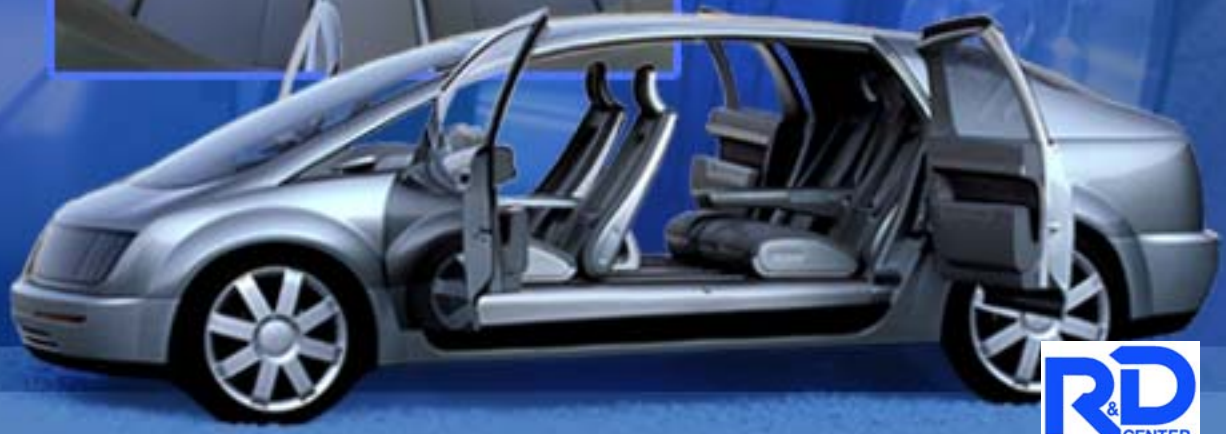
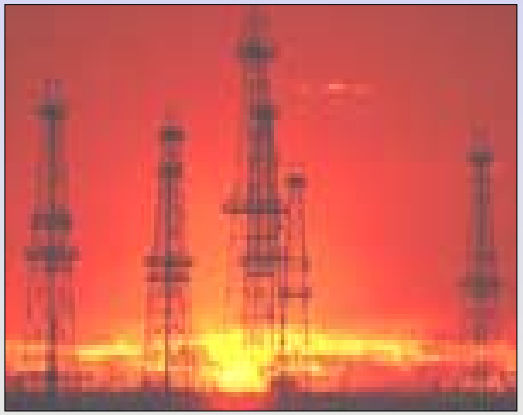
General Motors' Vision is to Become THE Leader in High-volume, Affordable, and Profitable Fuel Cell Vehicles

"Gotta Have" Fuel Cell Vehicles



Hydrogen Addresses the Societal Drivers

Petroleum Dependence



Balance of Payments

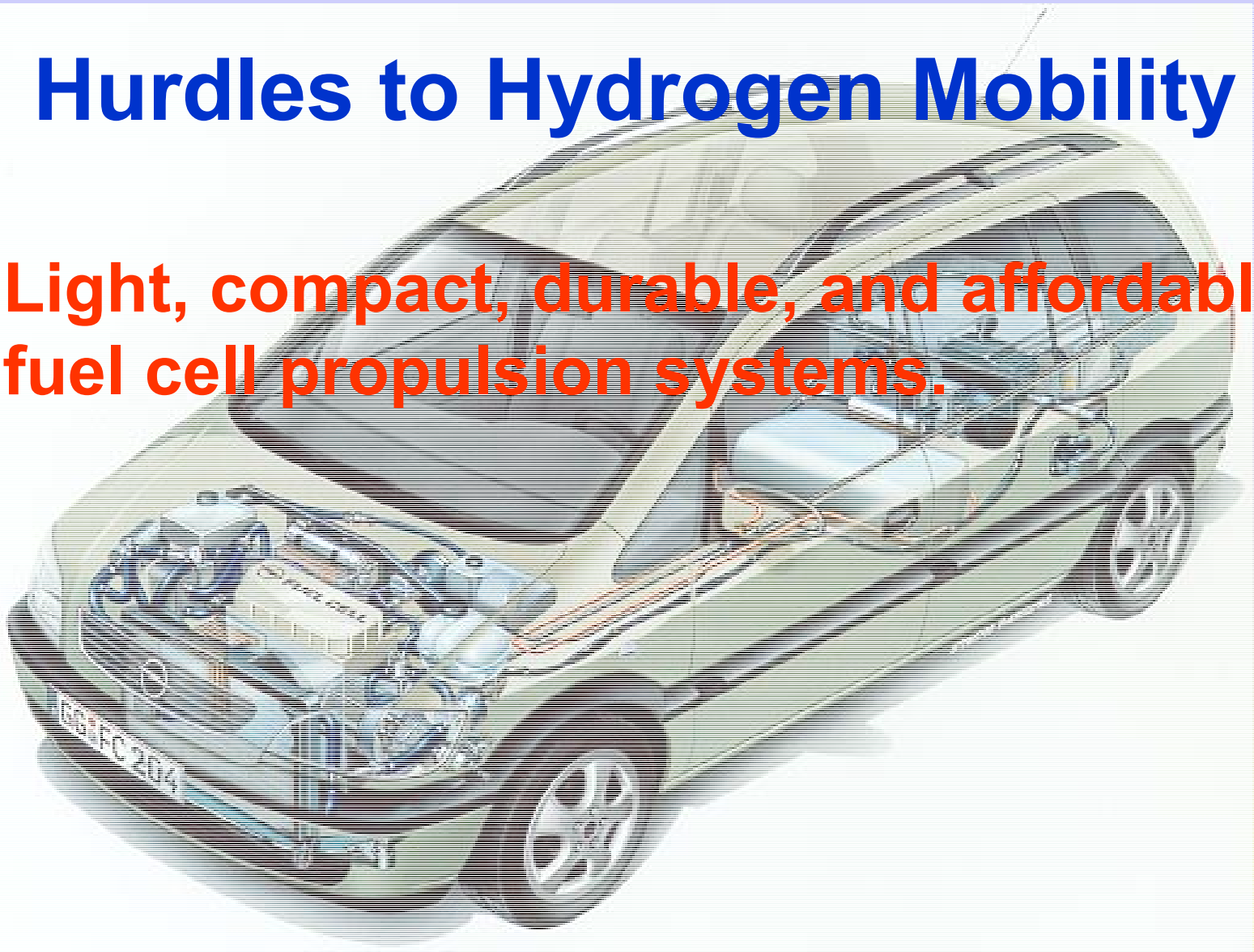
Hydrogen

Local Air Quality

Global Climate Change

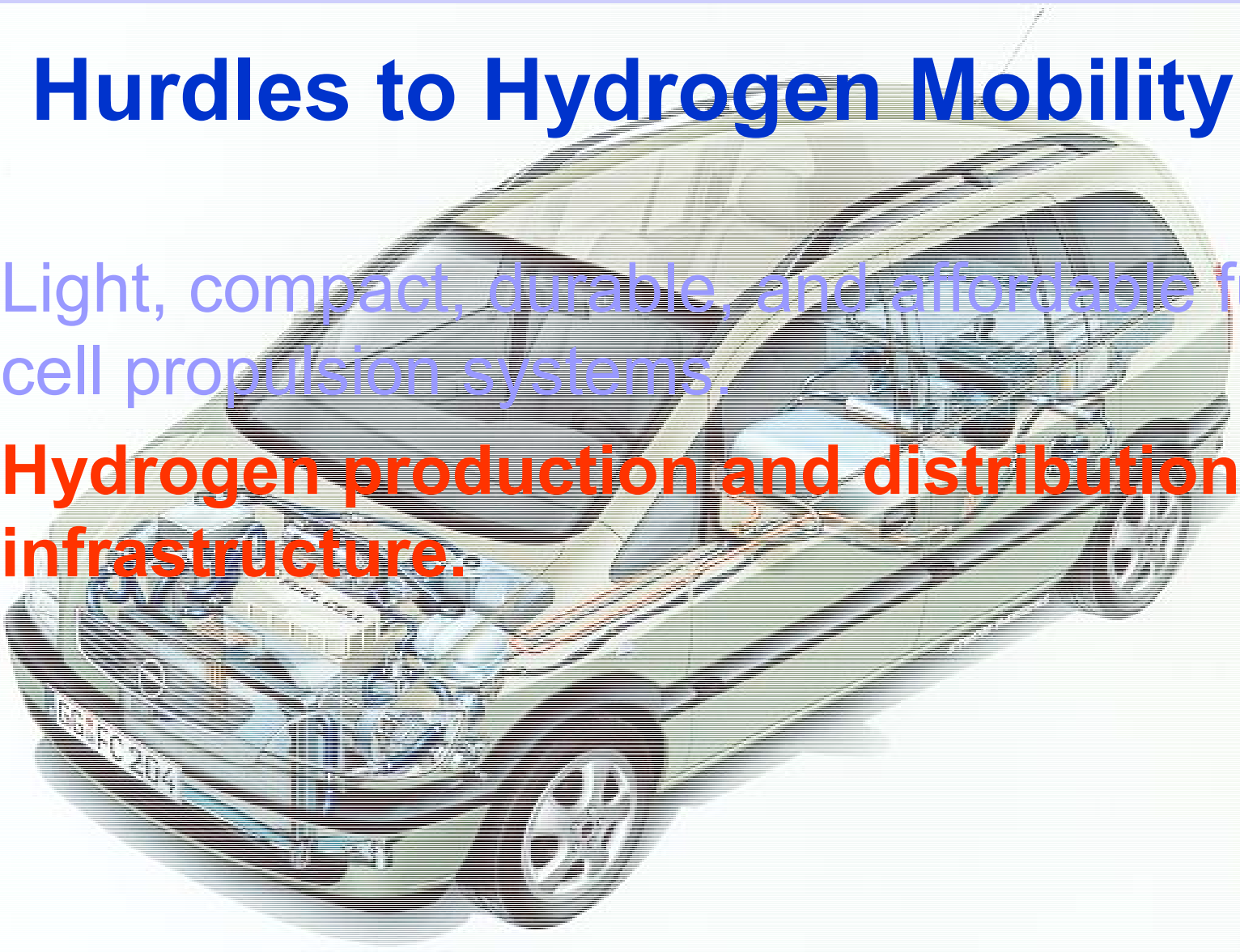
Hurdles to Hydrogen Mobility

- **Light, compact, durable, and affordable fuel cell propulsion systems.**



Hurdles to Hydrogen Mobility

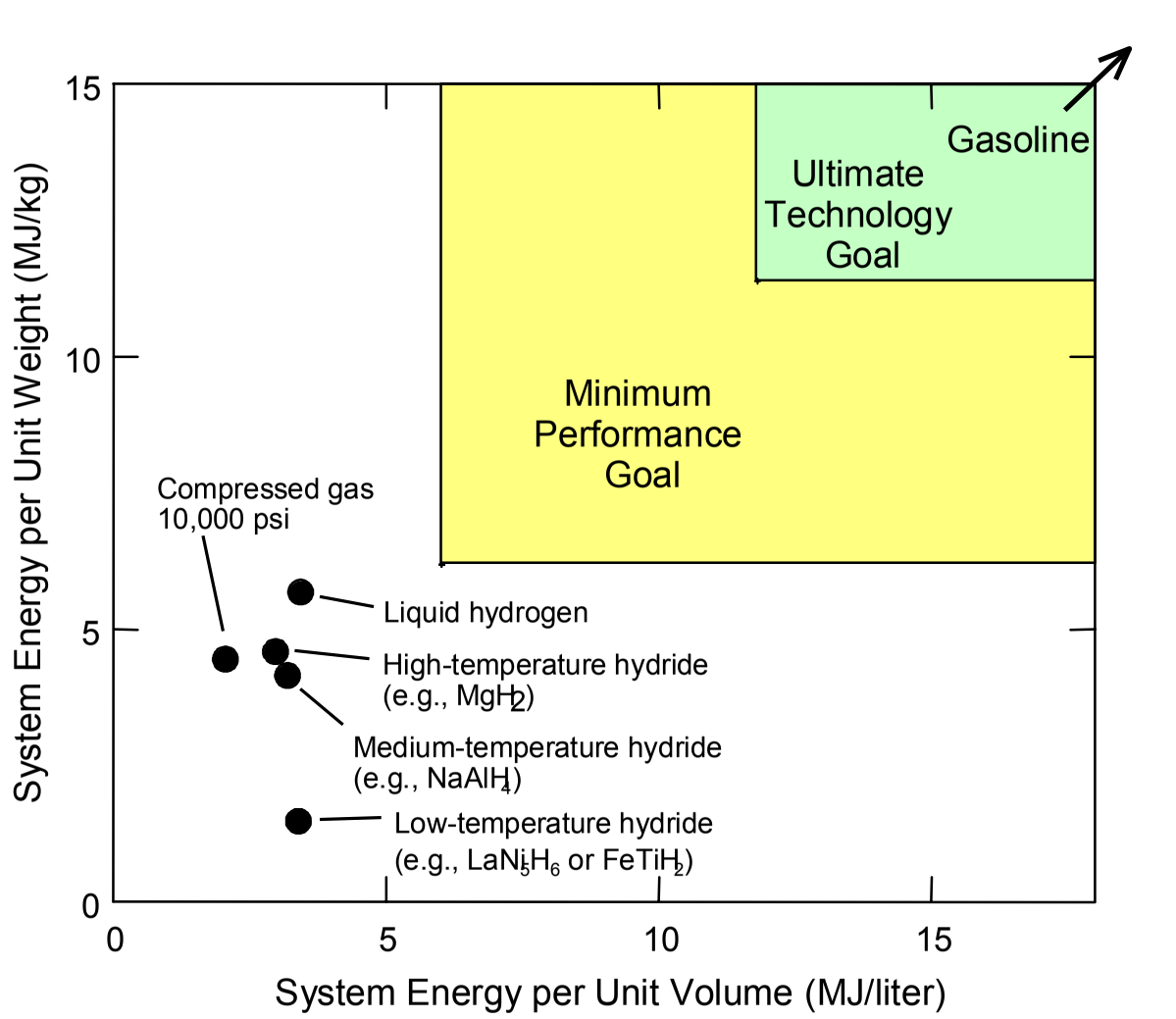
- Light, compact, durable, and affordable fuel cell propulsion systems.
- **Hydrogen production and distribution infrastructure.**



Hurdles to Hydrogen Mobility

- Light, compact, durable, and affordable fuel cell propulsion systems.
- Hydrogen production and distribution infrastructure.
- **Light, compact, durable, affordable, and responsive hydrogen storage system on-board the vehicle.**

Gravimetric Energy Density vs. Volumetric Energy Density of Fuel Cell Hydrogen Storage Systems

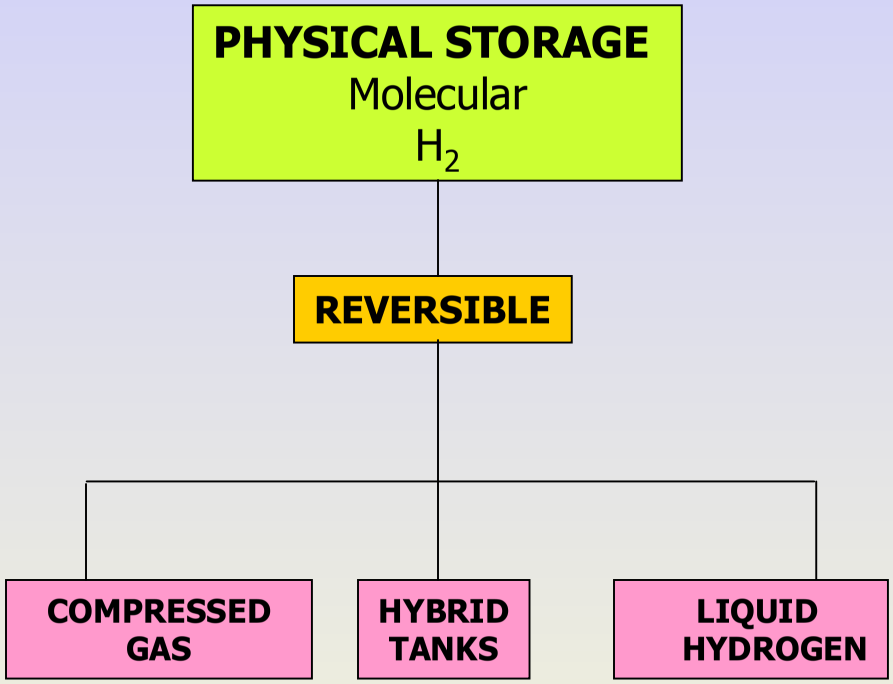


HYDROGEN STORAGE PARAMETER GOALS

METRIC	GOAL
• System energy per unit weight for conventional vehicles with 300-mile range	> 6 MJ/kg
• System energy per unit volume for conventional vehicles with 300-mile range	> 6 MJ/liter
• Usable energy consumed in releasing H_2	<5 %
• H_2 Release Temperature	~80 ºC
• Refueling Time	<5 minutes
• H_2 Ambient Release Temp Range	-40/+45 ºC
• Durability (to maintain 80% capacity)	150,000 miles

Options for Storing Hydrogen Today

HYDROGEN STORAGE OPTIONS



Compressed Storage Status

- Prototype vehicle applications developed
- Efficient high-volume manufacturing processes needed
- Less expensive materials needed
  - Fiber
  - Binder
- Evaluation of engineering factors related to safety required
  - Use of stress sensors
  - Understanding of failure process

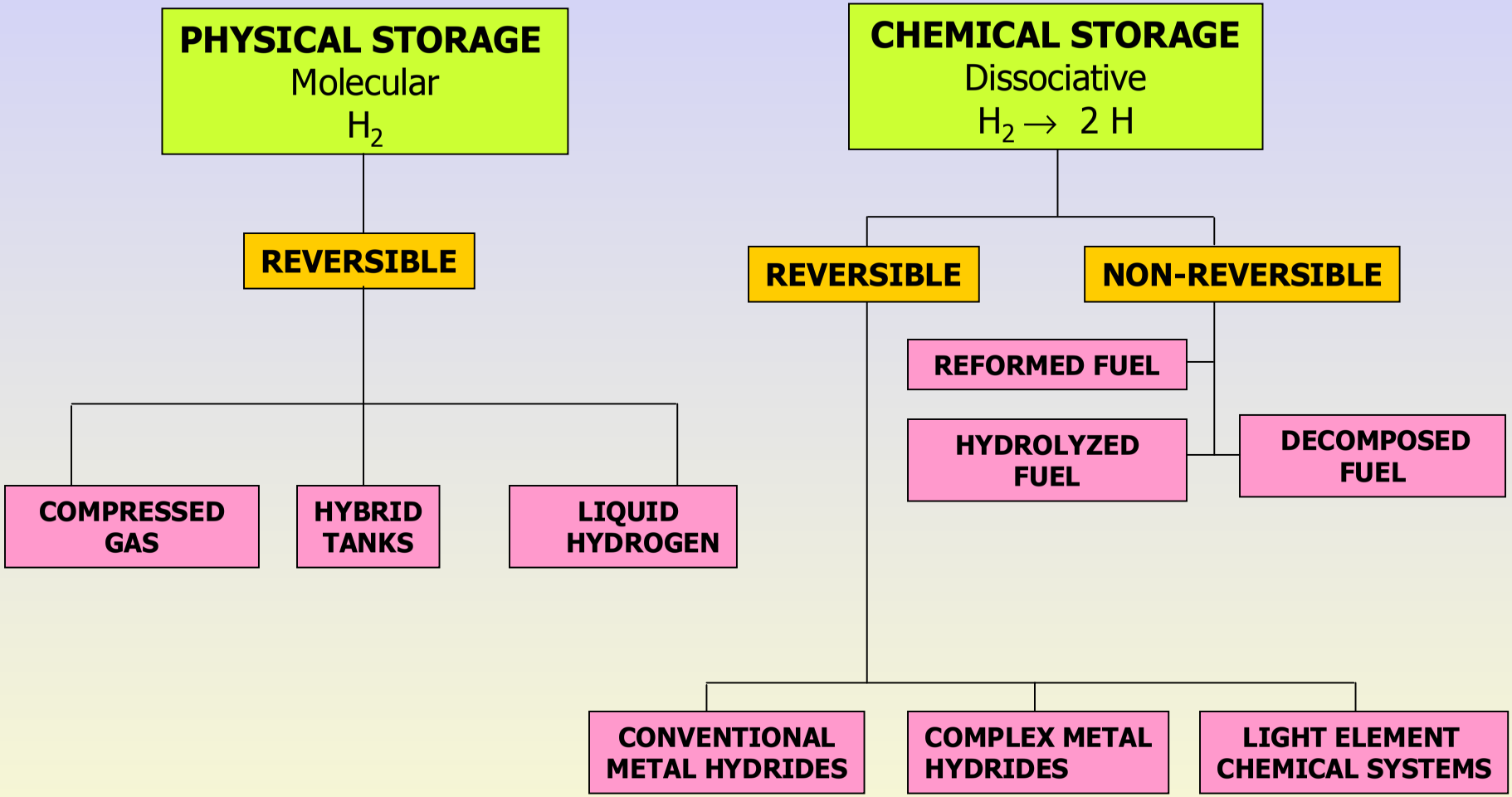
Liquid Storage Status

- Prototype vehicle applications developed
- Reduced mass and especially volume needed
- Reduced cost and development of high-volume production processes needed
- Extend dormancy (time to start of “boil off” loss) without increasing cost, mass, volume.
- Improve energy efficiency of liquefaction.

Hybrid Physical Storage Status

- Elevated pressure tanks integrated into cryogenic storage systems
- Compressed gas storage density increases at lower temperatures
- Possibly further density increase through use of adsorbents
- The best of both physical concepts, or the worst??
- Concepts under development

HYDROGEN STORAGE OPTIONS



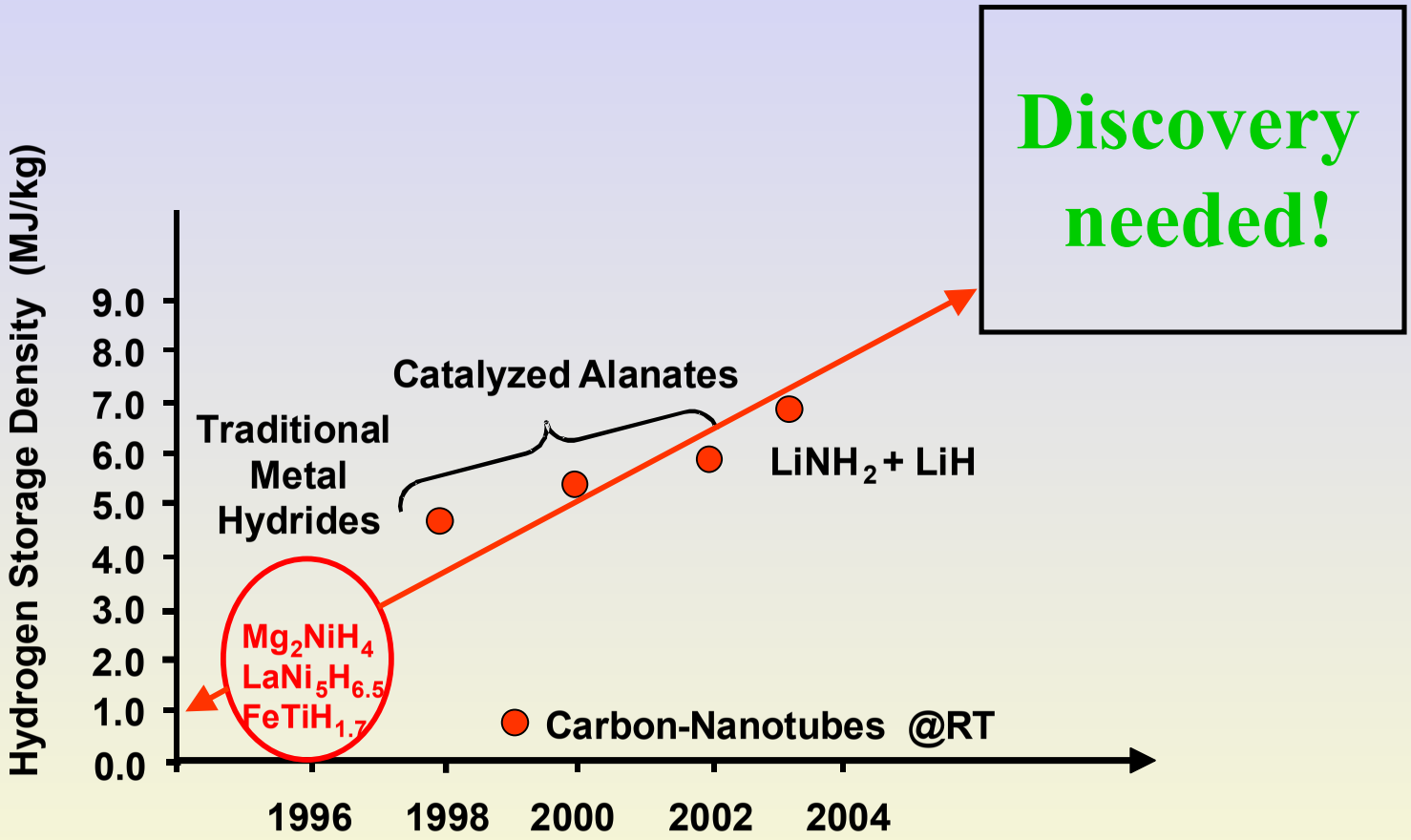
Non-reversible On-board Storage Status

- On-board reforming of fuels has been rejected as a source of hydrogen because of packaging and cost.
- Energy station reforming to provide compressed hydrogen is still a viable option
- Non-reversible reactions that minimize exothermic heat release on-board are needed
- Hydrolysis hydrides suffer from high heat rejection on-board and large energy requirements for recycle
- On-board decomposition of specialty fuels is a real option
  - Need desirable recycle process
  - Engineering development needed on refueling process

Reversible On-board Storage Status

- Reversible, solid state, on-board storage is the ultimate goal for automotive applications
- Accurate, fast computational techniques needed to scan new formulations and new classes of hydrides
- Thermodynamics of hydride systems can be “tuned” to improve system performance
  - Storage capacity
  - Temperature of hydrogen release
  - Speed of hydrogen refueling
- Catalysts and additives may also improve storage characteristics

Reversible On-Board Storage Capacity



SUMMARY

- Liquid and Compressed (Physical) Hydrogen Storage System
  - Technically feasible; in use on early vehicle prototypes
  - Focus is on meeting packaging, mass, and cost targets
  - Both concepts fall below energy density goals
  - Unique vehicle architecture and design could enable efficient packaging and extended range
  - Volume manufacturing capability being developed
- Solid-State Hydrogen Storage Systems
  - Fundamental discovery and intense development necessary
  - “Idea-rich” research environment
  - Both reversible and non-reversible on-board storage under investigation