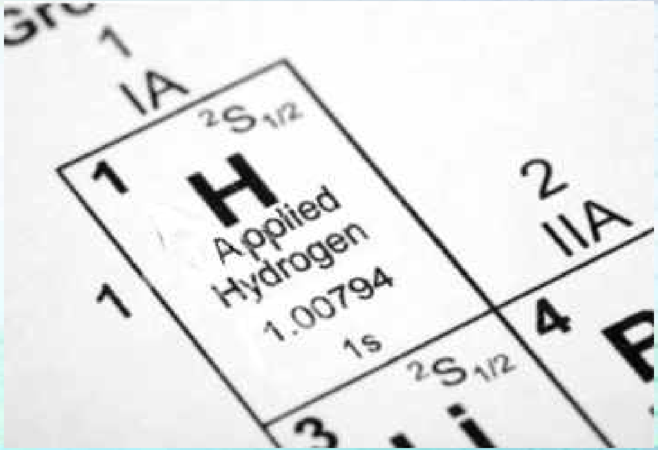
APPLIED HYDROGEN

Hydrogen Storage
Air Conditioning
Energy Storage



Conductive Hydrogen Packaging

Scope of the Project

Safe & Environment friendly hydrogen applications

- **Hydrogen Fuel Storage for Utilities, for Vehicles and for Merchant Delivery**
- **Freon free Air Conditioners and Coolers optionally using Waste heat**
- **Energy Storage, UPS, including renewable**

Fast Kinetics - High Efficiency

Business Opportunity

The scene is ripe for an advanced H_2 storage device that can fill the GAP in:

- Onboard Storage for Vehicles
- Merchant Hydrogen Delivery
- Renewable energy Storage (wind, solar, off peak).
- Emergency Power supply (UPS)
- Freon free cooling.
- Saves Energy
- decreases **carbon footprint** of vehicles

These are huge markets are now looking for

– our solution –

SAFE Hydrogen Storage

?Who Needs Hydrogen

- Hydrogen is clean.
- Hydrogen is renewable
- Hydrogen has high energy density
- Hydrogen has many applications
- Hydrogen is already a huge Industry
- Hydrogen storage is still the challenge.

No Hydrogen Economy without Hydrogen Storage

Main Product Lines

- Hydrogen Storage
- Hydrogen Cooling

H2 Storage Market

1 **Industrial and merchant H2 storage** – 2% efficiency – within 18 months, to replace H2 bottles, trucks, etc. market worth over 10$Bln, [400$*(20,000,000*0.1*10days)/0.71]

2 **Off-peak** power storage: wind, solar, electric power, etc. (up to 20% of all electric power)

3 Emergency Power Supplies – **UPS, over 50,000,000 already in place, from single PC to IT centers to Hospitals, etc.**

4 **Vehicular Onboard Storage** – 4.5% efficiency @500$/kgH2 – within 36 months. Market size huge, even if not immediate

Merchant Hydrogen

- Merchant H2 market is already huge: 5000 T/d merchant H2 in the US alone, 20,000 worldwide (abt 20% of all H2 produced)
- Main uses: Refineries – 45%, Ammonia production 28%, (mostly captive)
- other: metals, electronics, food, military (space), etc.
- Growing uses: Clean Energy - Vehicles, Wind, Solar, Intermittent Power storage.

Merchant Hydrogen Competition

- Today, 92% of hydrogen is compressed gas, 8% liquid.
- Industrial use gas transported in 150-360 atm bottles: ~0.56 kg in 101 kg steel bottles costing 400$ ea. and special trucks.
- Least expensive transport: pipelines (high pressure, very expensive, with hydrogen embrittlement issues).
- Onboard Vehicular: Carbon and Al Composite, fragile, expensive at 2000$/kg H2
- Powder hydrides – slow desorption, short lifecycle, not accepted in industrial environment.
- Most important issue: SAFETY
- H2 cost <2$US/kg (@pipeline)

Market Size

Availability	Size [$Bln]	Segment	Product
5-10 yrs Bln, very recognizable	>$2	Vehicles	Onboard Storage
Now, Bln, very Conservative	>$1	Merchant H_2	Transportable St.
Now,	>$2	UPS	Transportable St.
3-5 yrs, Price sensitive	>$10	Energy	Static

Time to market

Major Sales	Initial sales	Added value	Product
5 years	2 years	20-40%	Onboard Storage
3 yrs	18 m	20- 40%	Transportable St.
3 yrs	18 m	20-40%	Transportable St.
4 yrs	2 yrs	10-30%	Static

Cooling Applications

COOL HYDROGEN

Freon free

Air Conditioning **(optionally using solar heat)**

Chip level cooling

Computers, IT Centers

Food (industrial, entertainment (beer) home)

Target Markets: Summary

1 **Vehicular Air Conditioning**
700 million vehicles running worldwide, about 70,000,000 produced annually, 20% with AC

2 **Green Home and Office Air Conditioning**
Green, no Freon pollution, optionally based on solar energy, cogeneration or waste heat from other processes

3 **Cooling for Home and Industry,** optionally based on solar energy, cogeneration or waste heat from other processes

Competition

- Existent Freon AC – Freon is on its way out
- Compressor based and other MHAC, tested by GM and FIAT – working, but **sluggish** and **expensive**, see model
- Ammonia Cooling – Polluting, Smelly, Toxic
- Other cooling methods such as magnetic cooling still in basic R&D, low COP, **cannot use waste heat.**

Market

Time to Market	Size [$Bln]	Market	Product
3-5 years	>10	vehicles	Vehicular Air Conditioning
2-4	>>	Beer, Computers, components	Special cooling
2-4	>>>>	Home and Industrial	Green Cooling

Business Model Development

1. Demonstrate commercial feasibility.
2. Develop marketable product
3. Demonstrate Industrial strength capability
4. Form Strategic Alliances with Manufacturers
5. Develop pilot line production
6. License Large Scale Production
7. Keep critical material production and continued development capability

Where are we

- **Basic R&D Completed: small material quantity produced and tested, IP Protected**
- **Strategic Alliance with TATA Motors Approved**
- Additional Alliances Underway: MRI (NREL), Dantherm, h2logic, UTRC, etc.
- Support from EU, underway (BIRD F possible)

Time to Market

Timeline	Mile Stone
6-9 months	Commercial prototype
18 months	Commercially acceptable product
24 months	Pilot Production and Start of sales
36 months	Start of large series industrial production

Investment Needed

Disruptive Technology

- The Products
- How do they work
- Advantages

Onboard Storage Paradigm Shift

Present Concept

Integrated UHP 5000 psi tank

Major SAFETY concerns

Volumetric inefficiency.

Exorbitant Infrastructure

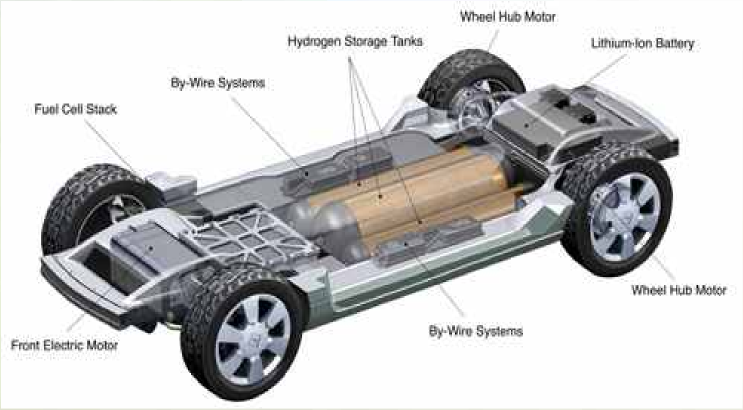
No upscaleability

AH New Paradigm

SAFE Solid Hydride – Solid, low pressure, low volume.

RAPID refueling using recyclable cassettes,

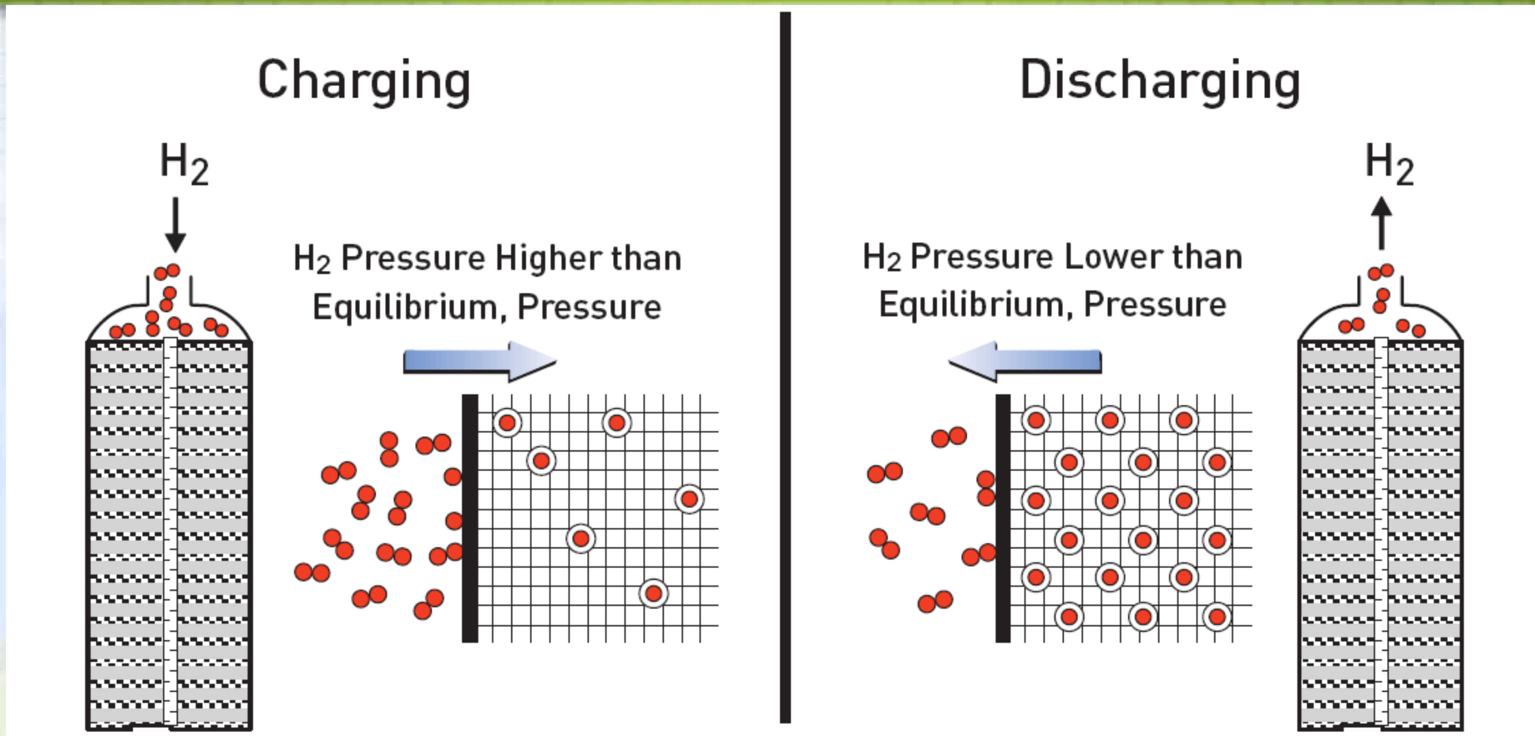
LOW Distribution Cost



Hydrogen Storage Alternatives

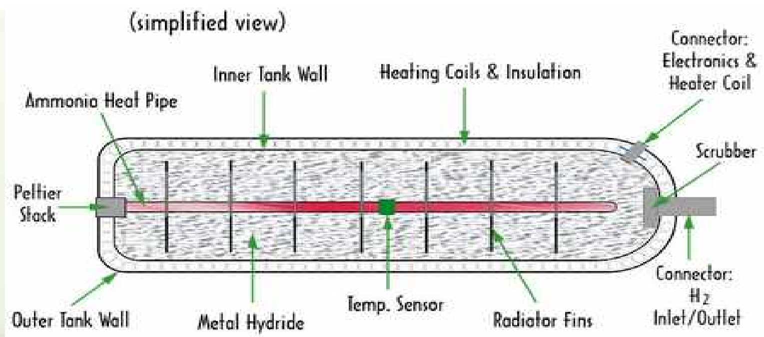
• Unsafe - Explosive tendency • Requires huge tanks or super high pressure	**Compressed Hydrogen** Gas
• Not energy efficient • Unstable – Explosive tendency	**Liquefied Hydrogen**
✓ **Safer** (even relative to gasoline) ✓ **Volume Efficient** - At less than 200 psi, Solid Hydride storage 3-5 times lower volume than compressed gas at 10,000 psi	**"Solid Hydrogen"** as **HYDRIDE**

HEAT TRANSFER IS CRITICALLY INVOLVED



EXOTHERMIC REACTION

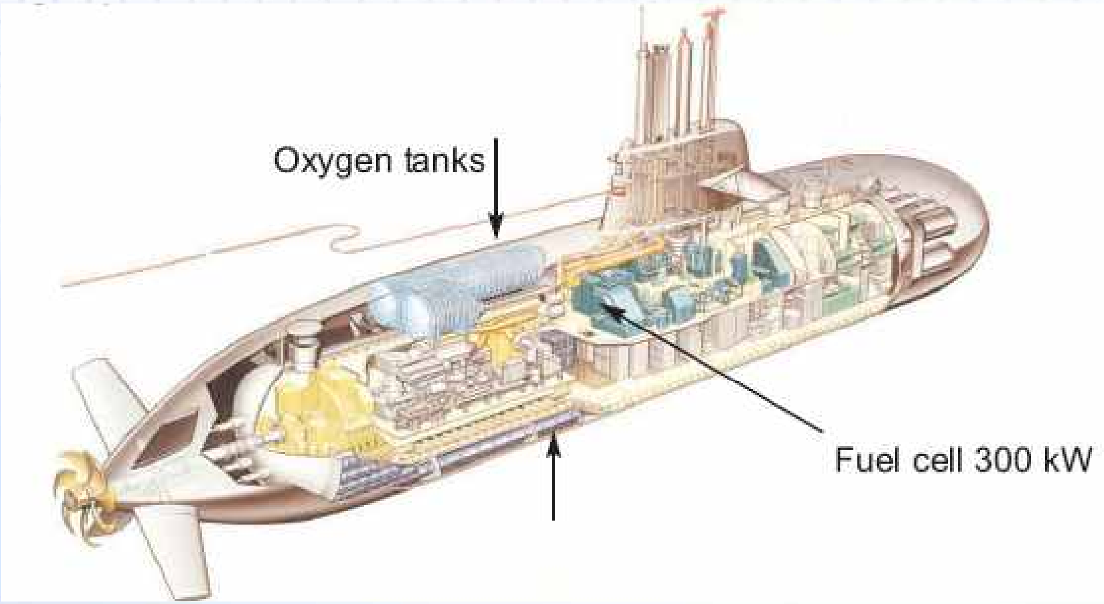
HEAT IS GENERATED AND NEEDS TO BE REMOVED TO ALLOW CONTINUED REACTION



ENDOTHERMIC REACTION

HEAT IS ABSORBED AND NEEDS TO BE SUPPLIED TO ALLOW CONTINUED REACTION

Hydride based Hydrogen Containment !IS commercially available



Ovonics, HBank, GfE, JMC, YM, APFCT, GKSS

SLOW release rate and SLOW refill due to low conductivity of powder bed (see table) preclude usable industrial acceptance	Problem

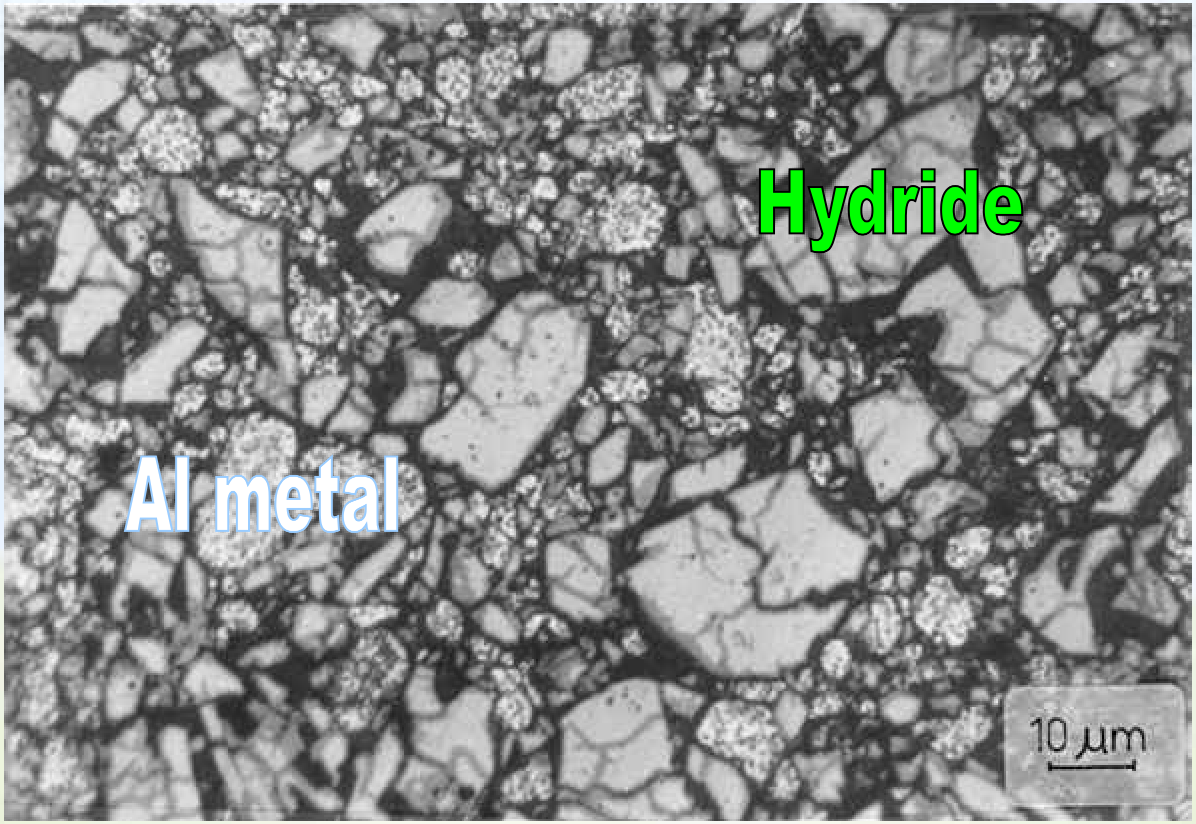
Opportunity: The Conductive Storage Solution

Applied Hydrogen HYDRIPAK provides HIGH HEAT .CONDUCTIVITY due to Metallic structural support

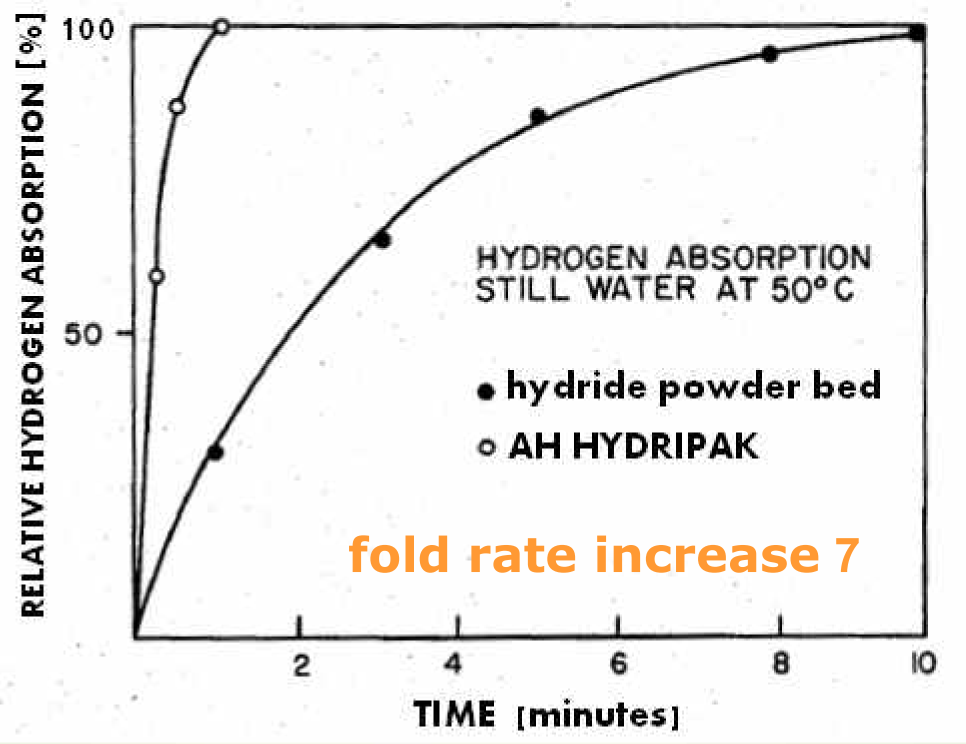
AH Porous metal support provides 10 times more conductivity than standard hydride containers.

	K_{pb} (Heat Conductivity) [W/m.K]	Matrix type
Limits all Heat transfer processes	~0.1	Present - Hydride powder bed
	~10	Solid metal – Aluminum, Copper
Depending on conductive fraction content	1-10	**APPLIED HYDROGEN microPorous Metallic Sinter**

Compact microstructure developed



Results show 3-10 times faster H_2 absorption



Hydride Air Conditioner

for Vehicles,

using Exhaust Waste Heat

Freon Free

Paradigm Shift

AH New Paradigm	Present Concept
Hydride Air Conditioner NO Freon – NO pollution SAVE Fuel - Using Waste Exhaust Heat	Over 100 million Vehicle Air Conditioners using Polluting Freon, spending up to 20% shaft power

Hydride Air Conditioner

- Hydrides are Hydrogen Containing Compounds, many based on metals (MH – Metal Hydride)

- When Hydrogen is absorbed, energy is liberated (exothermic), pressure is lowered

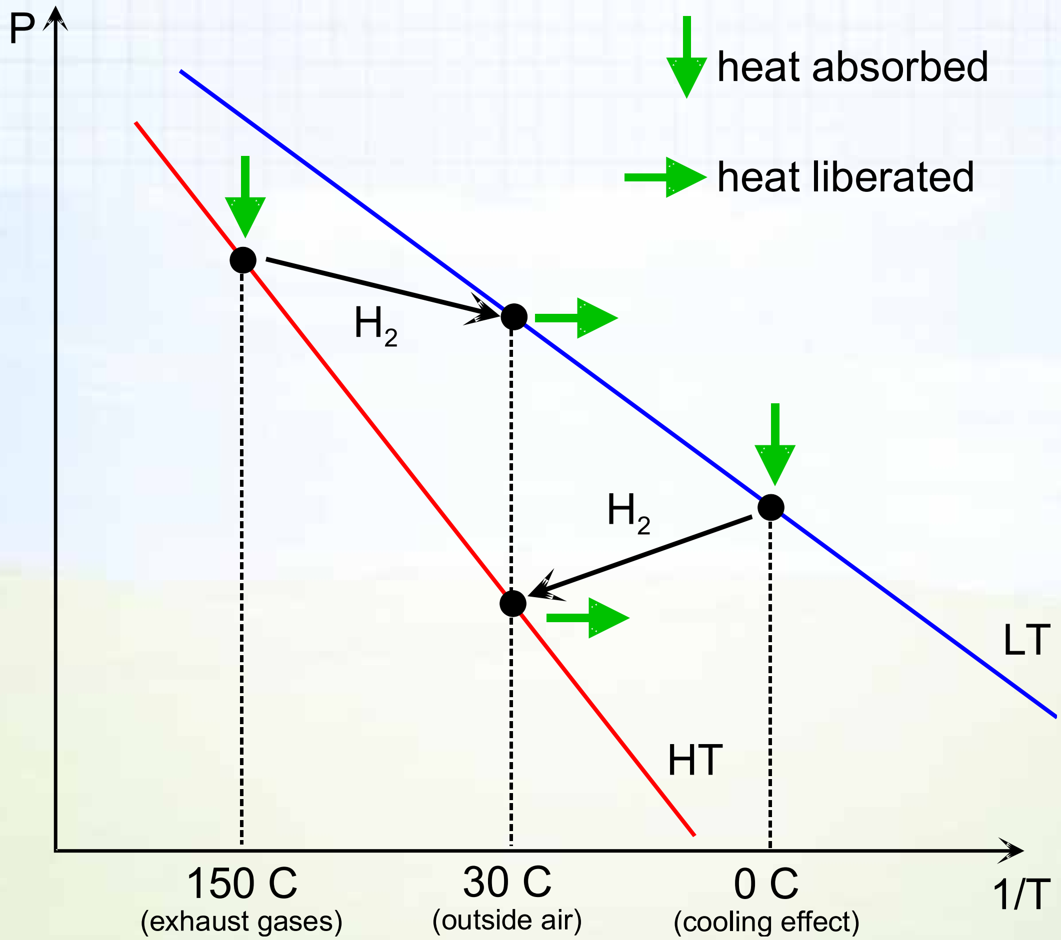
HYDRIDE HEATS UP - $Me + H_2 \rightarrow MeH_n + Q$

- When Hydrogen is released, energy is absorbed (endothermic) pressure grows

HYDRIDE COOLS $\rightarrow Me + H_2 - Q \leftarrow MeH_n$

- **We can use cycle to make a HEAT PUMP**

Physics of Operation



Schematic of Operation

METAL HYDRIDE AIR-CONDITIONER

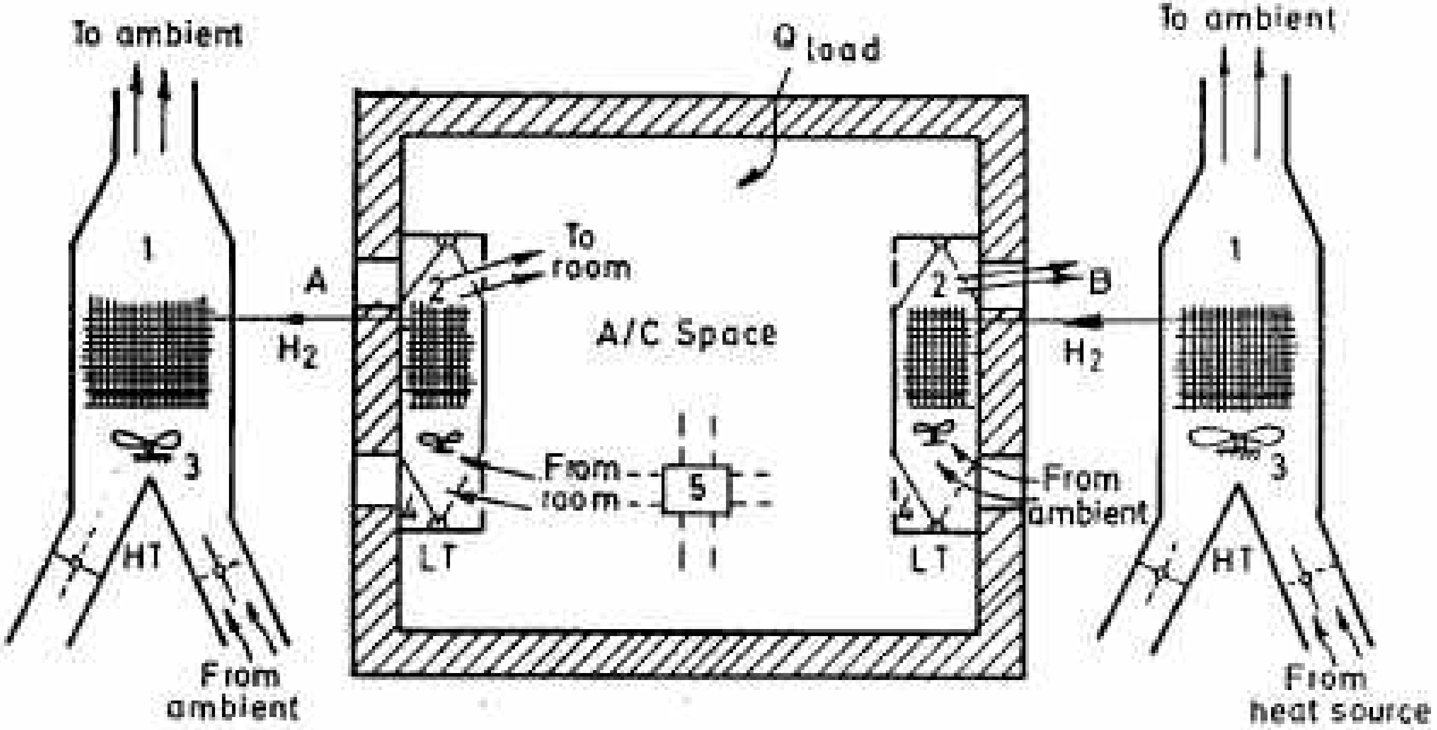
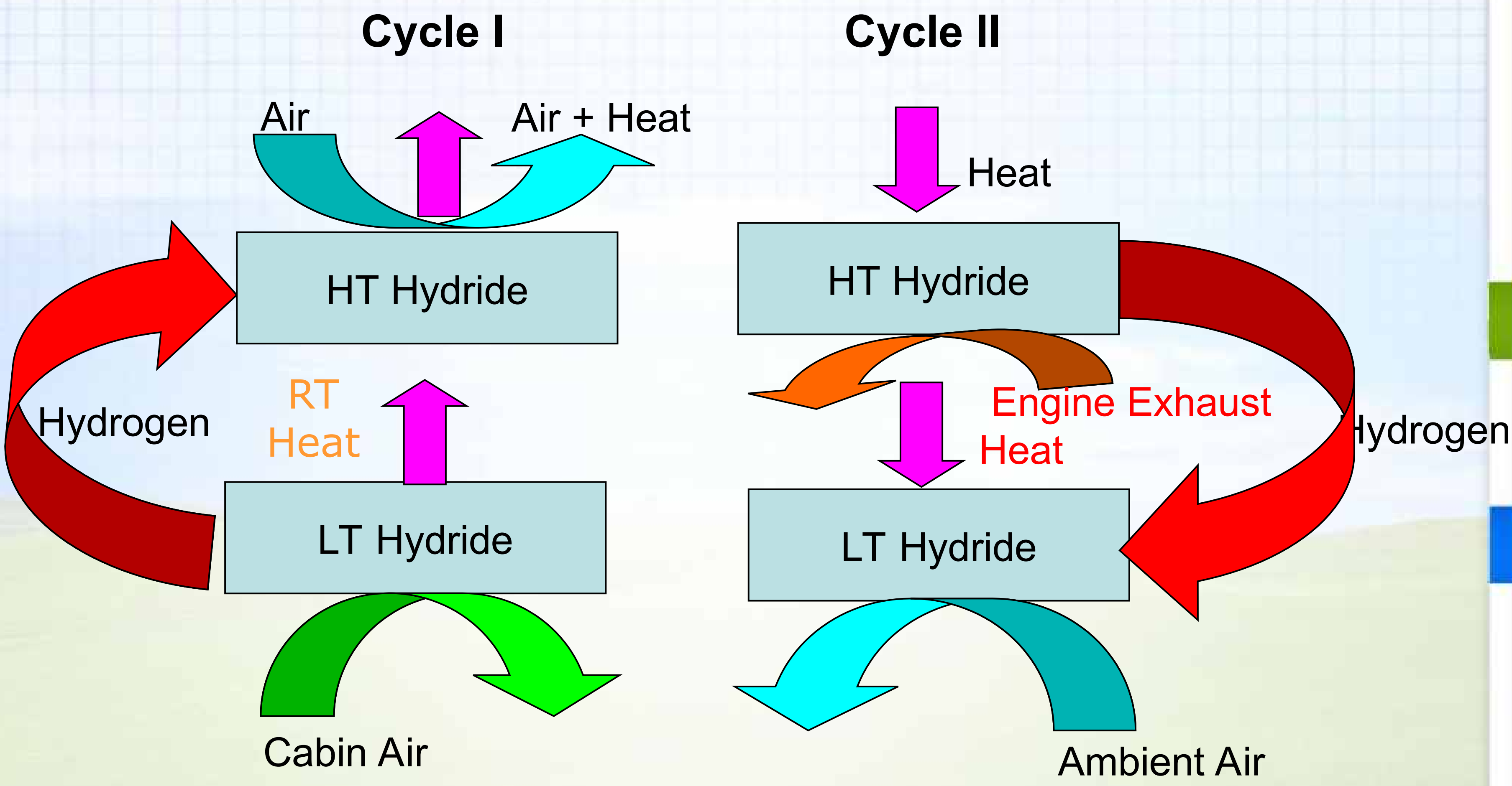


Figure 1. Schematic of the metal hydride air-conditioner

Functional Representation



Model Analysis of Operation

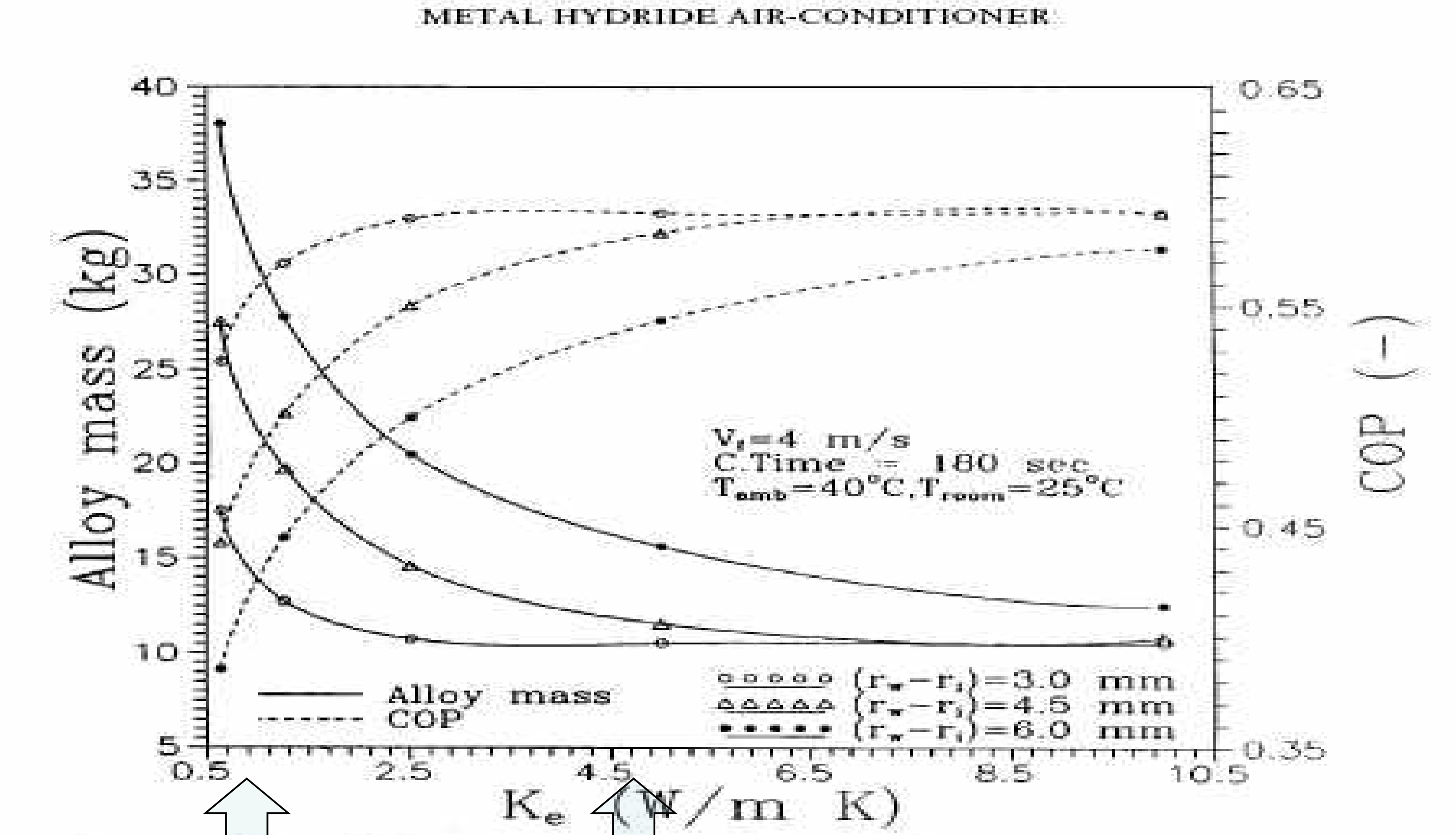


Figure 7. Effects of effective thermal conductivity and bed thickness on alloy mass and COP

Hydride Powder bed

Hydripak

Status of Project

- Basic research completed, lab quantity of material produced and tested
- Procedure for production developed
- MHAC model of operation fully developed and partially tested
- Team ready
- IP protected
- Contact with Vehicle manufacturers ongoing

AH Response to CHALLENGE

SAFER, FASTER, MORE EFFICIENT, ADAPTABLE HYDRIDE PACKAGING

- **Faster**: **Hydripak** releases Hydrogen 10 times faster than hydride powder bed due to much better heat conductivity.
- **Dimensional Stability** provides long cycling life
- **Safer** (incomparable to gas, better than standard hydrides)
- **Lighter,** due to more efficient structure (solid vs pressure vessel construction)
- **Low maintenance** cost: powder clogging is prevented
- **Shape efficient** (non-cylindrical form possible)
- **Adaptable** – future hydrides will be accommodated, with lower cost and higher efficiency.

IP

- Patent pending
- AH builds on existent basic demonstrated solution – M.Ron patents (exhausted)
- AH adds critical dimensions to the present knowledge by pending patents that cover:
  - Improved substrate materials
  - Improved active material such as nanomaterials
  - Optimized production procedure
  - Optimized tank structure
  - Distribution CONOPS

Our Team

Founder – Ido Shefler, ME, M.Sc.E, Colonel (res.)

- Expert in Vehicle Engineering - military and civil
- Expert in Management of Technological projects In Israel and abroad.

Founder – Dr. Fredy Ornath, D.Sc. Materials Engineering

- Director & Founder of Material Systems Ltd.
- Founder of Traceguard Technologies Inc. (publicly traded in NY as TCGD.OB).

Our Team

Professor David E. Cole, Chairman, Center for Automotive Research in Ann Arbor, Michigan. He was formerly Director of the Office for the Study of Automotive Transportation (OSAT) at the University of Michigan Transportation Research Institute (UMTRI).

Prof. Eugene Rabkin - Materials Engineering, **Technion.** Current research, improvement of hydrogen storage properties.

Continues R&D work based on Late **Prof. M. Ron's original pmh concept.**

Summary

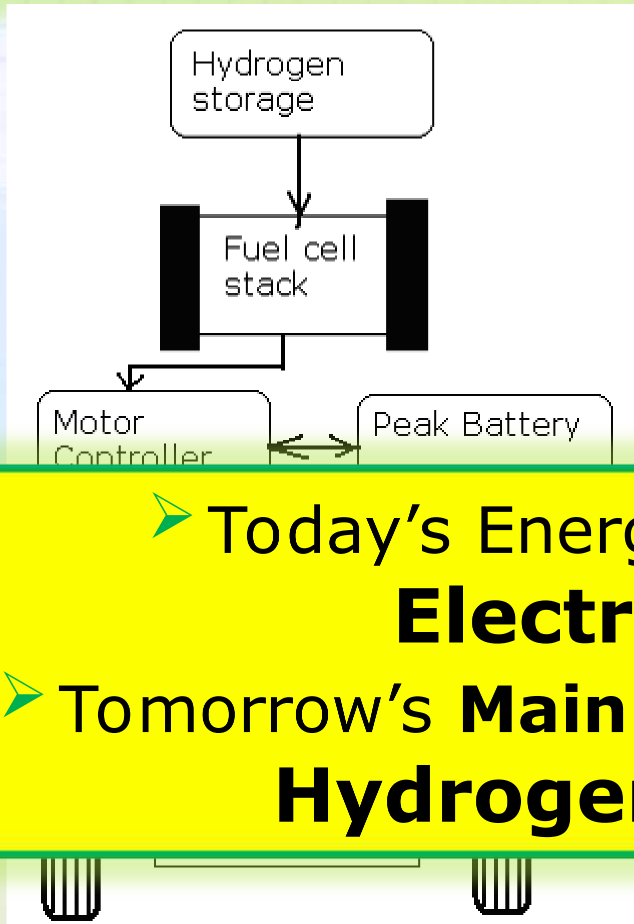
- Hydrogen is the **fuel of choice** and has large industrial market, but **Storage** is still the **challenge**
- Only Solid Hydride storage provides a workable solution, but has practical limitations
- Only **HYDRIPAK enables hydride deployment**
- **Applied Hydrogen** has The **Team** to transform **HYDRIPAK** into **Successful Business**
- **COOLING is a great alternative application**

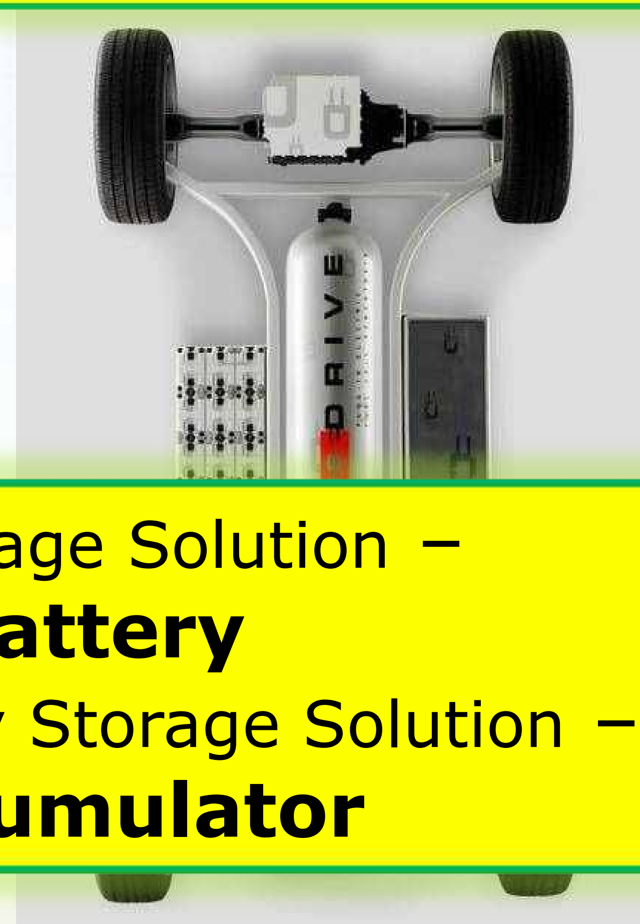
Back up slides to clarify FAQ

- GM and other Zero Emission Vehicles
- National Hydrogen Storage Project Milestones
- Hydrogen Vs. Gasoline
- Hydrogen vs Electrical
- Project Cost Model

The Future Car

ZEV = Zero Emission Vehicle





- Today’s Energy Storage Solution – **Electrical Battery**
- Tomorrow’s **Main** Energy Storage Solution – **Hydrogen Accumulator**

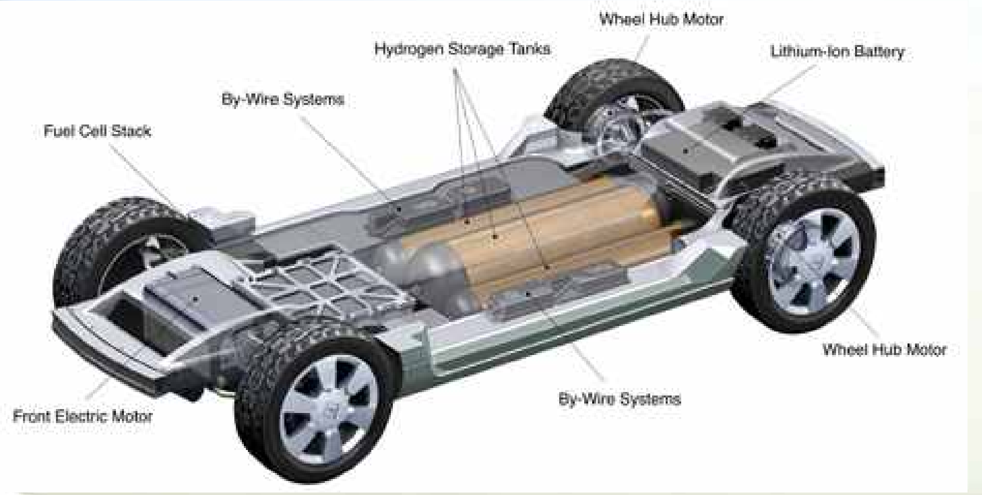
The Ford Hydrogen Car Wheelbase

The GM Hydrogen Car

GM pledged to develop a hydrogen-fuel-cell vehicle that could compete on cost with traditional vehicles-if it were to be built in high volumes-by 2010.

Equinox

Sequel



GM to support Hydrogen cars

;On-board hydrogen storage in solid

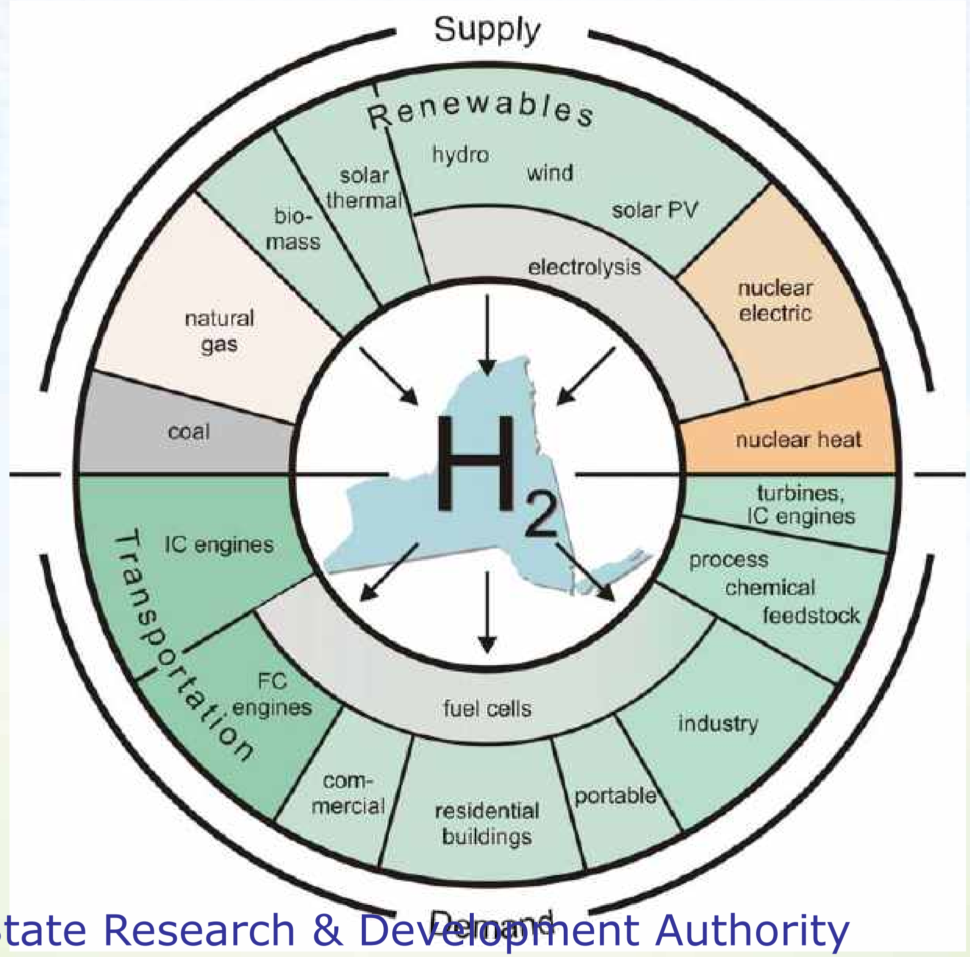
Home hydrogen refueling device (see also Honda)

Develop collaboration with Shell

Hydrogen is America's National Priority

- **President's Hydrogen Fuel Initiative:** 4.9 Billion Dollars Budget over 5 years.
- **Barack Obama's** New Program includes support for Car Manufacturers will push for modernization and lower fuel costs.
- US Department of energy has established a "**National Hydrogen Storage Project**" to fund research and development.
- **New York** and **California** lead.

The NY H_2 Energy Economy Vision



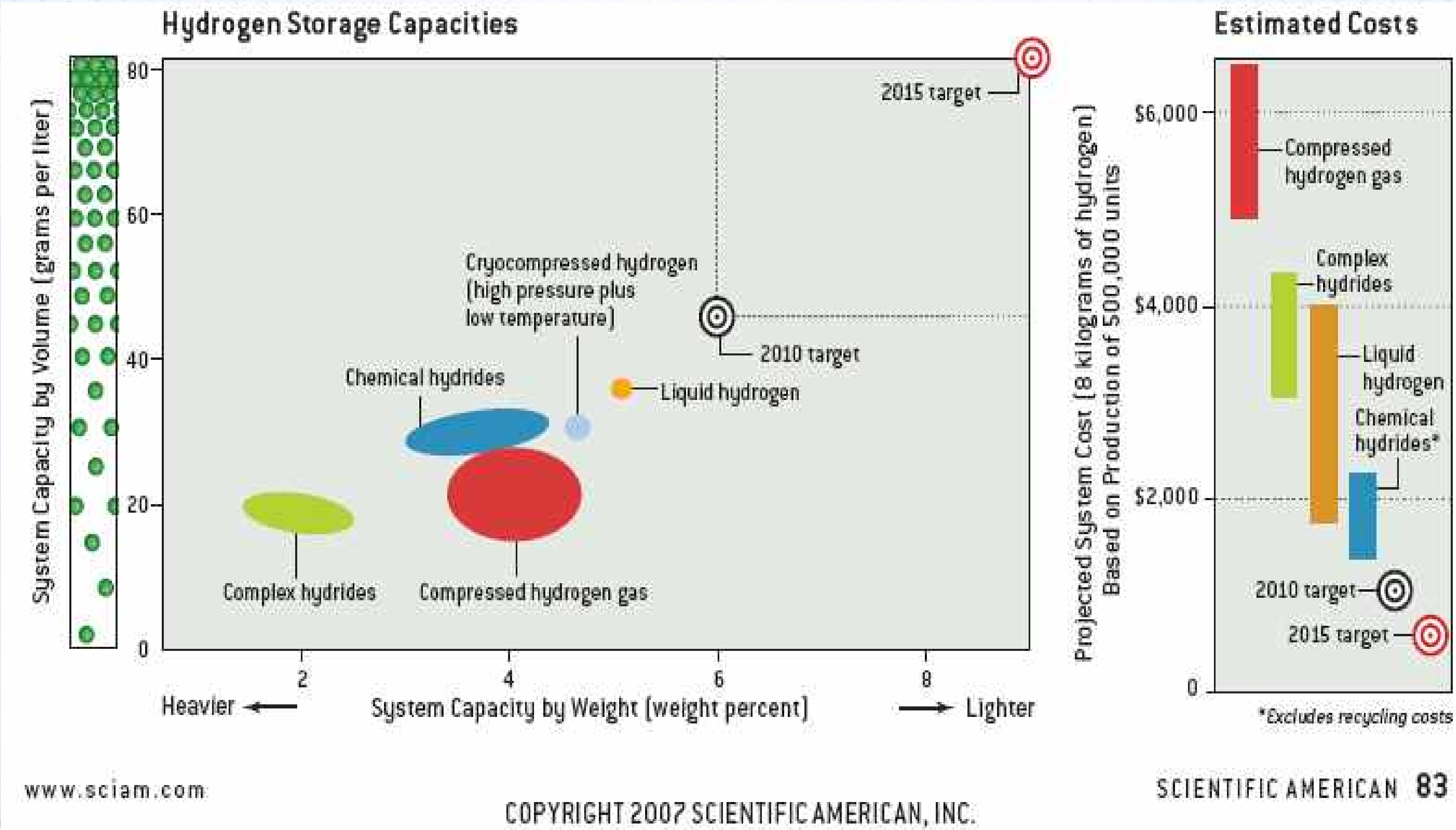
New York State Research & Development Authority
New York Power Authority
Long Island Power Authority

2005

Commercial Opportunity Model

OVONICS = $1.5 Billion Hydride Based Solutions

Hydrogen Storage Expectations



Weight & Cost Synergy with President's Hydrogen Initiative

Total Cost [$]	Matrix Cost [$/kgm]	Hydride cost [$/kgm]	Tank Weight [kg]	Hydrogen Content	Year
$13,972	5	50$	364	2%	2007
$1507	5	$15	121	6%	2010
$405	5	5$	81	9%	2015

What others did: Competition Analysis

Status	Properties	Concept
Produced by Ovonics & others	Low conductivity, easy to produce	Powder bed
Limited Conductivity & structural stability, limited to RT	Conductivity not reported.	Polymer matrix (Congdon)
High parasitic weight, difficult to produce, not applicable at higher temperatures	High Conductivity, simpler production concept	Copper coated hydrides with low MP metal binder
Demonstrated capability and properties. Existent production concept	High conductivity, high structural stability, inexpensive base metal	**Porous metallic hydride Al based**

R&D Challenges

- Incorporation of nanomaterial hydrides.
  Existent R&D shows that nanosize improves kinetics, but powder bed still limited.
  Optimization of heat and gas transport.
- Optimization of structural design (shape).
- Optimization of work pressures and temperatures.
- Design of interface smart connector
- Intelligent Storage (Quantity, pressure, temperature sensing and reporting)

National Hydrogen Storage Milestones

Hydrogen Capacity / Weight Achievement		Milestone	Year
[Wh/kgm]	[w/%]		
300	Current ~2%	Select hydrogen storage options	**2007**
900	6 %	Develop and verify safe on-board storage systems	**2010**
1400	9 %	Develop and verify safe on-board storage systems	**2015**

Hydrogen vs. Gasoline

- Effective energy:
  - Hydrogen has 7 times as much energy (per weight unit) as gasoline, but can be better than 10 times per km due to fuel cell's higher efficiency.
- Cost balance:
  - DOE research estimate hydrogen prices to drop lower than 2$/kg in 10 years.
  - Once hydrogen costs reach ~ 7$/kg it will be as cheap as gasoline and absolutely clean.

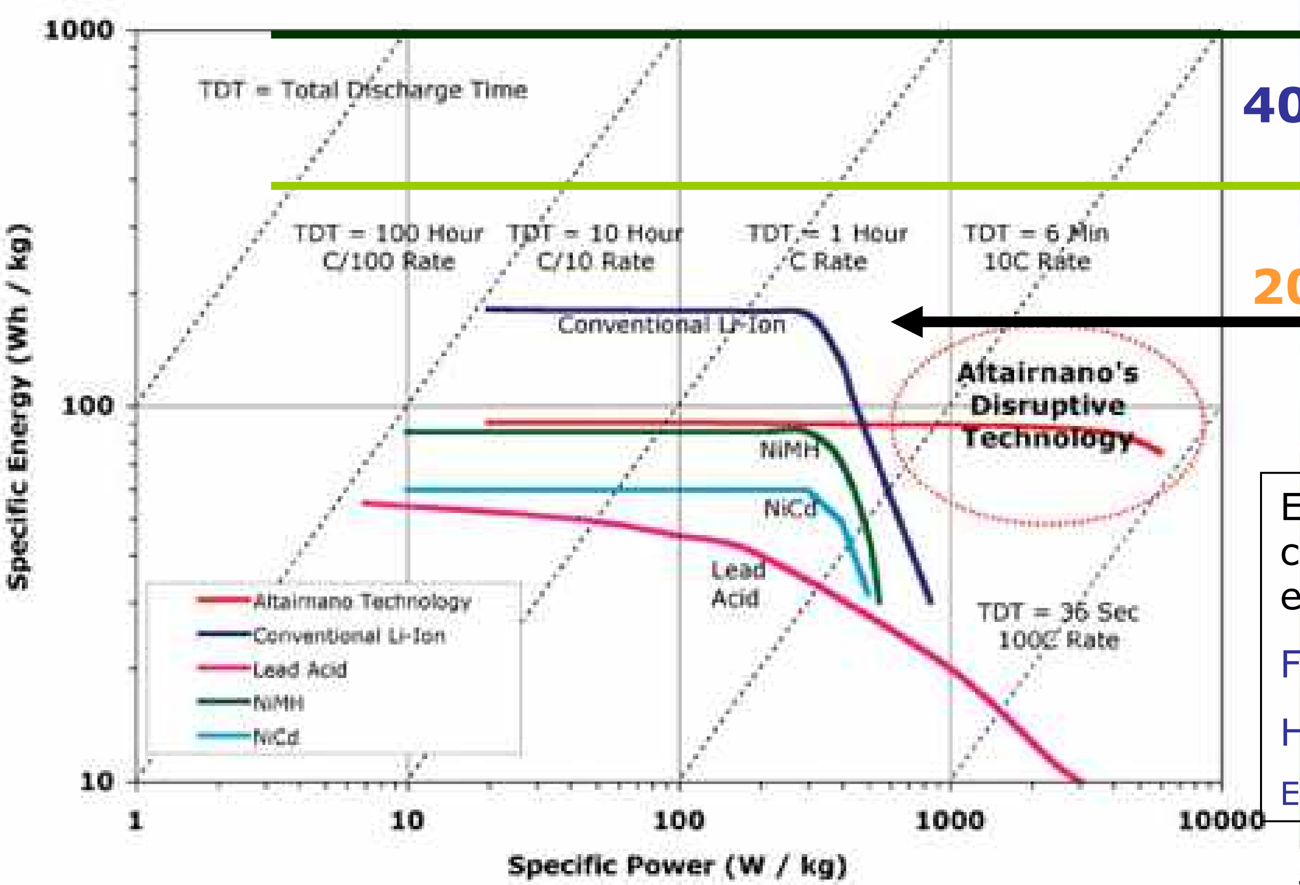
Hydrogen is 10 times more efficient than any Electrical Battery

Equivalent performance **1400 Wh/kg** 2015

est. per DoE H2 Storage goals **1000Wh/kg** 2010

400Wh/kg 2007

200Wh/kg Best Electric



Efficiency estimated after considering losses (FC, electrolysis, Enthalpy, etc.)

FC eff. ~0.46

H2 energy~120MJ/kgm

Electrical data after Altairnano