Plasma Kinetics

RESPONSIBLE, RENEWABLE, ENERGY SYSTEMS

Energy Transport

Problem

- Clean Energy providers need safe and cost-effective means to store and distribute energy in a 24-billion-dollar hydrogen market.
- Current clean energy storage and distribution methods are complex or costly:
  - Battery Storage
    - Expensive
    - Not recycled & creates toxic waste
    - Heavy and potentially flammable
  - Traditional Hydrogen Storage
    - Compressed to 3,000 -10,000 (200-700 bar)
    - Cooled to −423 °F (-252 °C)
    - Potentially flammable or explosive
  - Chemical Hydrogen Storage
    - Ammonia
      - Compressed and stored at 160 psi (11 bar)
      - Synthesis/cracking is costly
    - Methanol:
      - Synthesis/cracking is costly
      - Potentially flammable

Solution

- Containers of nano-photonic *light-activated solid-state* hydrogen thin film with no compression, no flammability and easy transport.

- Hydrogen stored in *light activated* (LAH) 17 kg H_2 *solid-state* canisters.
  - No pressure or cooling needed
  - No risk of fire or explosion
  - No transportation restrictions
  - Lower cost than batteries
  - Lower cost to ship hydrogen
  - 1000 kg of H_2 per 20 ft container bulk load

Light Activated Solid-state
1000 kg H_2
20 ft Container
with 70 x 17 H_2 kg
Canisters bulk loaded

Solution

- Hydrogen is absorbed into light activated film from multiple sources:
  - Wind/Solar
    - Electrolysis
  - Hydrogen from flue gases
    - Temperatures 20 to 400°C
    - Pressures 1 to 40 bar
    - CO_2 concentration up to 30% Molar Mass

Electro-Reformer Prototype Syngas Post H_2O Condensation Constituents				
Gas	**%Mol**	**%Mass**	**Sms3/h**	**Kg/h**
CH_4	0.07	0.08	0.04	0.03
CO_2	28.97	80.43	15.8	29.23
CO	6.03	10.66	3.29	3.87
H_2	64.35	8.17	35.09	2.97
H_2O	0.58	0.66	0.32	0.24
Total	**100**	**100**	**54.54**	**36.34**

Results

- 7005 to 10038 containers of hydrogen on a single container ship without modification or hazard.
- Containerized shipments allow immediate distribution onto inland waterway, truck or rail transportation at destination port.
- No need for compression, decompression, specialized ships, or certifications.
- Hydrogen shipments of any size, at any time, reduces logistics and increases revenue by providing distributed global customers just-in-time deliveries.

7005 containers of hydrogen
1215 kg H_2 each[1]
10038 containers of hydrogen
1000 kg H_2 each[1]
0.01 µm *t* (2024) which enables an H_2 energy capacity of >1500 Wh/l [1]

Enough energy to power 12.000 homes for 1 full year
Enough energy to allow large trucks to go 150.000.000 km

Market Opportunity

- Global H_2 market is expected to reach USD 24.5B by 2027. - Allied Market Research
- Global H_2 Storage market will reach USD 992M in 2026. – Prescient and Strategic Intelligence
- Solid H_2 storage is projected to be the most lucrative segment by 2027. - Allied Market Research
- Canisters of light-activated solid-state hydrogen ease shipment and can be directly implemented in applications like trucks, ships, rail, VTOL aircraft and grid stabilization.
- PacifiCorp reports USD 2B annually would be saved with clean energy over-generation management. - PacifiCorp
- Germany is creating 10 GW of electrolysis capacity for green H_2 by 2040. - CSIS
- European Truck manufactures agree to drop diesel by 2040. - ACEA
- U.S. ports restricting diesel use for berthed vessels to less than 20% of time in port and added emission control regulations. – U.S. EIA
- European ports require 55% reduction in emissions by 2023. – ESPO
- Maersk shipping will go carbon free by 2050. - Maersk
- There are 20.5 million intermodal containers world-wide.

Market Opportunity

- The global hydrogen generation market is USD 120.77B. An exponential increase in the demand for green fuel and government regulations to control pollution is driving the market. – Grand View Research

- 95% of the 70 million metric tons of H_2 produced annually is gray hydrogen and over 70% of gray hydrogen is produced from natural gas which yields 10 kg of CO_2 per kg of H_2. Blue H_2 yields 2 to 5 kg of CO_2 per kg H_2. Green hydrogen from solar and wind can be carbon free and needs cost effective storage. - Center for Strategic and International Studies.

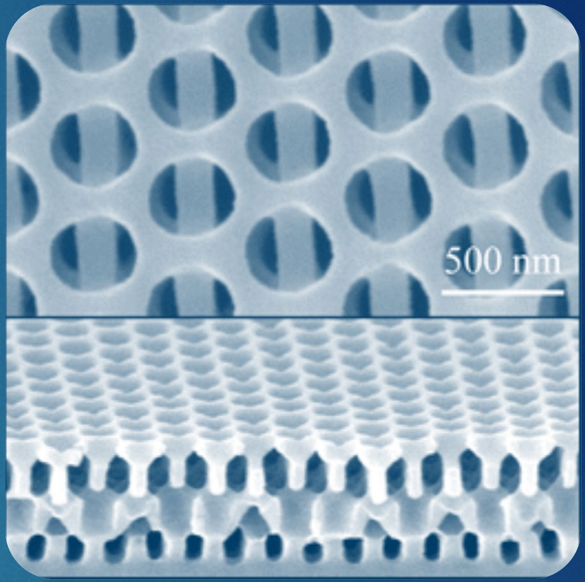
- Light Activated Solid State hydrogen requires no energy to store the hydrogen, is less than 50% the cost of batteries, and approximates the cost of compressed or liquid storage without the energy cost of compression or cooling, or risk of fire.

Business Model

- Build real-world hydrogen storage and transport application prototypes.
- Build pre-ordered hydrogen storage and transport products in concert with potential manufacturing licensee(s).
- Build relationships with hydrogen producers to store and ship hydrogen via container-based canisters.
- Build collection and distribution models based on shortlisted hydrogen producers and shortlisted countries.
- Build relationships with OEM truck manufactures and ship builders to implement distributed hydrogen directly from canisters without the need for compressed or liquid refueling stations.
- License technology for H_2 producers (bio-gasification, syngas, wind and solar) and end-users (automotive, aerospace and marine, microgrids, oil refining, forklifts, airport tugs, home backup systems, data centers).
  - Current interest from
    - U.S. Military (all branches), NASA, Boeing, Transcend Aero
    - Major Truck Manufactures
    - Wind/Solar over-production storage (value $100/kWh or USD $8B world-wide)

Technical – What is Nano-Photonic H_2 Thin Film?

A 0.028 mm *non-flammable* thin film with a nano-structure which captures hydrogen *without pressure* and interacts with light to release hydrogen at high pressure.



- 7 constituents (no rare-earths)
- PVD layering of materials
- NGF (nano-graphite-film) substrate
- High Temperature Shape Memory Alloy
- Post deposition nano-lithography
- Low CO_2 fabrication process

Technical – How does it work?

Like a movie projector or CD player.
Light shines on the film or disc
to release hydrogen.

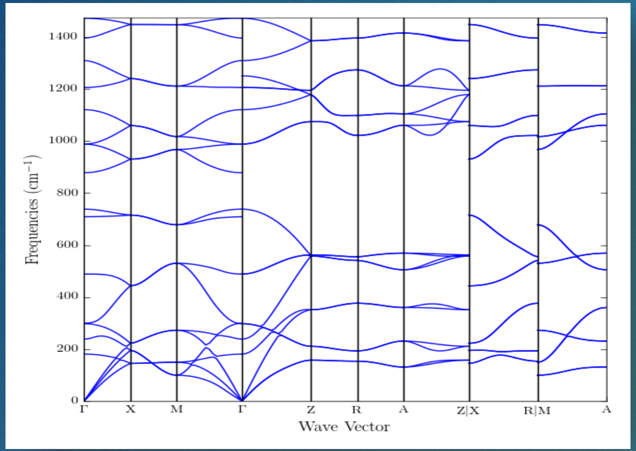
Plasma Kinetics CD prototype

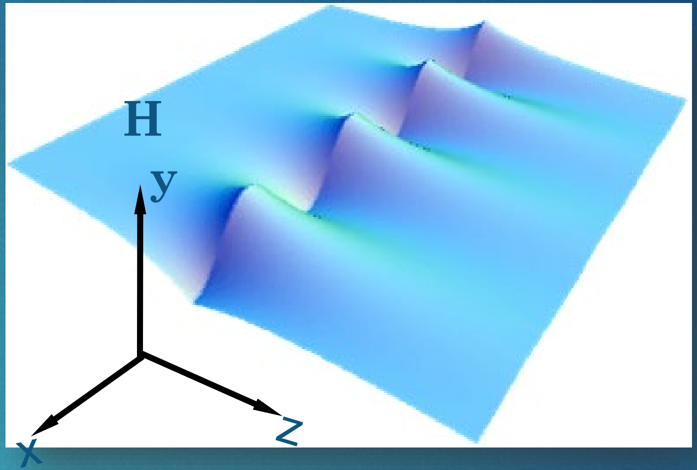
Cassette Film

Canister Film

CD Film

Technical Uniqueness





Angstroms thick shape memory alloy layers and metal hydride nanostructured layers provide a dielectric with black state forming constituents and a lower bond energy.

Photon absorption and polariton resonance support dissociative amplitude energies on photonic irradiation.

The result is safe, efficient, high-density, photo-reactive, solid-state hydrogen energy storage.

Recommended reading
Mg-Based Thin Films as Model Systems in the Search for Optimal Hydrogen Storage Materials
October 12, 2012, By Małgorzata Norek
https://www.intechopen.com/chapters/40236

Technical Uniqueness

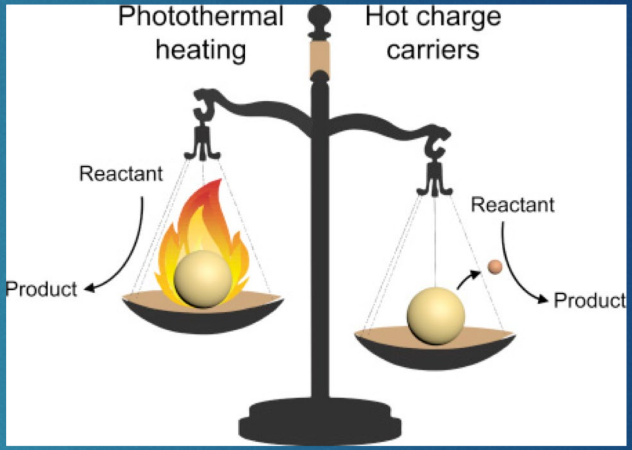
Slide from: DOE Hydrogen and Fuel Cells Program
2019 Annual Merit Review and Peer Evaluation Meeting
https://www.hydrogen.energy.gov/pdfs/review19/st131_gennett_2019_o.pdf

Relevance: Task 3 Plasmonic 'on-demand' hydrogen release in hydrogen carriers

Plasmonic nanostructures concentrate photon energy and can produce heat via the localized surface plasmon resonance (LSPR)

- plasmonic nanostructures act to locally and temporally heat a limited region
- LSPR and its local intensity is determined by the material shape, size and crystallinity

Plasmonic Hot Carriers - using low-energy photons, generate high energy electrons and holes



Utilize low energy light source to induce hydrogen sorption/desorption reactions and phase changes thermally and/or electrochemically

Pix from:
https://www.differ.nl/vacancies/internship-nea

Technical Uniqueness

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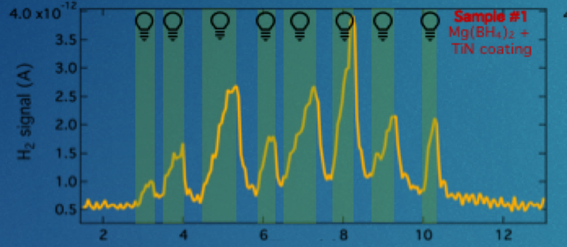
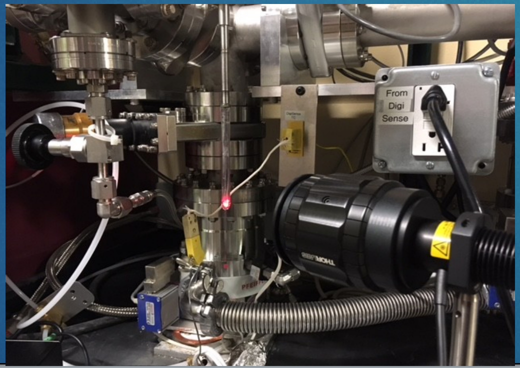
Accomplishment: Plasmonic ‘on-demand’ hydrogen release

Hydrogen Desorption using Photons – $Mg(BH_4)_2$ and MgH_2

Mix: 20 nm TiN with $Mg(BH_4)_2$ or MgH_2
ALD: Atomic layer deposition of TiN on $Mg(BH_4)_2$
MBH: $Mg(BH_4)_2$



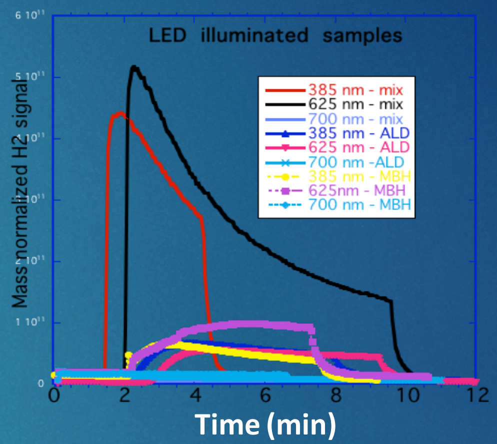
LEDs: 385 nm, 625 nm, 700 nm

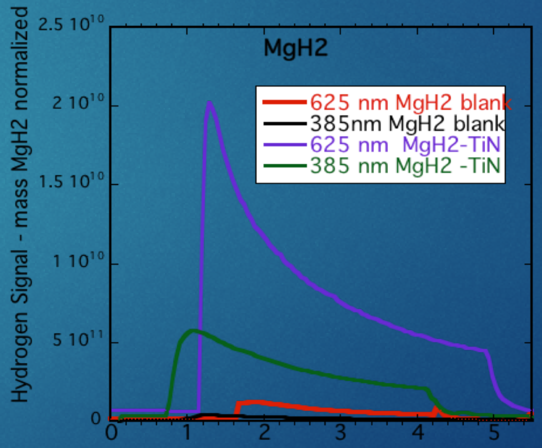


- 700 nm no hydrogen evolution
- 625 nm (plasmonic heating) only H_2 and B_2H_6 observed
- 385 nm (hot carrier)
  H_2, B_2H_6 and possibly B_3H_8, and B_2H_7 observed

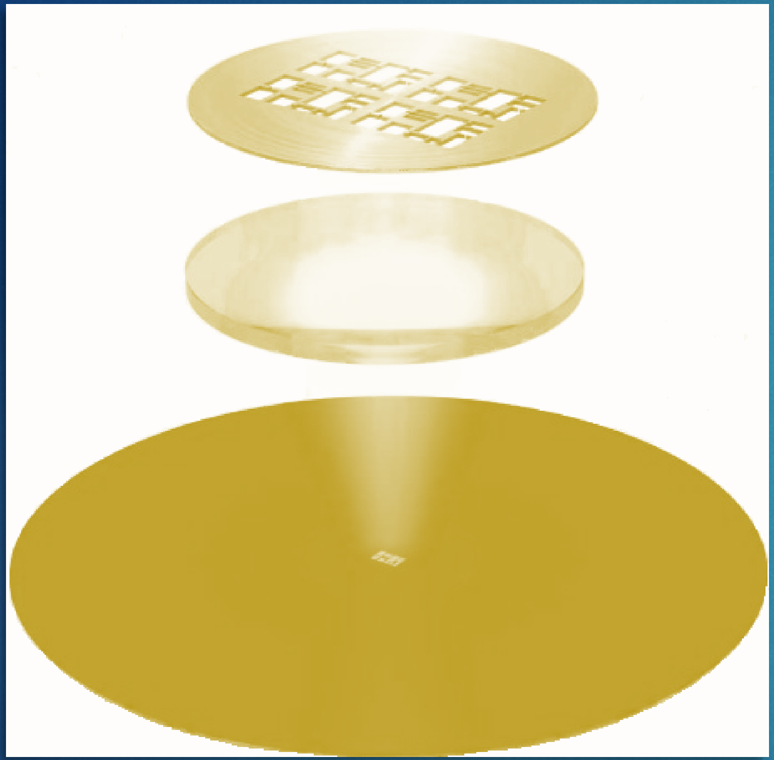
Preliminary Indications:
Non-optimized
625 nm – thermal degradation
385 nm – electrochemical reaction
Dual illumination and *in-situ* studies underway

$Mg(BH_4)_2$



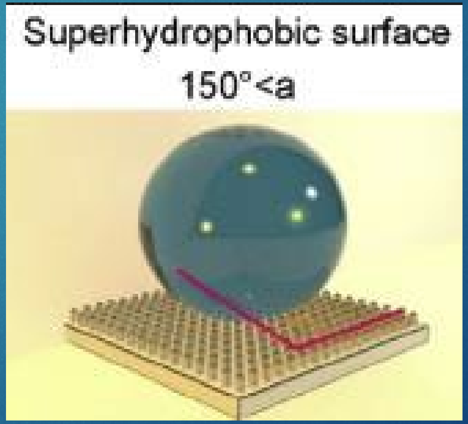


Technical Fabrication

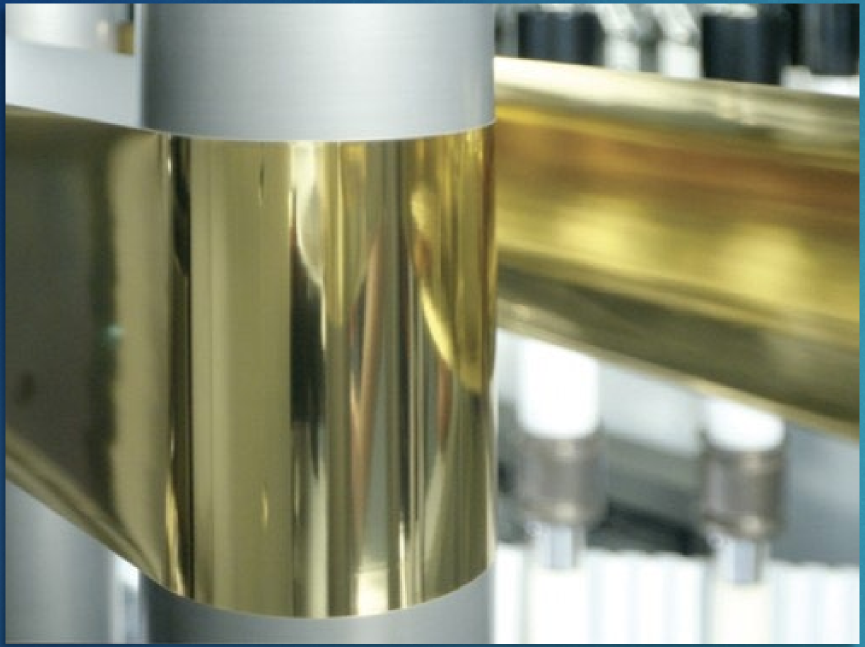


Fabrication process is comparable to micro-chip production

- Nano graphite film substrate
- Layered PVD deposition
- Post-PVD lithographic nano-structures
- Superhydrophobic surface reduces wetting

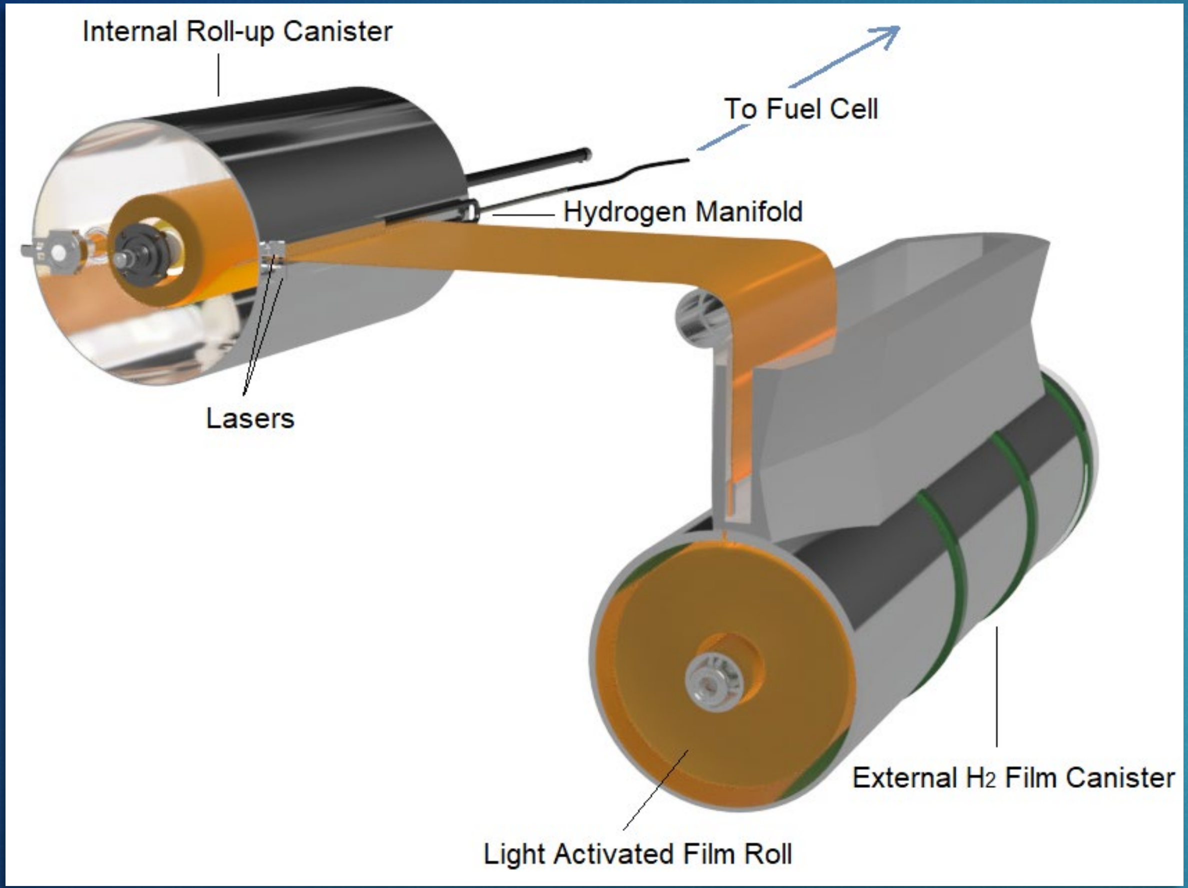


Technical Overview



- Light activated hydrogen storage film
- UL 94 V-0 non-flammable
- Tensile strength 35kg/cm
- Dielectric strength 8,000 volts
- Resistant to crepitation
- Heat resistant
- Rechargeable without pressure
- H_2 absorption in minutes
- Rechargeable over a hundred cycles
- Recyclable
- No rare-earth elements
- Non-toxic
- Resistant to contamination

Technology Implementation



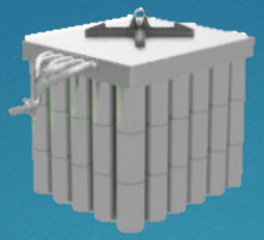
- Film stored in external canister
- Film rolls up in internal canister
- Light shines on ½ of film
- Hydrogen is released to fuel cell
- Lasers shift to other ½ of film
- Film rolls back to external canister
- Light on ½ of film on roll-back
- Hydrogen is released to fuel cell
- Laser canister moves
- Next film section rolls up
- Process repeats three times
- 1 internal for 2 external canisters

Technical Storage and Release

17Kg H_2 Canister

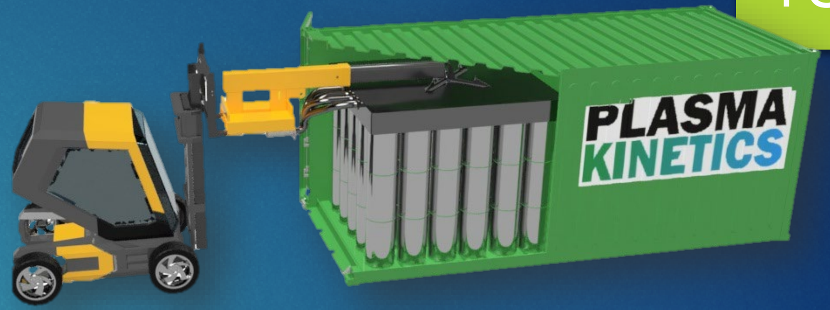
Volume
- $0.04\ m^3/kg\ H_2$
- $0.00124\ m^3/kWh$
- $806\ kWh/m^3$

Weight
- 400 kg system wt.
- $33.4\ kg/kg\ H_2$
- 1.0 kg/kWh



H_2 Charging Hood

- No pressure
- Multiple canisters
- No fire risk



H_2 Charged in 20ft Container

- 70 canisters (1000 Kg) charged
- Charging time 30 - 60 minutes

Technology Benefits and Value

- No pressure 
- Non-flammable 
- Long shelf-life 
- Quick recharging 

- Multiple fuel sources 
- Minimal Infrastructure 

- Safe 

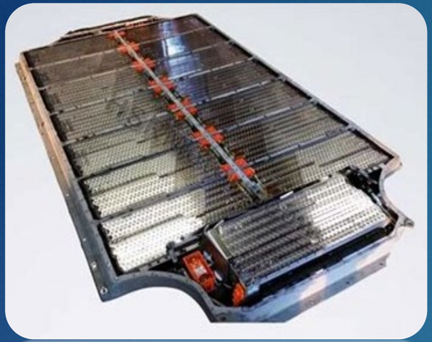
- Economical 

- Transportable 
- Quiet 
- Zero Carbon 

- Distributable 

Technology Comparison

LAH Energy Density ≈ 350 bar compressed H_2 without pressure




Energy Density	Li-ion Battery	Light Activated Solid-State Hydrogen	700 Bar Compressed Hydrogen	Synthetic Fuel Methanol	11 Bar or -33°C Ammonia
Gravimetric:	130 Wh/kg	1000 Wh/kg	1872 Wh/kg	5520 Wh/kg	5160 Wh/kg
Volumetric:	474 Wh/l	806 Wh/l	1300 Wh/l	4380 Wh/l	4270 Wh/l

≈ 350 Bar
Compressed Hydrogen

Technical – A comparison in trucking

Light Activated hydrogen truck

- Vehicle cost 180.000 €
- Not Compressed
- Fuel cost 0,15 €/kWh (save 20.000 €/year)
- CO_2 24k kg/year (save 40.000 kg/year)
- No refueling Infrastructure* (save 2,2M €/station)
- Non-flammable
- Same canisters for regional/local delivery
- Same canisters for use in trucks

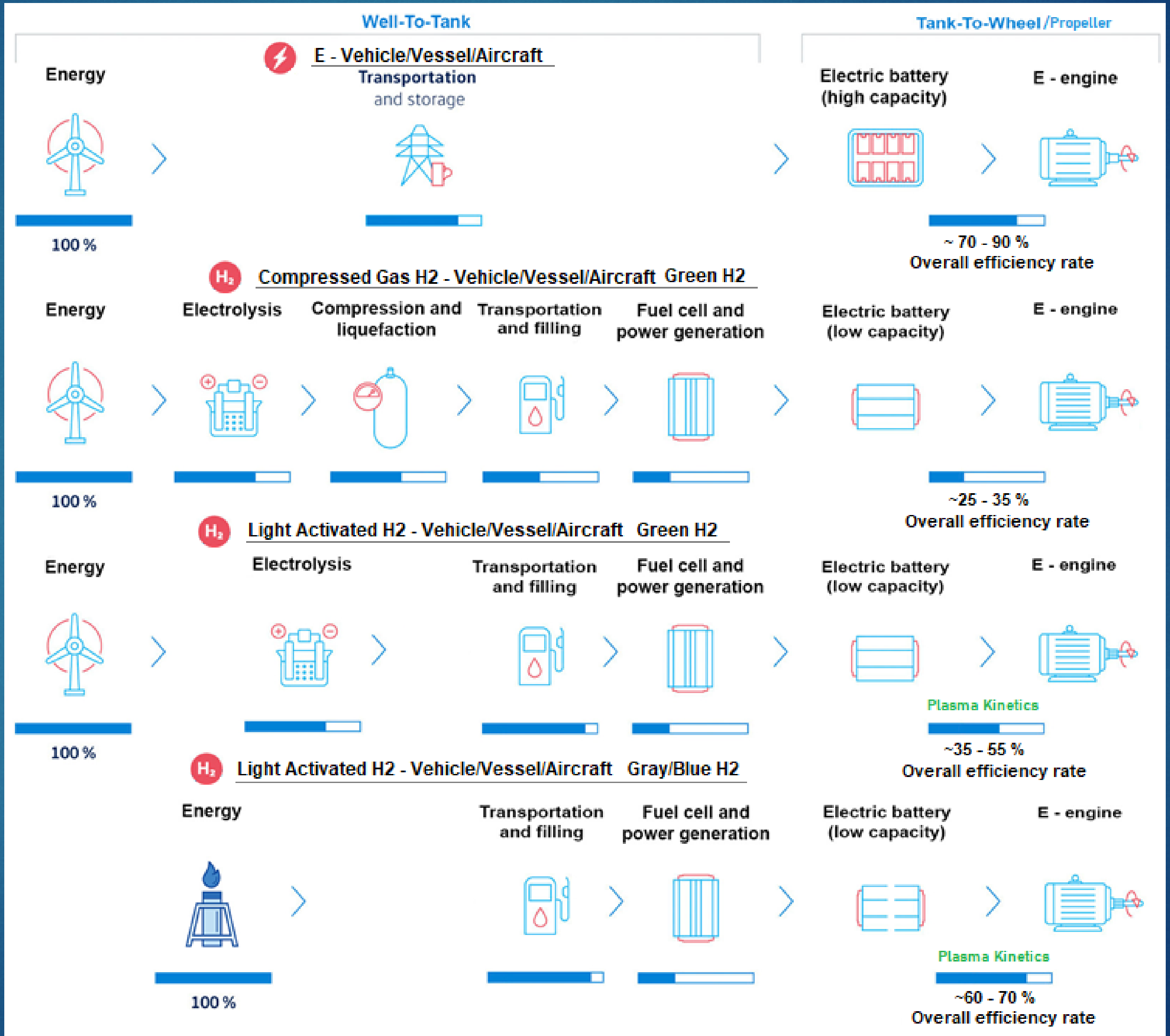
Compressed gas hydrogen truck

- Vehicle cost 160.000 €
- Compressed to 350 Bar
- Fuel cost 0,29 €/kWh
- CO_2 68k kg/year
- Refueling infrastructure 2,3M €/station
- Flammable
- Pipeline or custom truck for local delivery
- Carbon fiber tanks required for use in trucks

*container & forklift 200k €

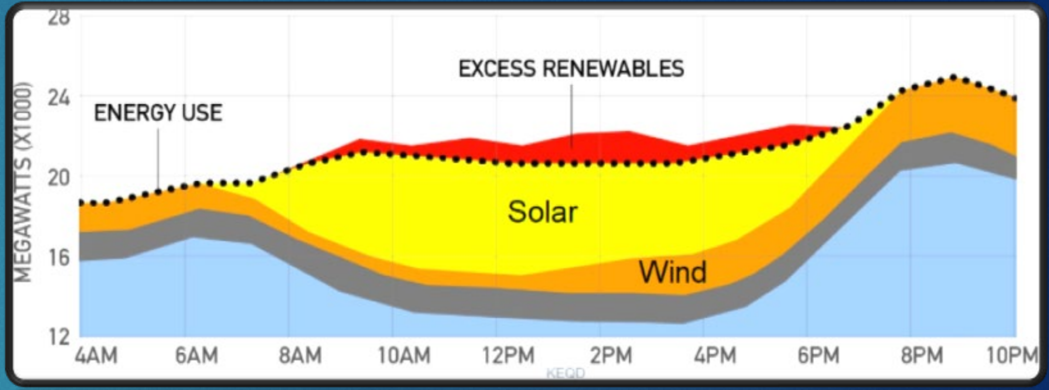
Technical – A comparison of Energy Efficiency

Plasma Kinetics Light Activated H_2 storage approximates battery efficiency.

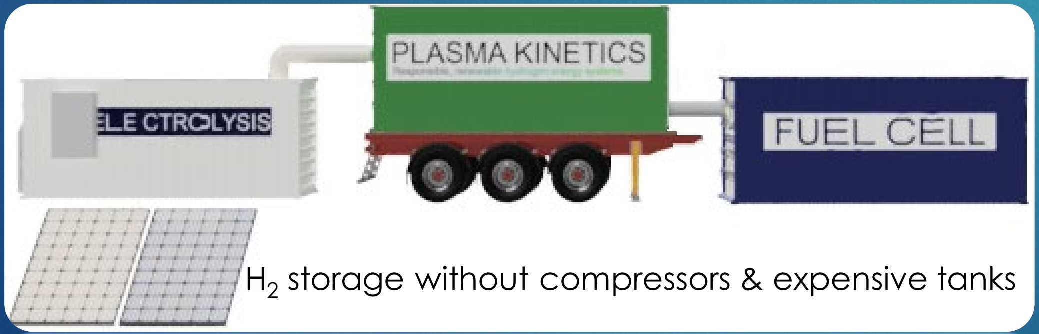


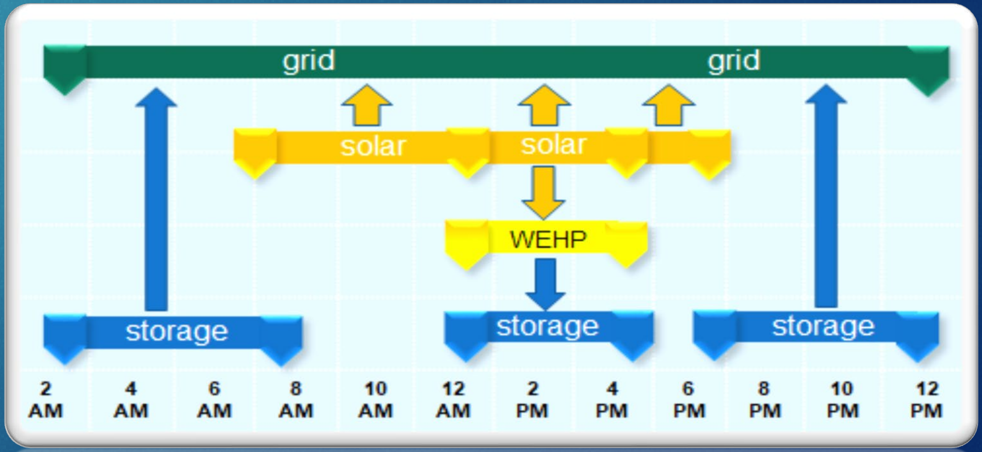
Problem Wind/Solar Overproduction

- Wind and Solar Farms need a way to provide energy 24/7.
  - 502 federally funded and 416 Utility-Scale Solar Projects in the U.S.
  - 404 GWh of Solar/Wind Energy produced in 2020 with a 20% oversupply during daylight hours.
    - US Energy Information Administration (EIA)
  - PacifiCorp reports $2 Billion annually would be saved with over generation management.

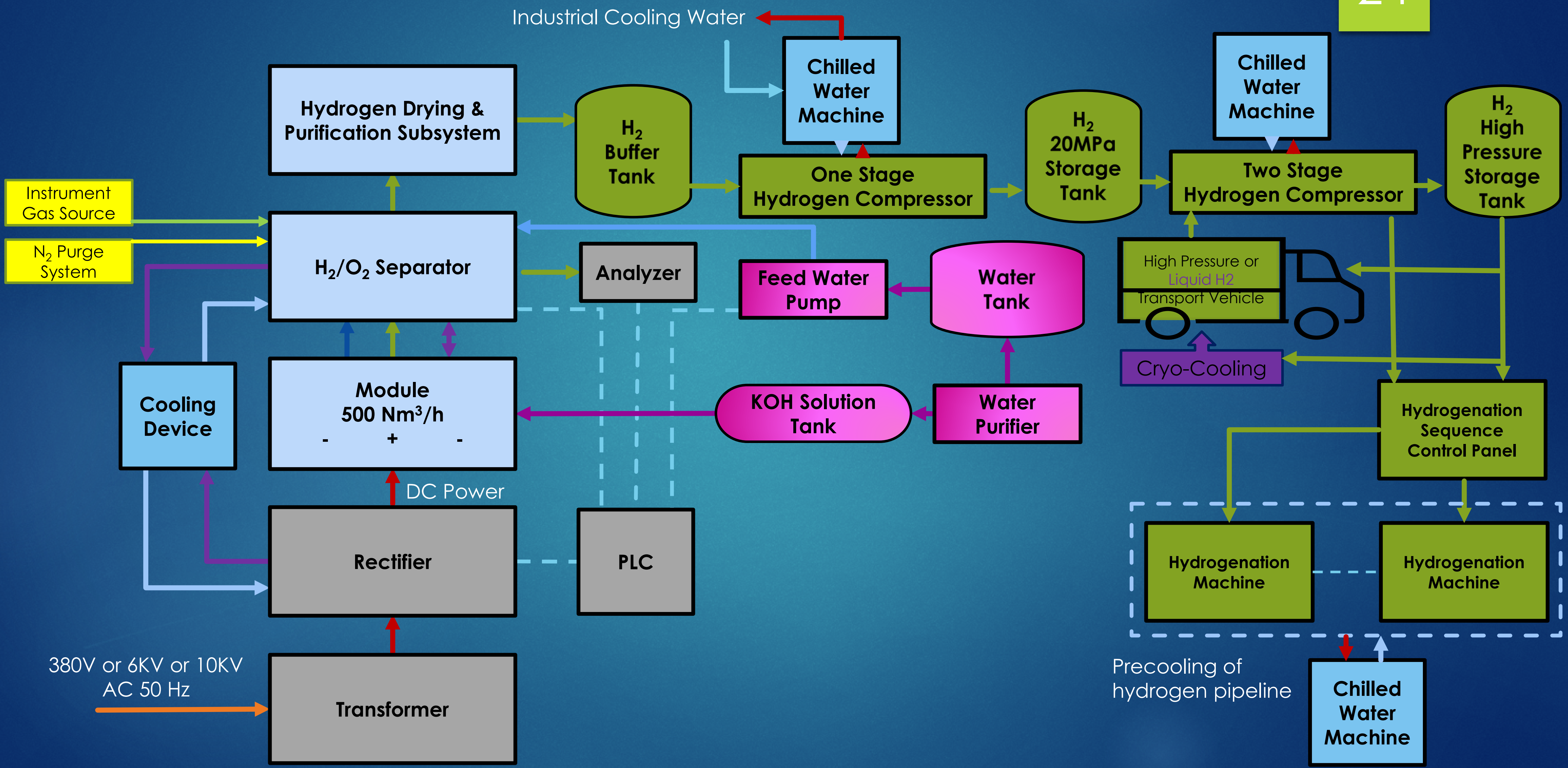


Solution LAH Storage

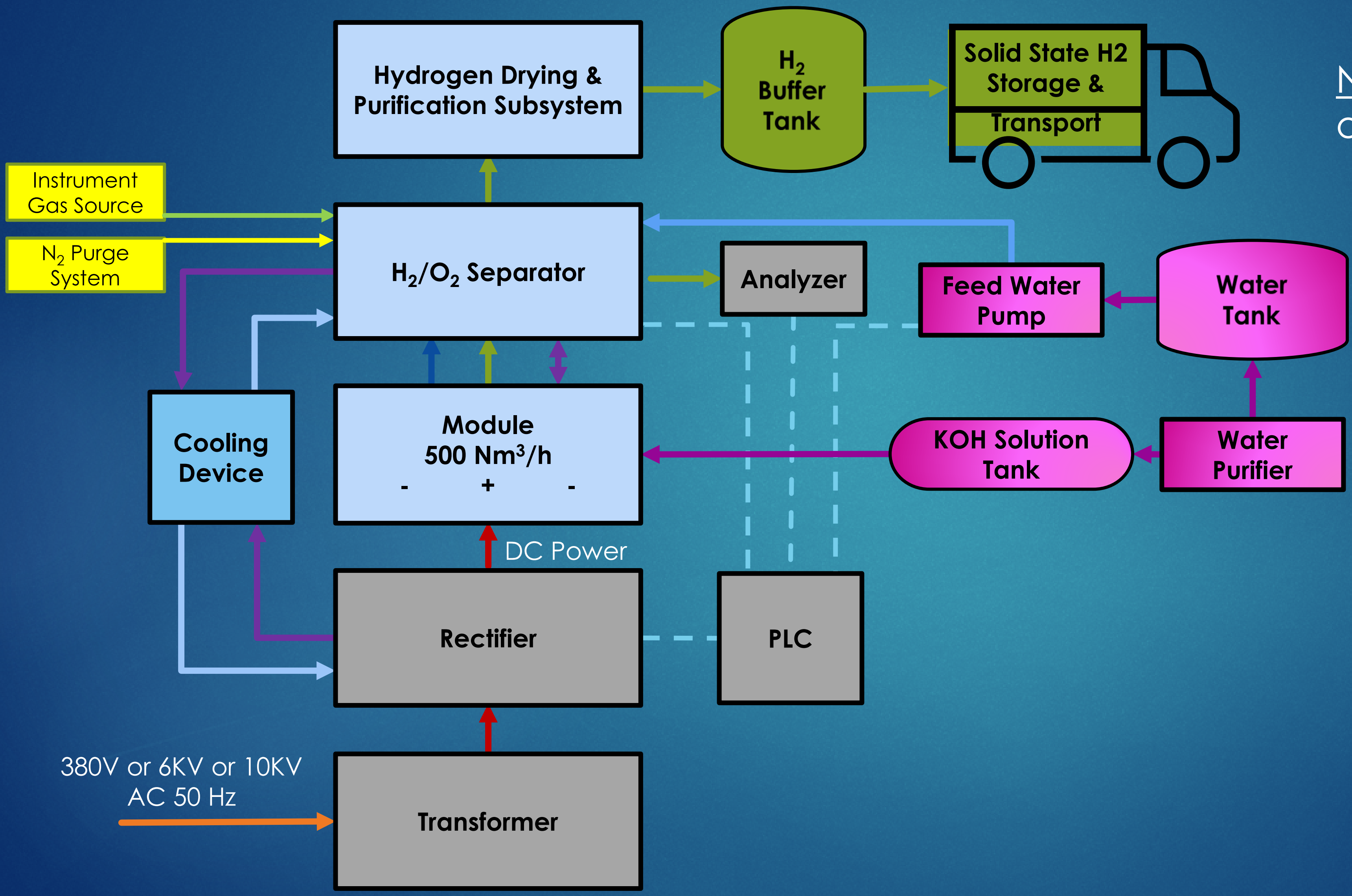




Technical – Conventional E-Hydrogen Generation

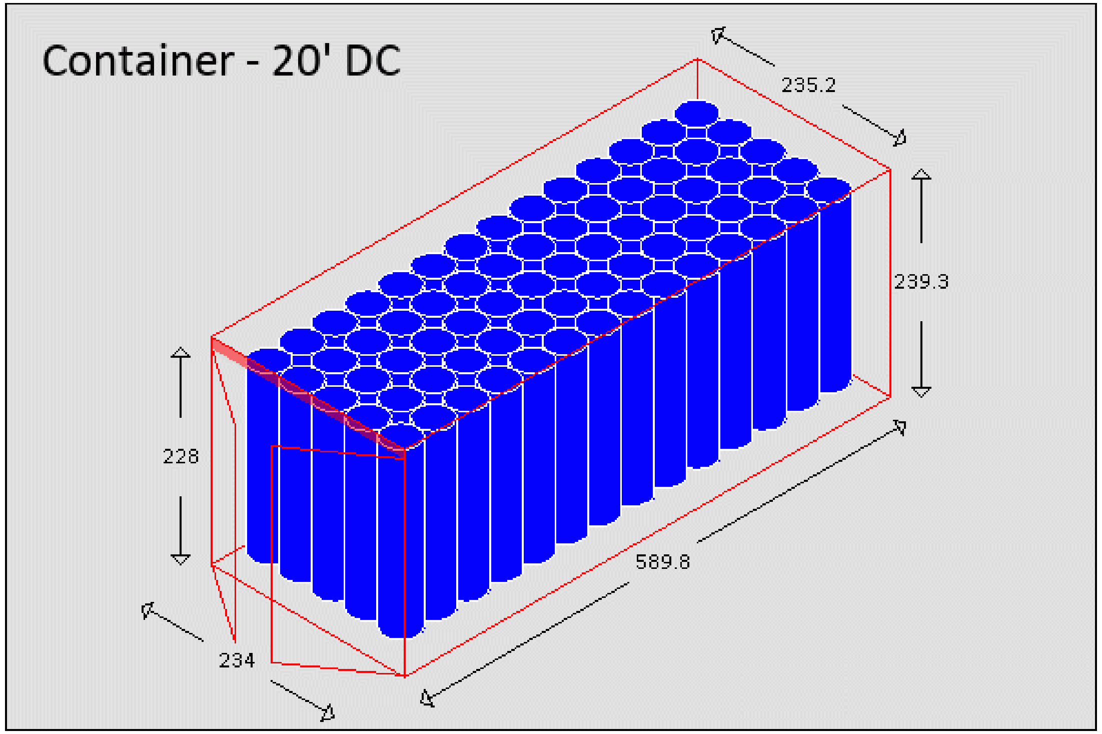


Technical – Solid-state E-Hydrogen Generation



No compression, cooling or high-pressure storage.

Technical - Solid-state Hydrogen Canisters/Container



Equipment : Container - 20' DC

Cargo name	Pieces loading	Pieces total
H2 Canisters	70	70

	Used	Free	Maximum
Weight (payload) in KG	28000	200	28200
Cubic Meter	22.4	10.796	33.196
Floor lenght centimeter	560	29.8	589.8
Floor sqaure meter	11.2	2.672	13.872
Pieces	70		

1000 kg H_2

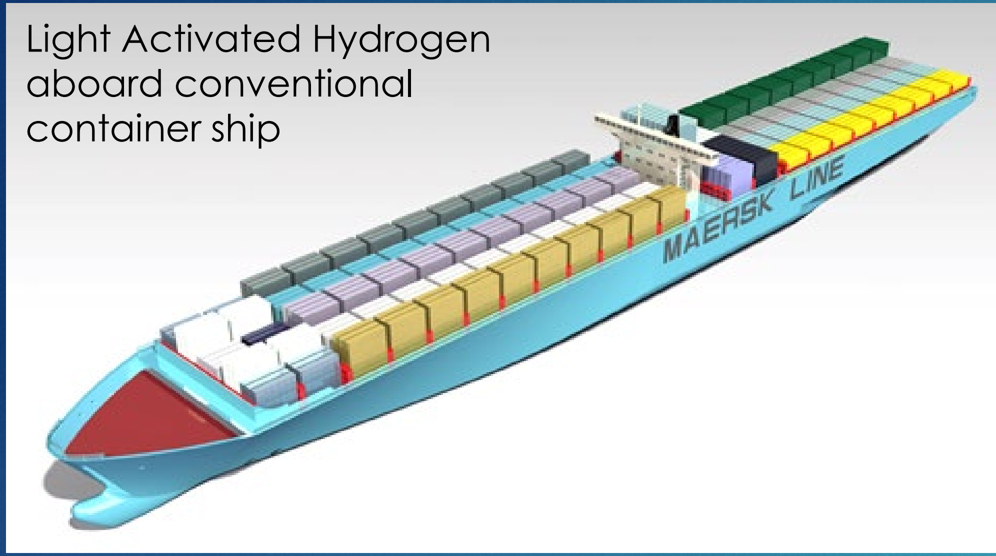
(1215 kg stored, minimum 850 kg usable)

(7005 containers per ship)

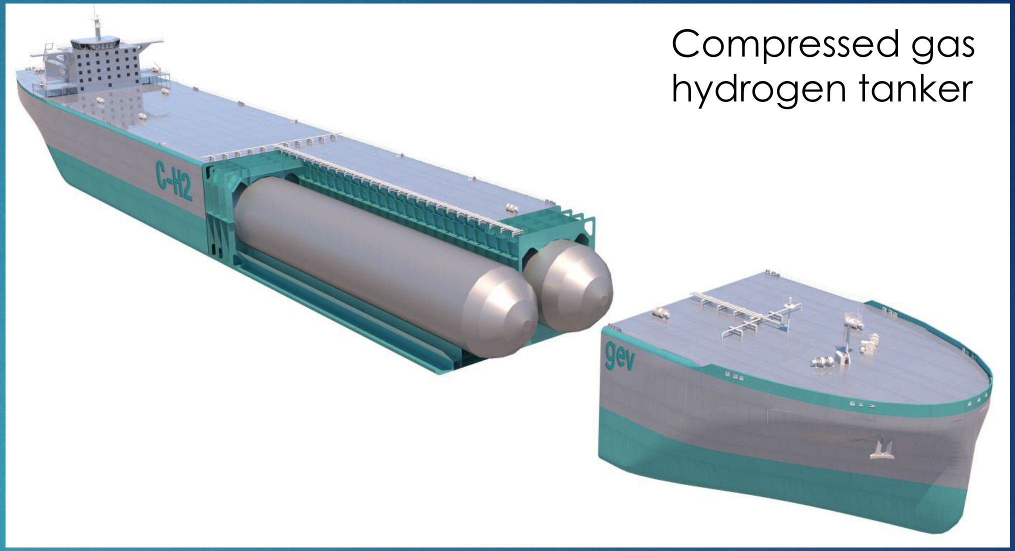
Full loading list

Group	Equipment name	Name	PCS	Weight total	Lenght	Width	Height
1	Container - 20' DC	H2 Canisters	70	28000	40	40	200

Technical – comparison in energy industrial shipping



Light Activated Hydrogen aboard conventional container ship

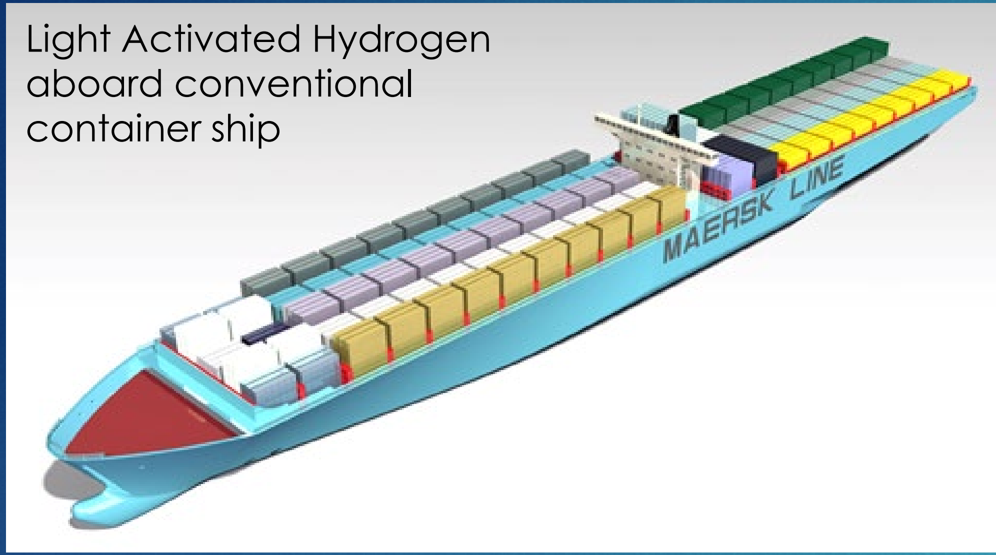


Compressed gas hydrogen tanker

- **10,000** Tons of Hydrogen
- Not Compressed
- 1 to 9.999 partial 1-ton shipments
- Partial deliveries at multiple ports
- Existing infrastructure to load/unload
- No port storage tanks required
- Non-flammable
- Same container for regional/local delivery
- 3,5k Kg CO_2 per ton of H_2 (50% smr without compression)
- Investment according H_2 production

- **2,000** Tons of Hydrogen
- Compressed***** to 250 Bar
- No partial shipments
- Single destination
- Custom Infrastructure Compress/decompress to load/unload
- Port storage tanks required
- Flammable
- Pipeline or custom truck for local delivery
- 6,1k Kg CO_2 per ton of H_2 (50% smr & compression)
- 250M € Investment

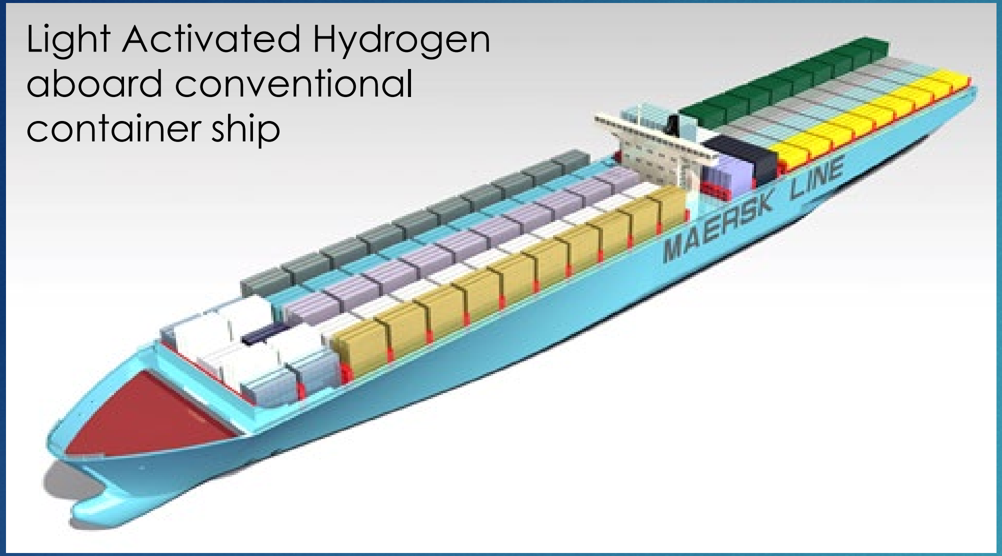
Technical – comparison in energy industrial shipping



- **10,000** Tons of Hydrogen
- Not Compressed
- 1 to 9.999 partial 1-ton shipments
- Partial deliveries at multiple ports
- Existing infrastructure to load/unload
- No port storage tanks required
- Non-flammable
- Same container for regional/local delivery
- 3,5k Kg CO_2 per ton of H_2 (50% smr without compression)
- Investment according H_2 production

- **90** Tons of Hydrogen in 1250 Cm of volume
- Liquefied* to -253° C/1bar
- No partial shipments
- Single destination
- Custom Infrastructure cooling/heating to load/unload
- Port Liquefied Hydrogen Receiving Terminal
- Flammable
- Pipeline or custom truck for local delivery
- 6,1k Kg CO_2 per ton of H_2(50% smr & compression)
- Costly Investment for infrastructures

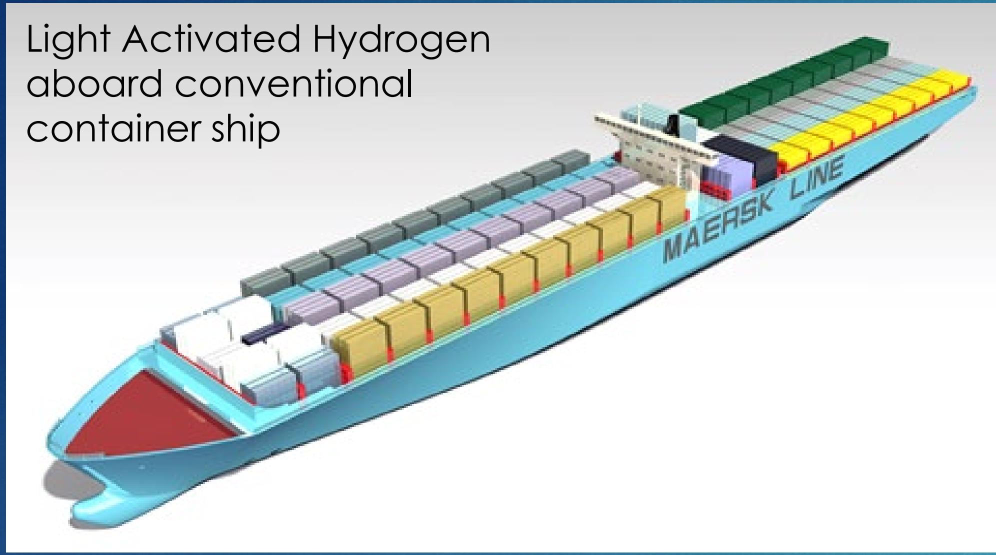
Technical – comparison in energy industrial shipping



- **10,000** Tons of Hydrogen
- Not Compressed
- 1 to 9.999 partial 1-ton shipments
- Partial deliveries at multiple ports
- Existing infrastructure to load/unload
- No port storage tanks required
- Non-flammable
- Same container for regional/local delivery
- 3,5k Kg CO_2 per ton of H_2 (50% smr without compression)
- Investment according H_2 production

- **580** Tons of Hydrogen in 3500 Tons. of Methanol
- Not Compressed
- Yes partial shipments
- Partial deliveries at multiple ports
- Existing infrastructure to load/unload
- Port storage tanks required
- Highly Flammable - Toxic
- Pipeline or custom truck for local delivery
- 6,0k Kg CO_2 per ton of H_2 (50% smr)
- Costly Investment for infrastructures

Technical – comparison in energy industrial shipping



Light Activated Hydrogen aboard conventional container ship

- **10,000** Tons of Hydrogen
- Not Compressed
- 1 to 9.999 partial 1-ton shipments
- Partial deliveries at multiple ports
- Existing infrastructure to load/unload
- No port storage tanks required
- Non-flammable
- Same container for regional/local delivery
- 3,5k Kg CO_2 per ton of H_2 (50% smr without compression)
- Investment according H_2 production

Compressed ammonia tanker

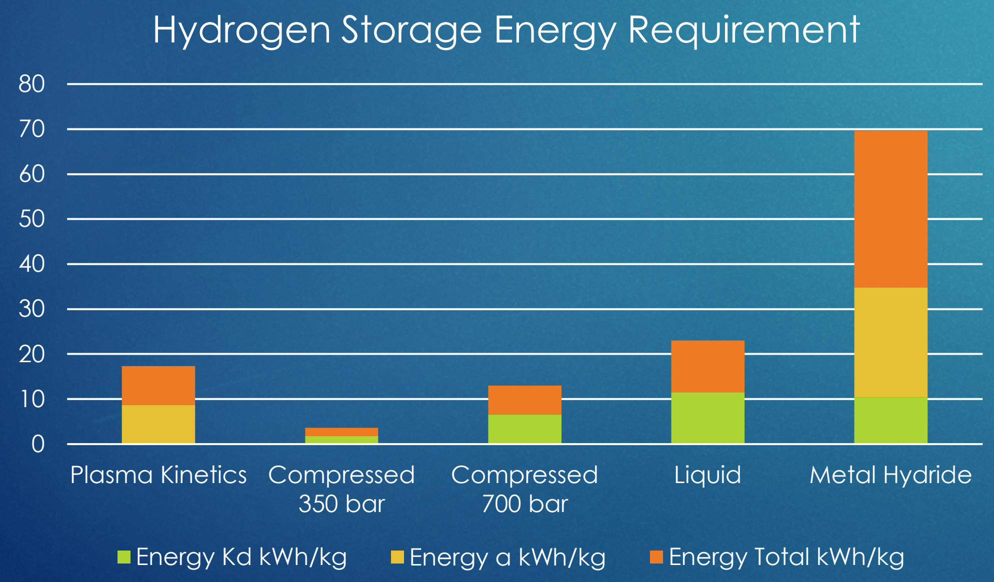
- **9,360** Tons of Hydrogen for 60.000 Tons of Ammonia
- Compressed to 11 bar or cooling -33 °C
- No partial shipments
- Single destination
- Custom Infrastructure Compress/decompress to load/unload
- Port storage tanks required
- Flammable -Toxic
- Pipeline or custom truck for local delivery
- 5,1k Kg CO_2 per ton of H_2 (50% smr & compression)
- Costly Investment for infrastructures

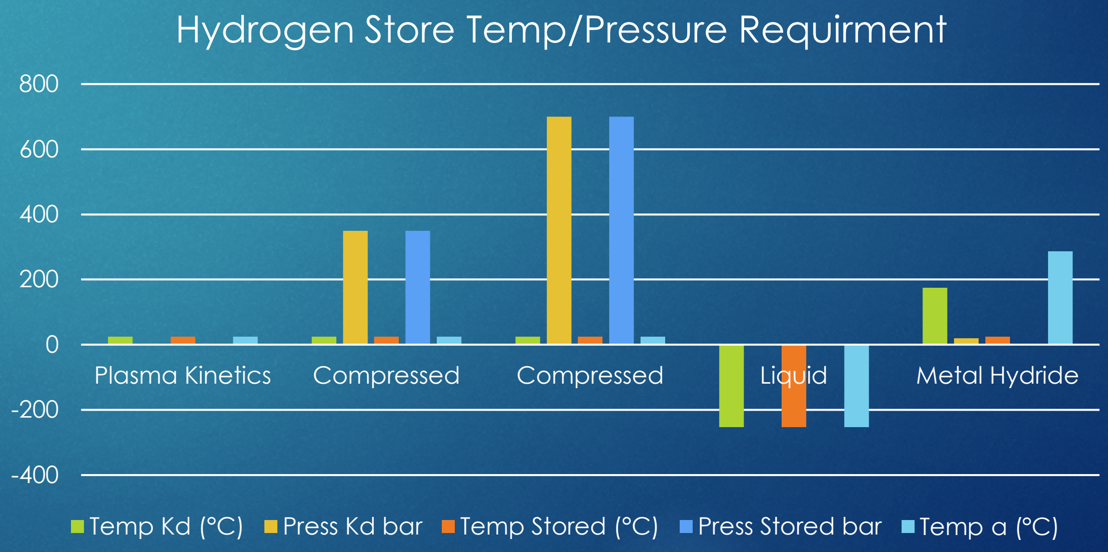
Technical - Solid-state Hydrogen Storage Comparison

Light Activated has lower energy requirement than Liquid hydrogen and the lowest "up-front" energy requirement.

Light Activated is at normal atmospheric temperature and pressure at all times.

Storage/Feature	Plasma Kinetics	Compressed	Liquid	Metal Hydride
Temperature K_d	25°C	25°C	−252.87°C	175+°C
Pressure K_d	1 bar	350-700 bar	1 bar	20 bar
Energy K_d	0.05 kWh/kg	1.8-6.5 kWh/kg	11.5 kWh/kg	10.4 kWh/kg
Temp/Press stored	25°C/1 bar	25°C/350-700 bar	−252.87°C/1bar	25°C/1 bar
Temperature α	25°C	25°C	−252.87°C	287+°C
Energy α	8.6 kWh/kg	0 kWh/kg	0 kWh/kg	24.4 kWh/kg
Energy Total	8.7 kWh/kg	1.8-6.5 kWh/kg	11.5 kWh/kg	34.8 kWh/kg
Storage Rate	1 kg/min	1 kg/min	1 kg/min	0.1 kg/min
Flammability	Non-Flammable	Flammable	Flammable	Flammable
Explosive in air	Non-Explosive	Explosive	Explosive	Non-Explosive
Stored Molecule	MgHX Hybrid	H_2 Covalent	H_2 Covalent	MgH_2 Covalent





Thank you!

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