

Green H₂: A Silver Bullet ?..Or Greatly Over Hyped ??



'Politicians love talking about hydrogen, it's modern and cool; it sounds like you're doing something'... "Mesmerized by 'EASY' Solutions"
....Energy analyst Michael Liebreich

"Only one industry can't survive without fossil fuels" ...
.....*M. Barnard*

Remember the Goal: Reduction GHGases

Monthly SST Anomaly (°C), World (60°S–60°N, 0–360°E)

Dataset: NOAA OISST V2.1 | Image Credit: ClimateReanalyzer.org, Climate Change Institute, University of Maine



Global Corals ; Crustaceans; Fish; All Marine life: Have Temperature limits !

- *Current Steam Reforming CH₄ or Coal:*
- **Emits = 100 million tons CO₂-equiv emissions**
 - **= 3 % America GHG emissions !!**
- * *There is a good reason why current Cheap H₂ .. is NOT currently used !*
- ***Because other solutions are much cheaper, simpler; more convenient !!!!!***

- Current USA – H₂ Production:
~ 10 million metric-tons/ yr

- * 40 % - NH₃ – Fertilizers

- * 45 % - Refinery : Hydrocracking to small molecules
& Eliminate sulfur

- * 15 % - Methanol & Misc chemicals

- ** NO Current use in Steel Blast Furnaces

These are Best End Uses for Green H₂ !

•Appalachian Hydrogen Hub (West Virginia, Ohio, Pennsylvania): Up to \$925 million will be available in a region with access to abundant low-cost natural gas and carbon dioxide sequestration options.

•California Hydrogen Hub: Up to \$1.2 billion will be available to produce hydrogen from renewable sources or biomass.

•Gulf Coast Hydrogen Hub (Texas): Up to \$1.2 billion will be available for large-scale hydrogen production using both natural gas with carbon capture and renewables-powered electrolysis in a region with abundant renewable energy and natural gas.

•Heartland Hydrogen Hub (Minnesota, North Dakota, South Dakota): Up to \$925 million will be available to leverage the region's abundant energy resources to help decarbonize the agricultural sector's production of fertilizer, decrease the regional cost of clean hydrogen, and use clean hydrogen for power generation.

•Mid-Atlantic Hydrogen Hub (Pennsylvania, Delaware, New Jersey): **Up to \$750 million will be available to repurpose historic oil infrastructure and use existing rights-of-way to support development of hydrogen production facilities using renewable (new built) and Nuclear electricity.= MACH 2**











•Midwest Hydrogen Hub (Illinois, Indiana, Michigan): Up to \$1 billion will be available to produce hydrogen by leveraging the region's diverse and abundant energy sources, including renewable energy, natural gas, and low-cost nuclear energy.

The region aims to use hydrogen for steel and glass production, power generation, refining, heavy-duty transportation, and sustainable aviation fuel.

•Pacific Northwest Hydrogen Hub (Washington, Oregon, Montana): Up to \$1 billion will be available to produce clean hydrogen exclusively via electrolysis using the region's abundant renewable resources.

THE HYDROGEN RAINBOW

COLOURS OF HYDROGEN BY CARBON FOOTPRINT

| PRODUCTION METHOD | HYDROGEN COLOUR | TECHNOLOGY | POWER SOURCE | CO2 FOOTPRINT* | EQUIVALENCE** |
|--|-----------------|--|---|---|-----------------------------------|
|  ELECTRICITY | GREEN | Electrolysis - Huge Amts Energy NUCLEAR ELECTROLYSIS |  WIND, SOLAR, HYDRO, TIDAL, GEOTHERMAL | NO CO2 EMISSIONS | 0 GALLONS OF GASOLINE CONSUMED |
| | PINK | |  NUCLEAR | | |
| | YELLOW | |  MIXED-ORIGIN GRID ENERGY | | |
| Carbon Capture <i>GreatPotential</i>  FOSSIL FUEL | BLUE | NATURAL GAS REFORMING, CCUS ***GASIFICATION, CCUS |  NATURAL GAS, COAL | 2 – 4 KGS OF CO2 EMISSIONS PER 1KG OF HYDROGEN PRODUCED | 0.45 GALLONS OF GASOLINE CONSUMED |
| | TURQUOISE | PYROLYSIS |  NATURAL GAS | 3 – 8 KGS OF CO2 EMISSIONS PER 1KG OF HYDROGEN PRODUCED | 0.9 GALLONS OF GASOLINE CONSUMED |
| | GRAY | NATURAL GAS REFORMING |  NATURAL GAS | 9 – 12 KGS OF CO2 EMISSIONS PER 1KG OF HYDROGEN PRODUCED | 1.4 GALLONS OF GASOLINE CONSUMED |
| | BROWN | GASIFICATION |  BROWN COAL | 20 – 27 KGS OF CO2 EMISSIONS PER 1KG OF HYDROGEN PRODUCED | 3 GALLONS OF GASOLINE CONSUMED |
| | BLACK | |  BLACK COAL | | |

Gold = White = Found in "Nature"

*CO2 footprint is based on various scientific estimates as a general guide, but each category can be higher in some use-cases

**Equivalent in equivalence to gallons of gasoline consumed

***CCUS: Carbon capture, utilization, and storage

Potentially, hydrogen has many applications

* It can be used to:

-- Power vehicles (but then it consumes 3 X as much energy as an electric car with a battery),

* - Heat houses (but heat pumps are 600 % more efficient)

* Replace CH₄ in utilities

.....(But 50/ 50 blend = 24 %CO₂ reduction....need 93% H₂ to reduce CO₂ by 80.% !)

..- OR use it in energy-intensive industries (e.g. for steel or fertilizer production) – YES !

Impressive list of H2 Disadvantages:

** CO\$T: **Green H2** \$5--\$6 / kg; **Gray/Blk H2** = Less \$1./ kg;

--- Storage Requires lots of ENERGY !! = \$\$

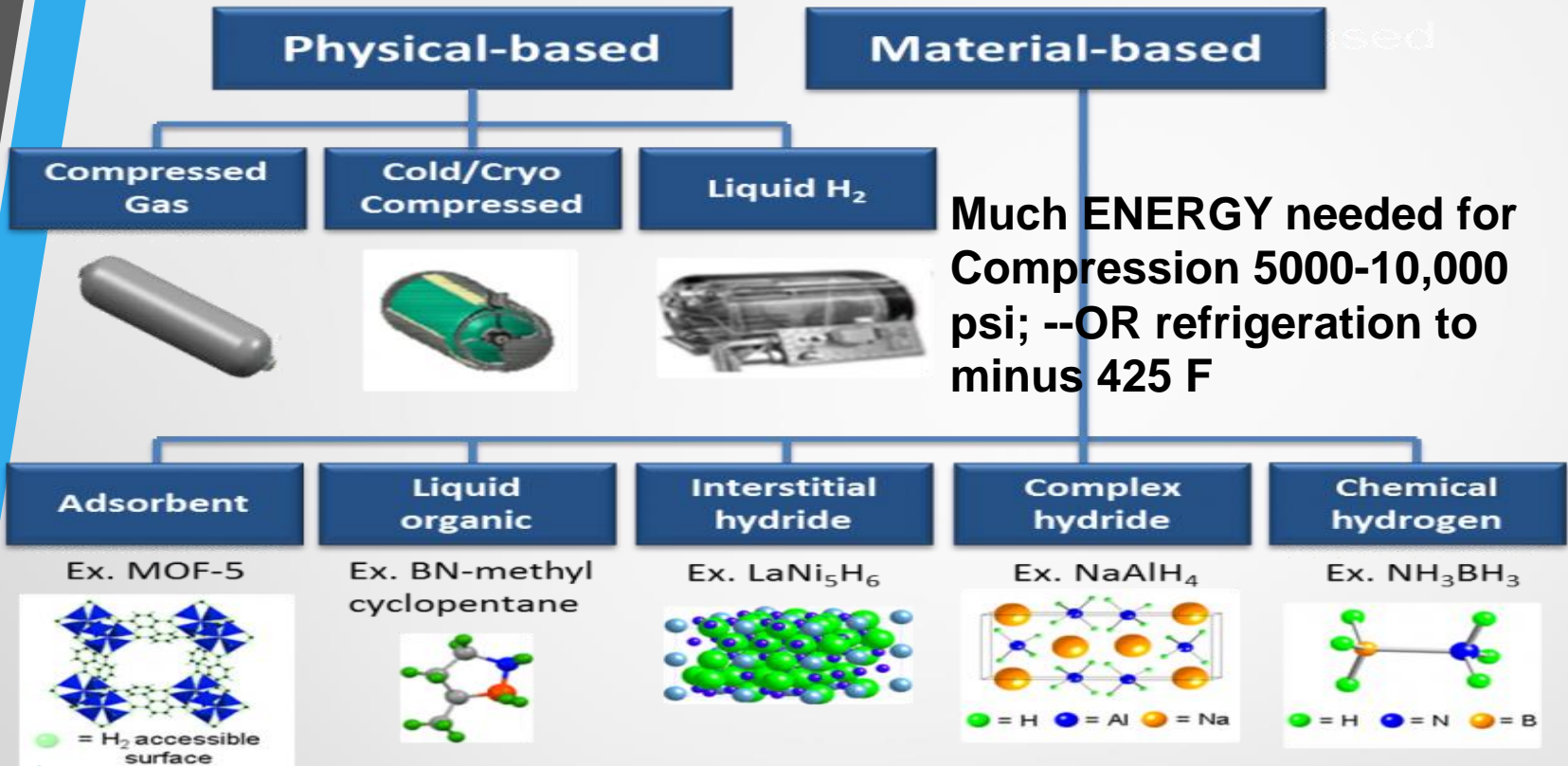
- Compression 5-10,000 psi; Or Refrigeration to Minus 425 F;
- H2 can embrittle metal; & Escapes through the tiniest leaks; Explosive



Global warming Potential ≥ 12 vs CO2 = 1; CH4 = 80 / 23

- Electrolyzers are \$\$ & use lots of Energy ; need uptime use!
- Reluctance to buy cheaper \$ Chinese Electrolyzers
- --Use 20 L Water = 1 kg Green H2 !!; Salt water technical barriers
- **Fundamental inefficiency of turning electricity into H₂, compressing it, storing it, moving it around and then converting it back into power in a vehicle.. = * 50% to 75% of the input power is wasted !!**

How is hydrogen stored?



* [Solid State Hydrogen Storage Technology | H2MOF...](#) Our technology enables high energy storage density at pressures as low as 20 bar, which is less than 3% of the pressure of the common 700-bar hydrogen tanks... ambient temps... \$\$\$; transport ??

• [Hydrogenious](#) \$80.9 million funding “.. H2 is chemically bound to the hardly flammable thermal oil benzyltoluene. “This can be stored and transported safely under ambient conditions, comparable to diesel,” Transport ? Cost ?

Green Hydrogen: A Multibillion-Dollar Energy Boondoggle ??

J. Lesser -fellow at the Manhattan Institute.

- * Hydrogen's "energy return on energy investment" (EROI); is less than one (0.5). .,.. Overall energy efficiency is dismal..
- Even under highly optimistic assumptions, the actual cost to produce green H₂ is highly unlikely to fall much below \$3/kg. (Table 2)
- Then Green H₂- When transported to End use- will cost \$\$ & Energy!..... BEST used where produced !

** EROI= energy to mfg vs output.

If Burn CH₄ = 30; Nuclear = 80; H₂= less than one



Goal= "zero GHG emissions"

H₂ is poor replacement for CH₄..

@ 50/50= only 24 % reduction ;... H₂ 93%= 80% reduction

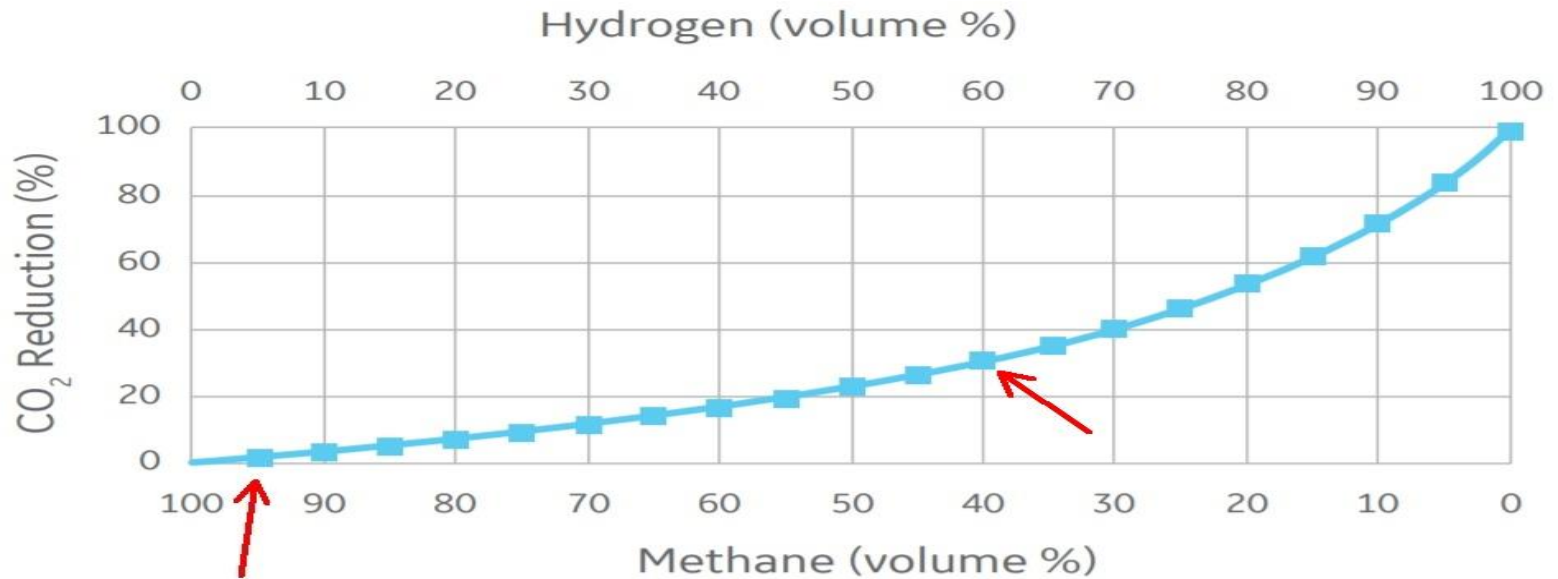


FIGURE 5: Relationship between CO₂ emissions and hydrogen/methane fuel blends (volume %)

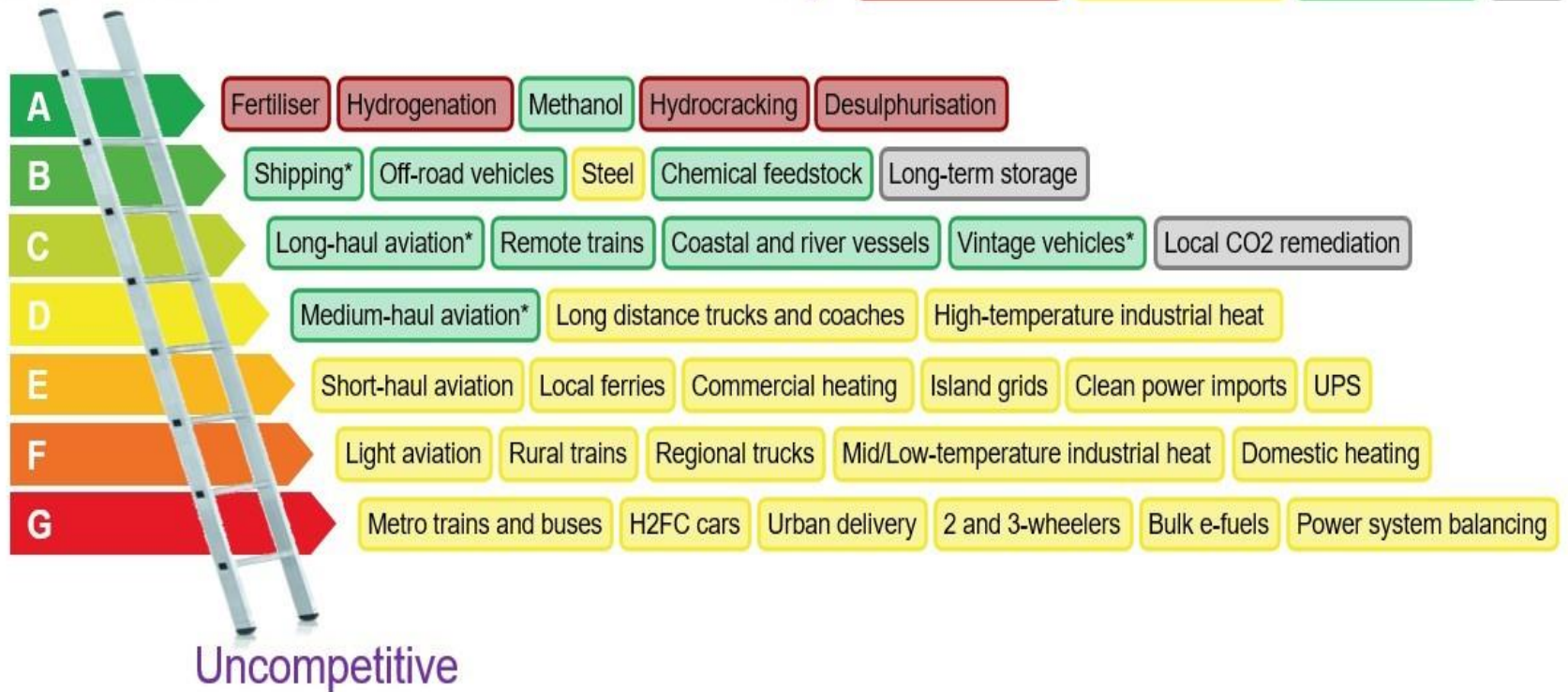
Existing fossil gas infrastructure such as pipelines and appliances are "mostly unusable" with hydrogen, without either major investment, or changes in operation that would significantly reduce the amount of energy delivered ..

.... *Energy Science and Engineering* journal, examined the risks and potential solutions

Clean Hydrogen Ladder: Competing technologies

Unavoidable

Key: No real alternative Electricity/batteries Biomass/biogas Other



* Via ammonia or e-fuel rather than H2 gas or liquid

Source: Liebreich Associates (concept credits: Adrian Hiel/Energy Cities & Paul Martin)

[\(62\) Annual Lecture 2024 - Michael Liebreich. Global Energy Transition Trends and Hydrogen – YouTube ... 90 min. Highly Recommend](#)

* BEST end Uses for Green H2 ?

= Current Gray end uses !

- **Refineries** : about 45 million of the 100 million tons H2 annual
- --Removing excess water from crude (hydrotreating) & Removing sulfur from crude (desulfurization...)
- *As peak oil demand drops & refineries have to pay much more for low-carbon hydrogen, the first crudes off the market will be the heaviest and most sour ones,... so hydrogen demand for refineries is going to plummet in the coming decades.*

- **Fertilizer: 50 % current use H2**
- About 150 million tons of ammonia almost entirely from CH4/ Coal
- A significant global warming problem: methane leaks & CO2
- **= 2 to 6 tons of CO2e/ ton of ammonia !**

- *** BLAST FURNACES: see next**
-
-

H2 Only 'Green' If GHGs are Minimal !!

- MUST : 3rd party reputable Verified LCA of upstream & mfg GHG emissions ..
- **Electrolyzers Need HUGE amt of New renewable Energy!
...Will compete with other uses of Ren Energy..**

Currently Only 21 % of electricity in USA is renewable

**States / Countries : "Sunny/ windy "
- have big Advantage !**

- **My Prediction:** *Electrolyzers will be replaced by cheaper*
 - *Pyrolysis of CH₄... 'turquoise H₂'*
 - *...With co-products paying !!*



- **EU countries are making deals with faraway countries to import hydrogen:**
- ... Namibia, Chile, Australia & the Middle East, those countries can produce a lot of cheap, renewable energy
- *‘ European leaders have NO idea how they’re going to get hydrogen from those locations into Europe. You can get cheap solar power and wind power in Namibia. ...*
-But liquid hydrogen is not going to be imported by ship”
- *It is simply not cost-effective.. In order to transport the amount of*
- *energy contained in ONE LNG carrier,*
...you would need five carriers filled with hydrogen.

• REF: <https://www.ftm.eu/articles/michael-liebreich-hydrogen-revolution?share=uti1BrcqWFYvPp2EvuAKOWZ%2FC8cZ%2BXzgv9ICwxiKpyUigAfkAMGZX8M92ypjQYU%3D>

Where is solar / wind cheap & plentiful ?

- NEOM Green Hydrogen Company (NGHC)--construction of the world's largest green hydrogen plant
- in Oxagon, Saudi Arabia.
 - **-Use H₂ there !; convert to NH₃; Methanol**
- A JV: ACWA Power, Air Products and NEOM, will produce up to 600 tonnes of carbon-free H₂/ day end of 2026.
- China's Sungrow - will provide its inverter skid technology & modular inverter solution for a 2.2 GW solar plant in Oxagon. NGHC's wind park will ultimately feature more than 250 wind turbines.

- **Another option is to convert hydrogen into ammonia and ship that**
- **At present, there are 50 ships carrying 20 million tons of NH₃ annually.**
- **... 'Twenty million is supposed to grow to nearly a billion tons of ammonia. And only 2 ships are being built currently.**
- ***"This is just delusional. Absolutely not going to happen."***
- ***But we are living in this amazing time that when you use the word hydrogen, your political stock index goes up, and everybody is happy because they think you've got a plan" ..M.Liebreich***
- **REF: <https://www.ftm.eu/articles/michael-liebreich-hydrogen-revolution?share=uti1BrcqWFYvPp2EvuAKOWZ%2FC8cZ%2BXzqv9ICwxiKpyUigAfkAMGZX8M92ypjQYU%3D>**

- *There is a simple economic reason why the sectors currently using grey hydrogen will not voluntarily switch to green hydrogen, even if there would be a sufficient supply:*
- green hydrogen is much more expensive than the fossil fuel variant.
- However, politicians prefer to discuss new applications, such as heating homes.
- Liebreich: *“44 scientific studies* concluding that a heat pump is much more energy efficient ...*than converting renewable energy into hydrogen, transporting it through gas pipelines that need to be modified, and eventually using it to heat homes....”*
- ***BUT: 'If you are a Nat Gas Industry & have a huge gas distribution network, the inevitable conclusion is that you will be out of business by net zero***
 - *REF: <https://www.ftm.eu/articles/michael-liebreich-hydrogen-revolution?share=uti1BrcqWFYvPp2EvuAKOWZ%2FC8cZ%2BXzqv9ICwxiKpyUigAfkAMGZX8M92ypjQYU%3D>*

*** What about using Nuclear power to run electrolyzers ?**

If sold out CO₂ Free electricity is Diverted from the nuclear site; ..

Then Electricity must be made up by utilities burning methane

This causes huge amounts of GHG including CH₄ leaks that far swamp any GHG savings from using green H₂ !

Dr. Arjun Makhijani, President of the Institute for Energy and Environmental Research (IEER), is an engineer specializing in nuclear fusion with studies on the nuclear fuel cycle

Three CRITICAL Pillars Clean H2- **Via Electrolyzers** :

- 1) *Electrolysis (LOTS of Energy !)* MUST be powered by clean electricity that is drawn from newly built carbon-free sources,
- 2) & Physically deliverable (same grid) to the electrolysis facility; RNGas OK.
- 3) ..& matched **hourly** (2028) with the electrolyzer's power consumption (*as opposed to a producer simply buying renewable energy certificates other grid, and calling it clean, as is the current default*) = **Heated debates!**
- **(DOES Not consider Turquoise H2) .**

REF: Jesse D. Jenkins is an assistant professor and macro-energy systems engineering and policy expert at Princeton University

- **BARRIERS OF HOURLY MATCHING: will be many lawsuits.**
- **A study from ACORE and E3 & Boston Consulting Group found that early hourly matching requirements would more than double the cost of green hydrogen.**
- To deliver consistent quantities of hydrogen under an hourly system will *require either battery energy storage to ensure the electrolyzer can be run consistently, or large-scale hydrogen storage (in underground salt caverns) so that electrolyzers can scale up and down with the availability of credits.*
- **RMI maintains that hourly matching could require up to twice the electrolyzer capacity and**
- **..potentially five times the amount of hydrogen storage capacity to produce the same amount of hydrogen and deliver it with the same consistency as an annually matched system.**

45 V Subsidies: GOVT cost Goal in 10 yrs = \$1. / kg vs \$6/kg..

2024

No Funding cap thru 2024 !- so many 'gold' miners !!

- Projects must begin construction by 2033
- Eligibility includes retrofit facilities
- Cannot stack with the Carbon Capture and Sequestration Tax Credit (45Q)
- Can stack with renewable energy production tax credit and zero-emission nuclear credit
- Projects are required to promote good-paying jobs by following prevailing wage standards and apprenticeship requirements to receive the full credit

•

NEED LCA DATA not "feelings" / Promises / loopholes

REF: [The Big Hydrogen Cash Grab - Union of Concerned Scientists \(ucsusa.org\)](https://www.ucsusa.org)

Carbon Intensity

(kg CO₂e per kg H₂)

Max Hydrogen Production Tax Credit

(\$/kg H₂)

4–2.5 highest CO₂ to get \$

\$0.60 (BLUE H₂ could meet 4 kg CO₂)

2.5–1.5

\$0.75

1.5–0.45

\$1.00

<0.45

\$3.00 PA HB 2227- definition

Accounting for upstream leaks of CH₄: BIG DEAL !

* Treasury's "well-to-gate" rules, hydrogen producers will need to account for "upstream" leakage that occurs before/ on the gas reaches their facilities... Use "45VH2 Greet model" to determine:

& Assumes an upstream methane leak rate of only 0.9 % !!

* **BUT..NEW DATA: 3/24...** US oil and gas system emissions from nearly Million aerial site measurements.. Nature (2024)...- **Emissions range from 0.75 to 9.63 %.**

The six-region weighted average is 2.95%; = 3X the Gov Greet Model

* **& NEW DATA: Drillers emit far more methane than US estimates, aerial survey shows..** 12. basins are emitting around 4 times more methane than federal regulators have estimated. .

REF: Environmental Defense Fund and partners including Google, BAE Systems; New Zealand Space Agency

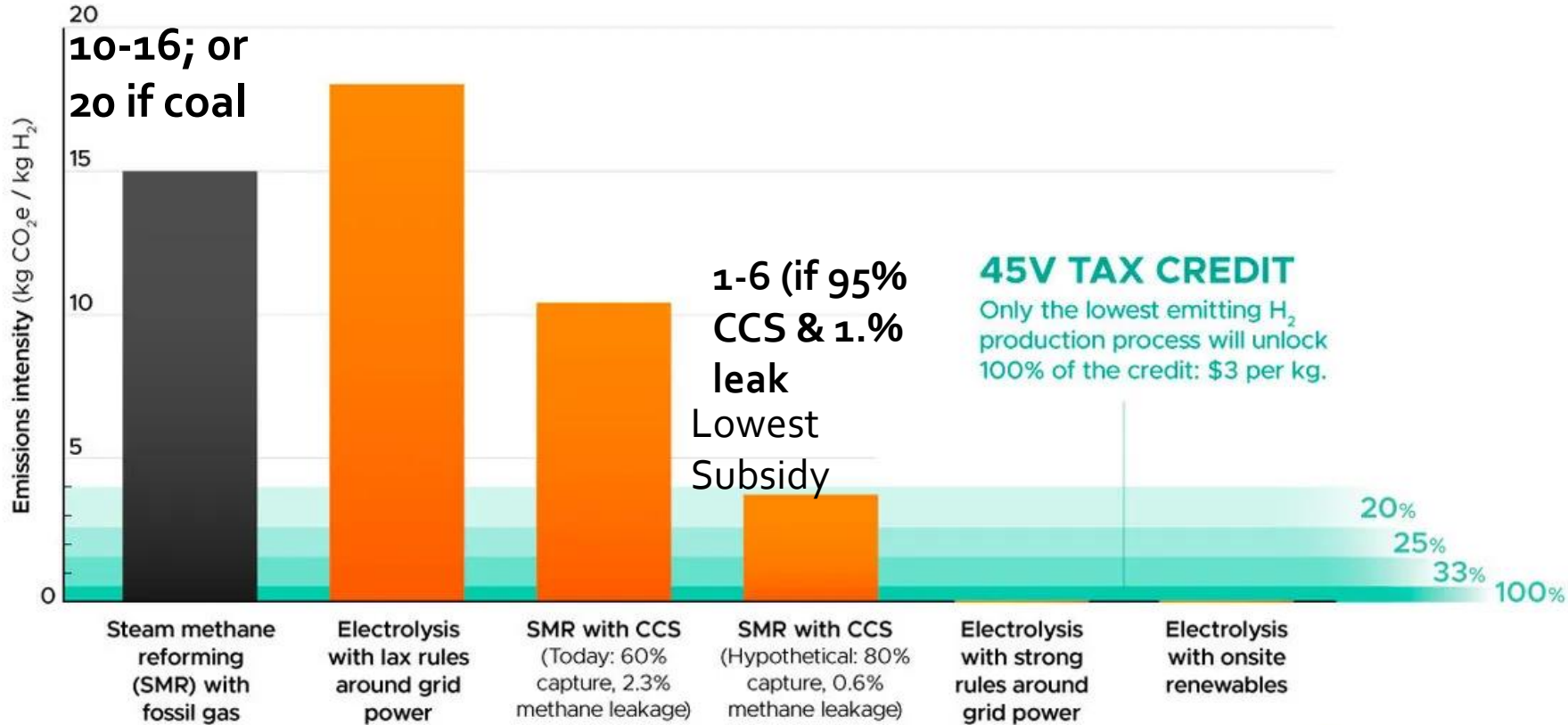
Let's Review "Blue H2" Footprint

- Since the 45V counts upstream emissions from natural gas based on the average in the US,... rather than a project-by-project basis, ...this would exclude any of these carbon-capture-based facilities from claiming even the lowest rung of the tax credit
- SO: Majors going BLUE..
- Air Products: \$4.5bn- Louisiana Clean Energy Complex, a 1,700 tonnes-a-day blue hydrogen and NH3 onstream in 2028.
- * Linde: Blue H2 to Dow's, Alberta; \$1.48 billion to build. The complex will capture more than 2 million metric tons of CO2/yr "Upon completion in 2028, will be the largest clean hydrogen production facility in Canada, and one of the largest globally,"
- Avoid \$\$ building massive amount of new renewables & \$\$ Electrolysis ! ...
- & will claim the 45Q tax credit (Inflation Reduction Act)..= \$85 of subsidies per tonne of CO2 captured and permanently stored, or \$60 if used in industry.
- NOTE: Much Lower GHG (60-70%) than H2 from Gray Steam reforming !!

Shorter bars are better !

Some ways of making “clean” hydrogen come with high emissions

CO₂ intensity of hydrogen production process compared to CO₂ thresholds to access 45V tax credit



Source: Data are representative values shared by climate think tank RMI.

[ogo. David Schlissel and Anika Juhn, IEEFA, Blue Hydrogen Not Clean Not Low Carbon.pdf \(energy.gov\)](#)

STEAM METHANE REFORMING OR---AUTOTHERMAL REFORMING

= 20 yr GWP; Carbon Intensity= at various CH4 leaks & carbon capture

| | If: CH4 1% leak ...2.5 %.....4 % | | | 1% 2.5 %....4% leak | | |
|--------------------|----------------------------------|------|------|---------------------|------|----|
| No Carbon capture: | 13.5 | 15.3 | 16.9 | 15 | 20 | 25 |
| 85% CC | 6.6 | 11.7 | 16.5 | 7.3 | 12.3 | 17 |
| 96.2% | 5.5 | 10.5 | 15.4 | 94.5%= 6.4 | 11.4 | 16 |

**** DOE subsidy at Carbon intensity of 4 kg / H2 = \$0.6**

BUT- this “BLUE” is 65-70.% better than Gray H2

..... Need “Verified LCA “ (1% leak Max; 95%min capture; & Ren Eng for CO2 capture)

= ‘LOW C’

EU legislation:

“ .. need to deliver GHGas emissions savings of 70 % vs fossil fuels. “

Equivalent to 3.4 kg CO₂ / kg of hydrogen in lifecycle

THUS: Blue H₂ has Env. Benefits !

| Carbon Intensity (kg CO ₂ e per kg H ₂) | Max Hydrogen Production Tax Credit (\$/kg H ₂) |
|---|---|
| 4–2.5 highest to get \$\$ | \$0.60 (EU legislation would meet) |
| 2.5–1.5 | \$0.75 |
| 1.5–0.45 | \$1.00 |
| <0.45 | \$3.00 ..PA HB 2227- definition |

- *How green is blue hydrogen?

Robert W. Howarth and Mark Z. Jacobson

- “ Greenhouse gas emissions from the production of blue hydrogen are quite high, particularly due to the release of fugitive methane thru lifecycle and carbon capture energy.”

- **Default assumptions : (3.5% leak rate of methane from natural gas and GWP= 86 ; & 85% Carbon capture**

- *= only 10% less than for GRAY H2 Emissions from (STEAM Reforming CH4).. Burning Blue H2 makes no sense*

- *WCH: DOE/ EPA should allow 3rd party LCA for other H2 routes !*

*** US pledges up to \$1B for two pioneering 'green steel' projects**

Steelmakers Cleveland-Cliffs and SSAB: could get up to \$500.M each to build novel facilities that can make iron for steelmaking using hydrogen.

*** Cleveland-Cliffs Inc:**

**Successful completion of first hydrogen (H₂) injection trial at its Indiana Harbor #7 blast furnace (largest in North America) ..
--& Successful trial at Middletown Works in May 2023;**

*** Australia to meet strong demand from China for green iron:**

Fortescue readies a pilot plant to begin using renewable energy next year. The world's fourth-largest iron ore miner will use green electricity from solar farms in Western Australia to produce 1,500 tons per year of high purity green iron.

How much clean energy Needed “green” H₂?

- ***Fully running Cleveland-Cliff’s plant with clean H₂ = Need 2X the amount of wind and solar power now installed in Ohio.***
- To run the Ohio steel plant exclusively on Gr-H₂, would need approx. 160 kilotons of H₂ annually. Require 8.3 terawatt-hours of renewable power per year..(RMI)
- This could potentially be produced with 1.5 gigawatts of NEW wind capacity and 2 GW of NEW solar capacity vs current- 3.5 GW in total installed renewable capacity as 2/2024
- ***-Mississippi mfg site-the equivalent of a 5 X increase in renewables just for SSAB’s plant. That’s on top of the additional capacity that will be needed to meet other rising electricity demand***
- ***This Will be Very Hard to do !! Many other end uses !!!-***
- ***Thus: Opportunity for “ Verified” BLUE H₂ supply chain ??***
-

**** Better to FUND New tech vs Green H2 ??**

**** Boston Metal: New electrolysis process that eliminates the need for coal or H2 in steel production – 100 % renewable electricity; NO CO2**

This direct approach eliminates several steps in the steelmaking process and does not require coke production, iron ore sintering and pelletizing, blast furnace reduction or basic oxygen furnace refinement.

*** first facility : its Molten Oxide Electrolysis (MOE) technology platform to recover high-value metals from mining waste in Brazil**

- a major milestone for Boston Metal's technology and operations as it works toward commercializing MOE for green steel in 2026.

*** U.S. DOE: 13 projects in nine states to receive a total of \$28 million through (ARPA-E). .. to spur solutions that can eliminate CO2 emissions from the ironmaking process**

*** Electra: Colorado, is developing electrochemical devices similar to batteries that can turn iron ore into iron at about the same temperature as a fresh cup of coffee; claims it can slash emissions from ironmaking by 80 % and at half the cost of existing traditional processes.**

***Limelight Steel, uses laser technology to make molten iron. The Oakland, California; could reduce energy consumption by nearly half and curb emissions by 80%. Limelight and Electra are each set to receive \$2.9 million for their projects.**

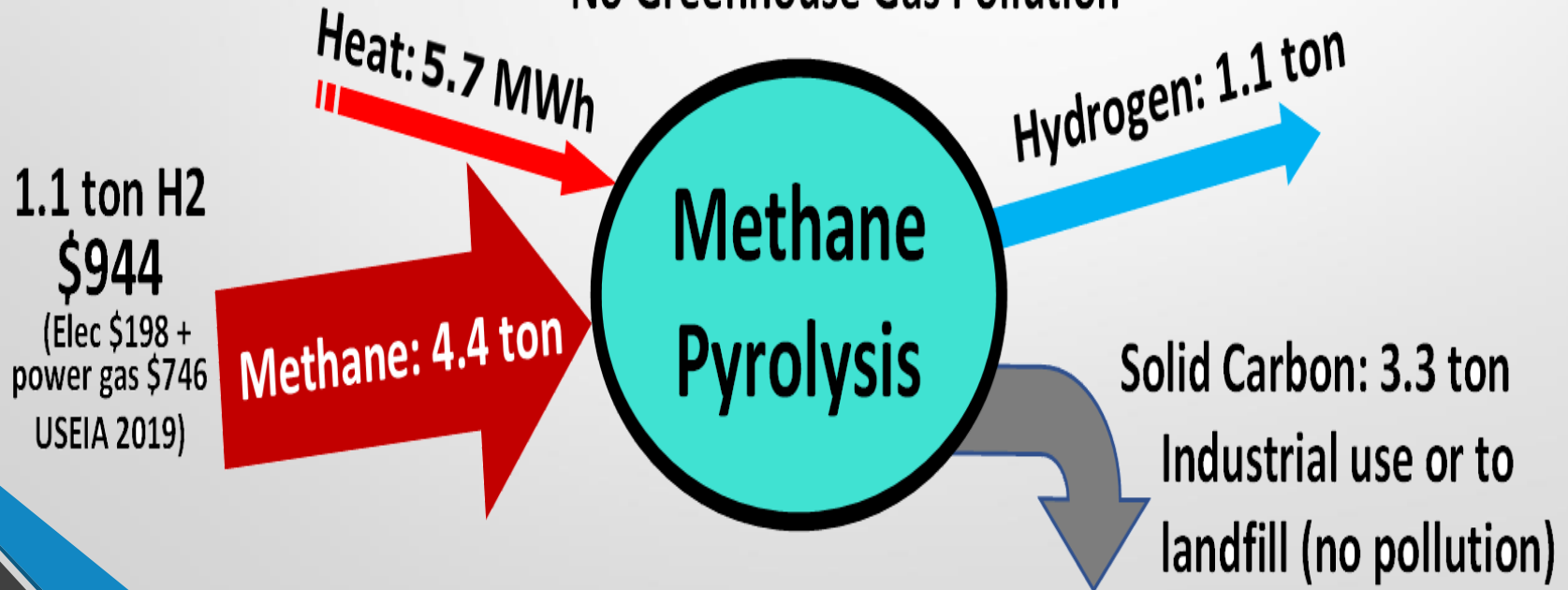
Argonne National Laboratory for a \$3 million award to further develop its zero-emission ironmaking process, which involves using hydrogen plasma (TurQ) in a "microwave-powered rotary kiln" reactor.

“Turquoise H2 ” = “Minimal” CO2 emissions...

** Target the production of high value forms of co-product carbon ; eg: \$\$ Carbon nanotubes; graphite, graphene; -
--OR...treat Carbon by product as sequestered

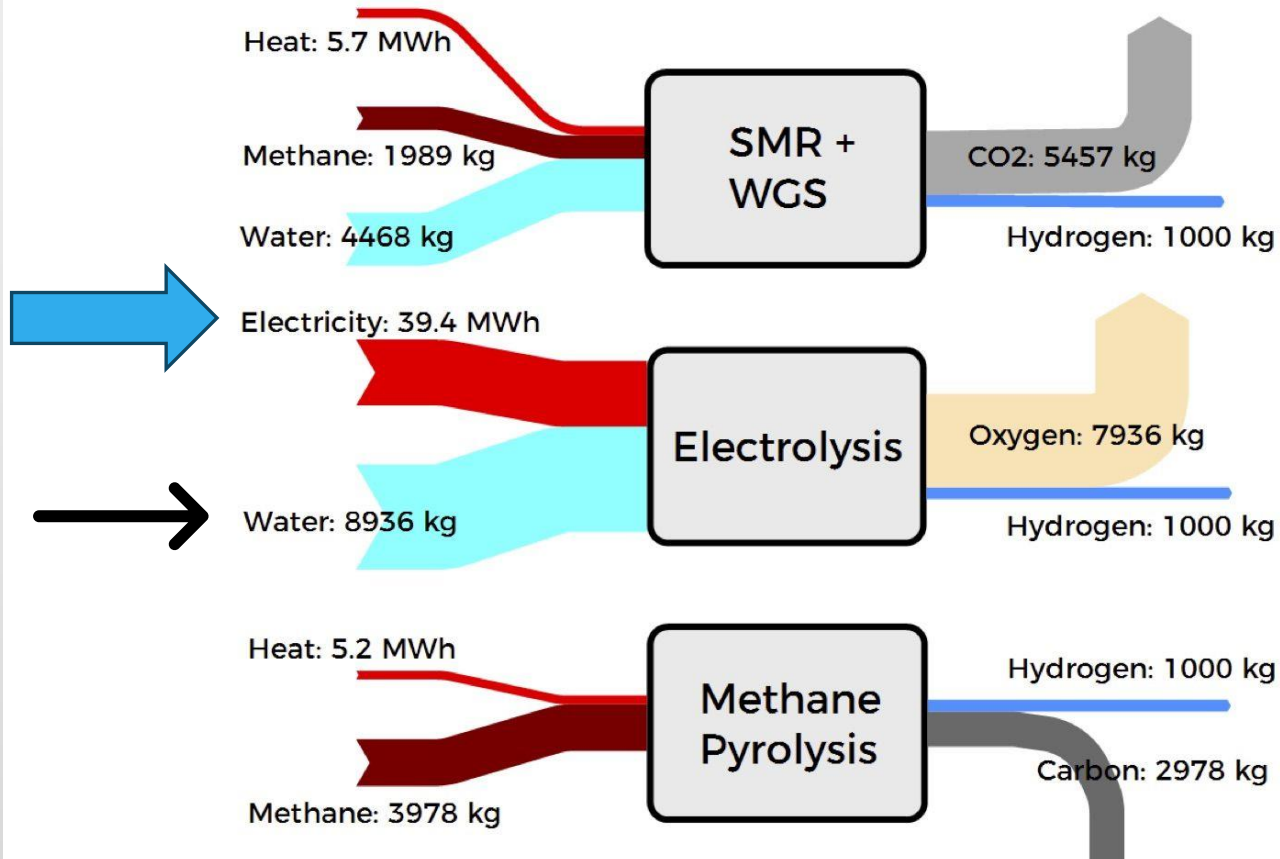
40 START UPS: Various Evolving technologies !

Newer Hydrogen Production Method
No Greenhouse Gas Pollution



HYDROGEN PRODUCTION PATHWAYS

(at 100% efficiency)



Note 2X CH₄ vs SMR; No CO₂;.. Plus Hi Value Carbon

Technology Great Potential BUT: Many scale up experiments; diff catalysts; temps; reactor designs.. ISSUE of crude on walls;

Various Turquoise Tech

- **Rimere** : ...Uses **sequential hybrid plasma** technology to deconstruct methane (CH₄) at a molecular level; then recombine
- *First excite (electric, etc) the methane to an ionized state, and then use high voltage and high frequency arcs to crack the ionized gas under an induced electromagnetic field....*
- **Aurora's**: **Microwave technology** heats natural gas to produce H₂ & solid carbon.Electrolysis requires 80% more energy to break down a water molecule. On top of *that efficiency, Aurora's technology is designed to produce hydrogen at the point of use.*
- **Hycamite**: **2024** hydrogen & carbon plant has begun operation in Finland ...However, the plant will focus its efforts on supplying customers solid carbon ahead of an expansion of its business into the US.

• Monolith & Goodyear Tire & Rubber:

- Partner on the [use of carbon black byproduct](#) from its Olive Creek facility in Hallam, Nebraska. ..
 - will produce 194,000 tons of carbon black annually, **alongside its Major product: 275,000 tons of clean ammonia (via pyrolysis)**
- **Conventional carbon blk: produced by burning used oil or coal tar, releasing large amounts of GH Gases !**
- [\\$1.04 billion, Title XVII loan](#) : **Monolith's expansion plans for Olive Creek, which will become the largest producer of carbon black in the US by 2025. ..big reduction CO2 !!**

MOLTON:

2024 raised \$25m in Series A funding,
...\$\$ by Breakthrough Energy Ventures (Gates; Bezos; Ma ;
etc) —

“While clean methods of hydrogen production exist ; like water electrolysis — they rely on large amounts of renewable wind and solar energy.”

*Our solution uses five times LESS energy than electrolysis
and can use existing natural gas networks to produce clean
hydrogen where it is consumed*

**Electrolysis is Doomed !!*

MOLTON INDUSTRIES: Use H₂ in Blast Furnace !!

7/ 24, DOE awarded a \$5.4 Mil. grant for the construction of a pilot clean-steel project that
....will integrate zero-carbon **turquoise hydrogen production with a direct-reduced iron furnace**

US Steel will provide the iron ore that will be reduced & produce clean steel in an electric arc furnace, with California-based start-up Molten Industries methane-pyrolysis technology

The process emits No greenhouse gases (except for upstream methane emissions outside Molten's control).

White= Gold H₂= “Natural”

BUT \$ Must: Find/ Clean up/ Compress/ transport

- **U.S. Geological**: “a small fraction of reservoirs (water & “Iron rocks”) Could provide enough H₂ for hundreds of years”
- **Natural Hydrogen Energy LLC**, America’s **first** exploratory well, in Nebraska,
- ..“We think we’ve uncovered one of the largest deposits of natural H₂ anywhere in the world.”.. **France’s National Center for Scientific Research**,
- Australia, **Gold Hydrogen**, natural H₂ near Adelaide ; “historical papers from two oil wells drilled in the 1930s showed vast amounts of high-purity H₂”
- **Koloma**, Colorado – looking H₂ in a geological rift in the Midwest.**raised \$245 million round of BEVentures funding to develop tools and technologies**

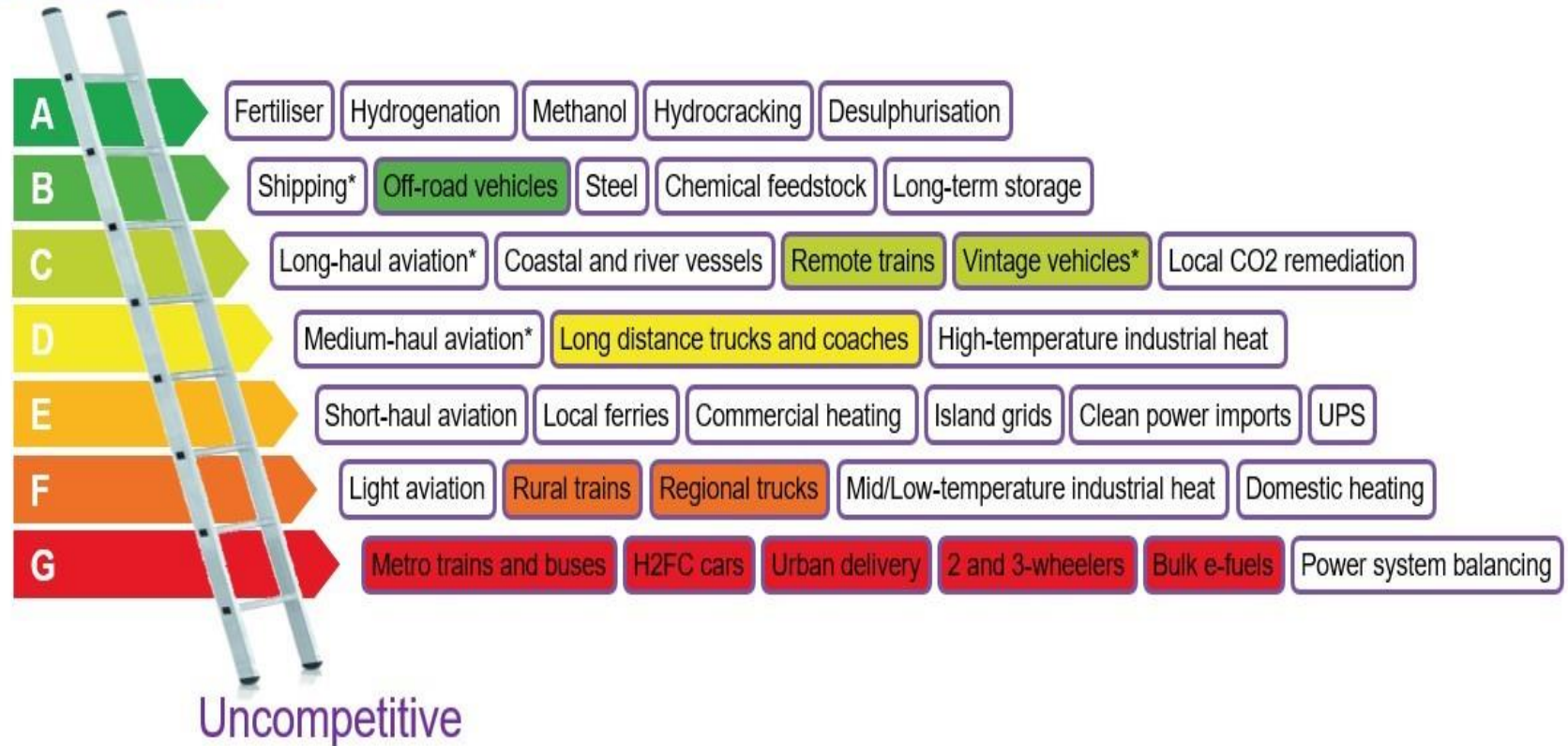
White= Gold H₂= “Natural”

Must: Clean up; Compress; transport \$\$

- [Helios Aragon](#), Spain has permits spanning more than 200,000 acres...
- [Max Power Mining](#) has permits to search 1,244.sq km in the **Canadian Saskatchewan** for naturally occurring, underground H₂...Data from 45 wells, seven sites showed H₂ concentrations of more than 10%,
- [UK-based Bluejay Mining](#) a “low cost and wide-ranging” programme to evaluate what it believes could be a large deposit of natural H₂,..in the **Finnish region** ...evidence of “high concentrations” of natural hydrogen (46%)
- **BUT: “ to produce liquid hydrogen, you need to produce 10,000 tons per year... If you want to be producing ammonia, you're probably about of like 50,000 tons per year,”** At good cost - Capture/ clean/ compress/ transport..
- **“ Need to prove out reserves that would allow you to produce those kinds of volumes of H₂ over a 20-30-year lifetime, that is like the watershed moment of a commercially relevant, large reservoir discovery.”**

Clean Hydrogen Ladder: Land transportation

Unavoidable



* Via ammonia or e-fuel rather than H2 gas or liquid

Source: Liebreich Associates (concept credit: Adrian Hiel/Energy Cities)

* Regional trucks: Batteries Win !

* 85% of Trucks do less than 500.km per day. That distance lends itself perfectly well to battery-electric vehicles.

... by the time you've taken out the internal combustion drive train, a 40-tonne battery truck will weigh barely more.

* Long-distance trucks are a MAYBE.. But Co\$t

* You could build a Hydrogen Infrastructure just for the 15% of trucks that do very long, but equally you could just invest in a bunch of high-capacity charging.

-Since that all local trucks are going to be BEVs, along with anything doing up to 500km/ day, the infrastructure for electric long distance trucks will be in place

Long-distance coaches will go the same way as trucks..

* Off-road vehicles: H2 an attractive option here !

EG: graders used in mining and road works: Cranes and construction machinery, Forestry vehicles:

-- operate in environments where there are generally not great grid connections--

Trucks: Electric vs H2 Fuel Cells ?

- **Big electric-truck charging depots are coming to California..** \$75.6 million in federal grants, startup WattEV will build three megawatt-scale charging stations aimed at extending the range of heavy-duty EV trucks
- *New Toshiba batteries can help charge electric buses 0-80% in 10 minutes:...Toshiba's cells have been previously tested in various EV cars but these new cells can be useful for electric buses, heavy vehicles.*
-
- **3/2024, the Biden admin. its National Zero-Emission Freight Corridor Strategy. -- will coordinate and accelerate billions in cross-sector investments to build the charging infrastructure needed...**
- **First EV charging stations of scale for freight trucks is opening near the major ports of Los Angeles and Long Beach, California..= 25% of all ocean cargo in USA**
 - Sweden-based freight mobility Einride and EV charging infrastructure company Voltera, the Lynwood Smartcharger Station along Interstate 710 has 65 chargers and the ability to charge 200 vehicles a day, initially for routes run by global shipping giant A.P. Moller-Maersk.

Trucks: Electric or H2 Fuel Cells ?

- The first Electric trucks from Volvo with fossil-free steel are now being delivered to customers. Heavy-duty electric, 44 tonne trucks
- Alex Vlaskamp, CEO of German heavy truck maker MAN Truck & Bus, “ it was, impossible for hydrogen to effectively compete with battery electric trucks”
- **Electric Fire trucks & small diesel Generator: trials in Canada; EU; LA; Minnesota;**



- NEW: hydrogeninsight.com/transport/green-hydrogen-powered-trucks-will-require-four-times-as-much-renewable-energy-as-battery-equivalents-study/2-1-1701721

Volvo's FH Electric truck, with its double trailer and load, the heaviest battery-powered electric road vehicle.

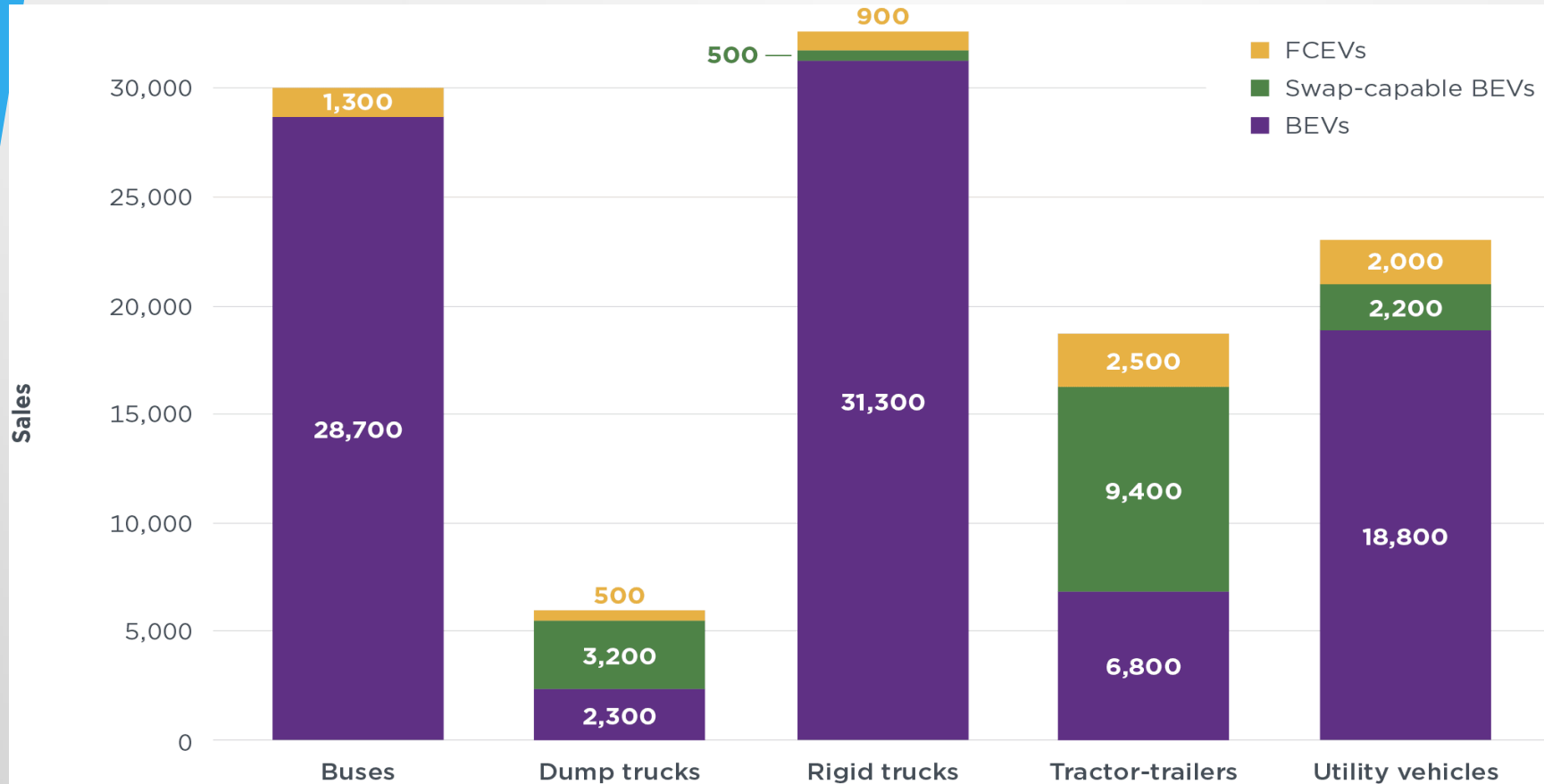
One currently being tested in Gothenburg, Sweden, features [a 74 tonne, 13m-long \(43ft\) version of this truck](#) and trailer system.

"They are running in commercial traffic every day," says Niklas Andersson, director of electric solutions at Volvo Trucks.



RACE TO ZERO: ZERO-EMISSION BUS AND TRUCK MARKET IN CHINA IN 2023

8/21,/2024 | By: Lingzhi Jin and Shiyue Mao



Sodium batteries are a new technology that could prove cheaper and safer than today's lithium-ion cells ... they use widely available sodium instead of lithium, which is expensive to produce and extremely volatile in price. They also skip other troublesome metals like cobalt and rare earths..

Railroads:

- The world is putting up overhead catenary lines above railroad tracks that don't already have them...
- They are adding battery cars to get past bridges and tunnels where the expensive of adding wires is too high.....
- ENGLAND: **Great Western Railway's (GWR's) fast charge battery train trial broke records for UK distance without recharging;**
- **-of 86 miles travel on battery power (still 40%) without recharging. That meant the battery train operated in a real-world environment at speeds of up to 60 mph, stopping and starting over a hilly route, with elevation changes of up to 200 meters.**
- Only North America is resisting this, and North American railroads are pushing themselves into an uncompetitive corner
 - **Four million rail cars a year of coal are going away !**
 - **Seventy thousand cars of oil a year are going away !**
 - **Road freight will electrify and reduce labor costs with more autonomous highway trucking**

Hydrogen demand through 2100 by Michael Barnard,
Chief Strategist, TFIE Strategy Inc

- Tesla's "Giga Train,": first all-electric battery-powered train, in Germany. the station at the company's facility, about 20 miles. Currently, 500 people can be transported on the train, with 120 seats, space for bicycles. Eventually to transport 4,500 employees to and from the factory..
- *The Swiss H2 train FLIRT-H2. only 2 cars with one Fuel cell :*
- RECORD Run: traveled 1,741 miles; over 46 hours, all on a single fuel tank. **However, it is unlikely to be replicated in real-life scenarios since the train did not stop and start multiple times during the record attempt, nor did it travel on different inclines.Nor refuel- how ??\$\$\$\$\$**



- ****Long distance maritime shipping:**
- - YES ! Green H2: BUT in the form of synthetic ammonia or methanol... Gr H2 mfg/ used on site
- ...Higher capital costs, higher operating costs and in the case of ammonia, higher safety engineering...
- **--Means the maritime industry is mostly going to buy biofuels..... Not burn Green H2 !**
- the ships in question are dual & tri-energy ships : methanol or ammonia, diesel and batteries
-

- **2021, Maersk ordered the world's first "Green" methanol-enabled container vessel following their**
- ***--- commitment of only ordering newbuilt vessels that can sail on green fuels.***
- * **Maersk now has 25 methanol-enabled vessels on order**
- **Just two years later, the global orderbook stands at more than 100 methanol-enabled vessels**

* <https://volticshipping.com/> startup reducing GHGs in the shipping industry by retrofitting diesel ships to be electric.. making a boat that is both greener and cheaper. We've closed our first customer, who will pay us to ship containers for them. We've received funding from Y Combinator and the Department of Energy, and are supported by professors from MIT's Ocean Engineering Department.

OVERHYPE: Co\$t of fuel & where Fill up?

the [Toyota Mirai](#), a high-power fuel cell backed with a battery storing energy.....and the vehicle travels up to 402 miles per hydrogen fill-up...

* Shell closes 6 of 7 Calif H₂ light duty fueling stations.
Barely used/ high maintenance / aiming for Hvy trucks



Ferries

*** Washington State Ferries, the largest U.S. ferry system by ridership**

Retrofitting the first of three diesel ferries with hybrid-electric systems..online in 2027

- **In San Francisco;**
- ... launching battery-powered vessels,
- as well as **America's first hydrogen-powered ferry.**

**** America's first fully electric, ship-assist 82 ft-harbor tugboat .**

-The eWolf Tug utilizes ABB's integrated [electrical propulsion](#) system and Schottel's RudderPropellers type SRP 430 with the LE-Drive,

- uses a 6.2 (MWh) battery; has two electric motors. When docked eWolf will plug into the charging station, which is also a microgrid. The facility, which includes two 1.5 MWh batteries covered by solar panels, is also connected to [San Diego Gas & Electric](#)'s power grid.



Industrial heat : emits 30. % % of the global emissions

* Many people seem to think that high-temperature industrial heat has to be delivered by gas. That is simply not true, there are lots of ways of delivering high-temperature heat electrically economically

* Will be site by site needs cost vs customer demand low C

REF: 1.“Heat Pumps: Decarbonizing the Process Industries..2/1, 2024 Jörg Freckmann, *As the chemical process industries push to decarbonize their businesses, ..*

Ref: 2. that electrification is an accessible and viable option within certain conditions.. Electrification can be undertaken today for many low- and medium-temperature heat processes (up to 600°C), but technologies for high- and very-high-temperature heat needs (above 600°C) still need to mature.

[The feasibility of net-zero electrical heat | McKinsey](#)

Glass Mfg or Recycling is Extremely energy intensive...

- Most burn natural gas heat to 1,500C. ..Glass furnaces are never turned off..
- Europe's first hybrid furnace: .. world's most advanced hybrid glass furnace is undergoing trials, at Ardagh Glass Packaging (AGP). Germany
- ..large furnace with a capacity of 350 tonnes - enough to make about a million beer bottles a day...
- **When fully operational it will run on 80% sustainable electricity and 20% gas, which AGP says will save 45,000 tonnes of CO2 per year.**

Class 2:

- **Libbey Glass:** The Flexible Fuel Electric Hybrid Glass Furnace Demonstration project..
- .. replace four regenerative furnaces with two larger hybrid electric furnaces to reduce an 60% of CO₂ emissions
- **Gallo Glass Co:** ..to install a hybrid electric furnace that will reduce natural gas use by 70%
- **O-I Glass:** to rebuild four furnaces across three facilities in California, Ohio and Virginia to reduce CO₂ emissions by an estimated 48,000 tons/ yr
- **The rebuilds combine five furnace technologies on each furnace, marking the first time that all five technologies have been implemented simultaneously**

Chemicals?

-- Virtually all heat in chemical plants can be electric, it's only economics that drives it to fossil fuels, and electricity will always be cheaper and more efficient than hydrogen

REF: "DOE clean energy Demos" -- 34 exp of DeCarbonization...note..Gr- H2
only 2 demos in green steel

[REF: -Public-Private Partnerships Spur Decarbonization Efforts - Chemical Engineering | Page 3 \(chemengonline.com\)..](#)

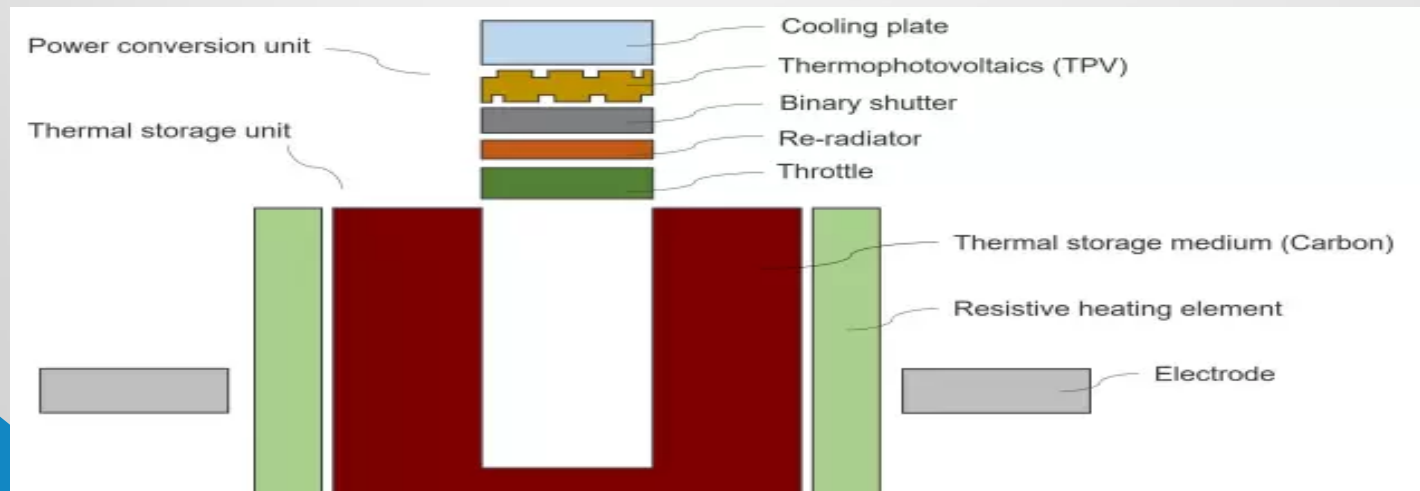
Long Term Energy Storage: many Techniques-
Cheaper; better than Green H2

.. Recent innovations in thermal storage, compressed air energy storage (CAES), and flow batteries have improved efficiency, scalability, and cost-effectiveness

****SHOULD be Charged by Wind/ solar/ geothermal/ nuclear***

HEAT STORAGE: ANTORA

1. When cheap renewable electricity is available, Antora's thermal battery uses it to resistively heat carbon blocks to glowing-hot temperatures in an insulated module.
2. The stored heat (1800. C) is reliably delivered at the scale and temperatures that large industrial operations demand. "Hard to decarbonize end uses !
3. Using Antora's thermophotovoltaic (TPV) technology, which converts the stored heat directly into electricity with NO moving parts, the system can also deliver on-demand electricity to industrial customers
 - Black Rock & The Nature Conservancy and a subsidiary of NextEra Energy Resources participated in this funding // \$150.m million



RONDO: Very Hi heat Storage

- Heat Battery uses electroheating elements to turn power into high-temperature heat... convert electrical energy into heat 1500. C at 100% efficiency, Thousands of tons of brick are heated directly by this thermal radiation, store energy for days less than 1% per day. Lowest-cost energy storage
- **Partnering with Portugal energy EDP, Rondo will power up to 2 GW of heat battery installations across Europe**
- **Alcoholic drinks giant Diageo will replace natural gas-fired heat with Rondo Energy's Heat Batteries at its production sites in Kentucky and Illinois.....Saving 17,000 m-tons CO2...**
- **Others: Covestro AG; Germany;.. Calectra; Calif; Brenmiller Energy..Israel. which use crushed rock as an energy-storage medium,**



The Rondo Heat Battery
Rondo Energy makes decarbonization profitable for the most challenging sectors.



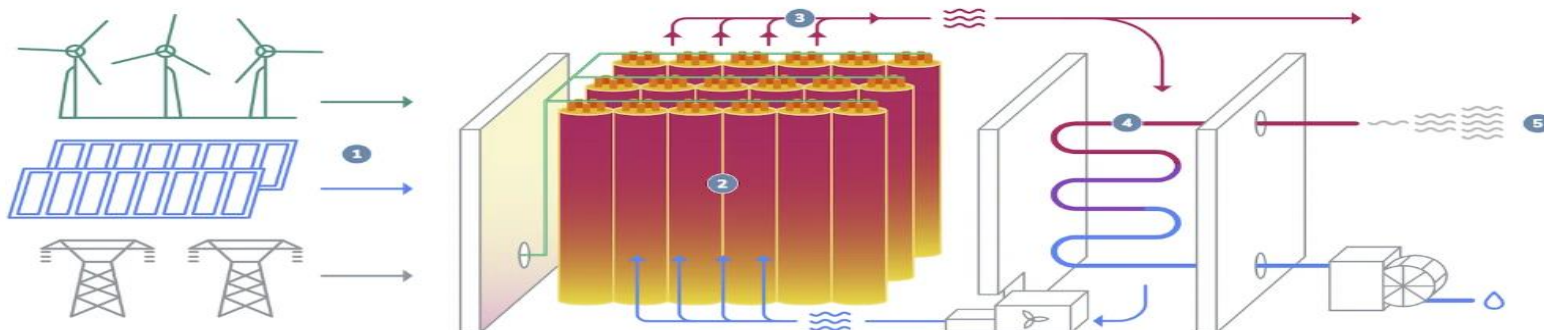
Seamless Integration



Proven Materials



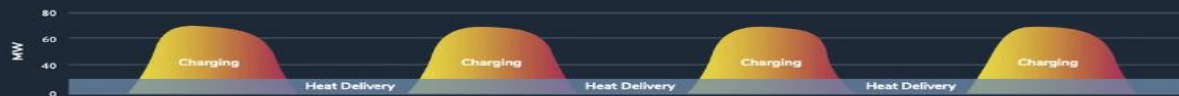
Modular & Scalable



- 1 Low-cost, intermittent electricity powers electric heaters.
- 2 Electric heaters store thermal energy in bricks at temperatures up to 2,100°F.
- 3 Air is heated by passing through the bricks.

- 4 Air can be used to generate steam through a boiler package.
- 5 Air and/or steam is delivered to any industrial process.

Energy Storage: 24/7/365
Emissions: Zero-emissions drop-in boiler replacement
Cost: Lower cost than natural gas, or other zero-carbon pathways.

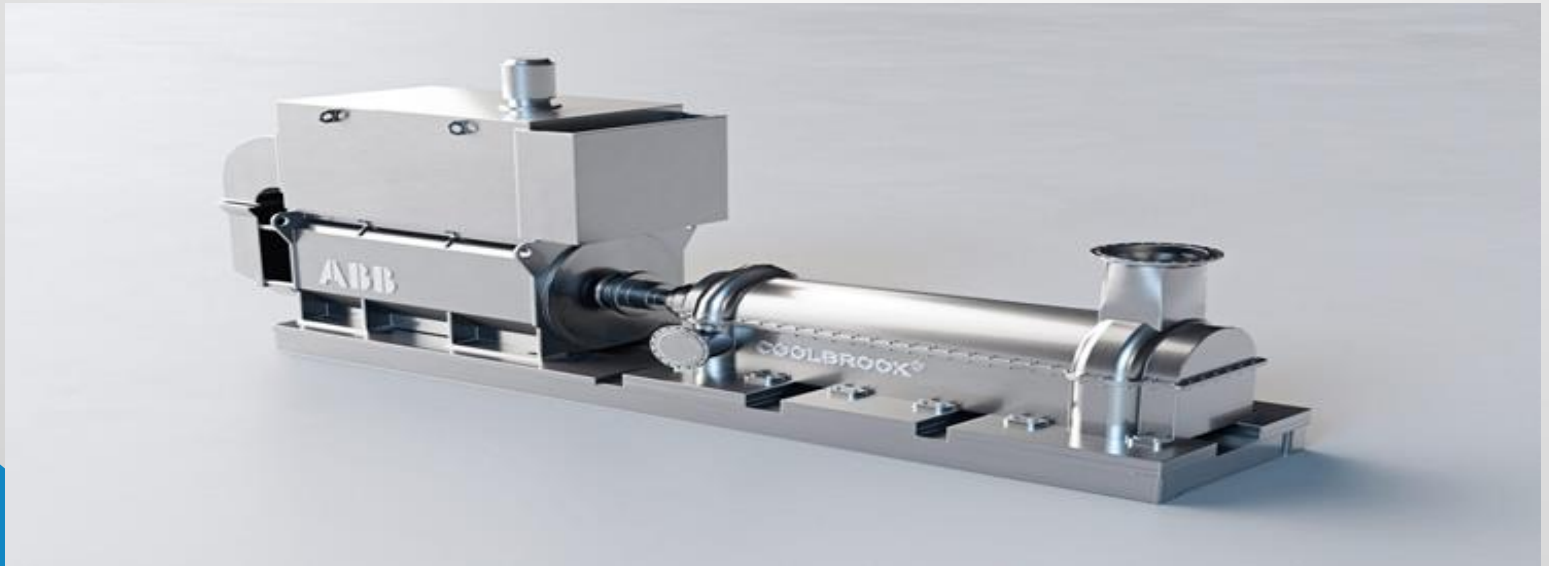


WATER PRESSURE= Energy !

- 2028 at a cost of (\$217m) Varanto (Finland) will be built in caverns together measuring 1.1 million cubic metres –
- -enough to fit the Empire State Bldg... These caverns, 300. ft underground, will be filled with hot water.
- Pressure will be created within the space, allowing the water to reach temperatures of up to 140 C without boiling or evaporating.....
- At 90. GWh, it can pack in as much power as a typical 1GW nuclear plant generates in nearly four days. Or around 1.3 million electric car batteries.
- -----
- SAGE: “EarthStore” facility, Texas will store up to 3 megawatts of excess renewable energy via pressurized water deep underground.
- ...The storage system will target six- to 10-hour durations, and Sage will essentially act as an ERCOT energy trader.
- the project will deliver a roundtrip efficiency of between 70% and 75%

New tech to make very Hi heat

- Coolbrook- RotoDynamic Heater™
- the world's only electric technology capable of using clean electrification to reach the extremely high temperature heat needed industrial processes, to heat up to 1700 °C.
- In 2023, the successfully completed first test phase demonstrated RDH technology's capabilities for industrial use in high-temperature process heating. The pilot testing has reached the level of 1000 °C.
- To deploy industrial scale projects at customer sites, in 2024, while full commercial deployment is expected to start around 2025.
- partnering with **ABB & LINDE ENG; SHELL; SABIC !**



*** Huge Utility project to supply Los Angeles : First peaker plants then 100 % H2 : Makes NO Sense !!!**

*** The 300-GWh Advanced Clean Energy Storage Hub (ACES Delta), in Delta, Utah (large cavern)..- in 2025. ...**

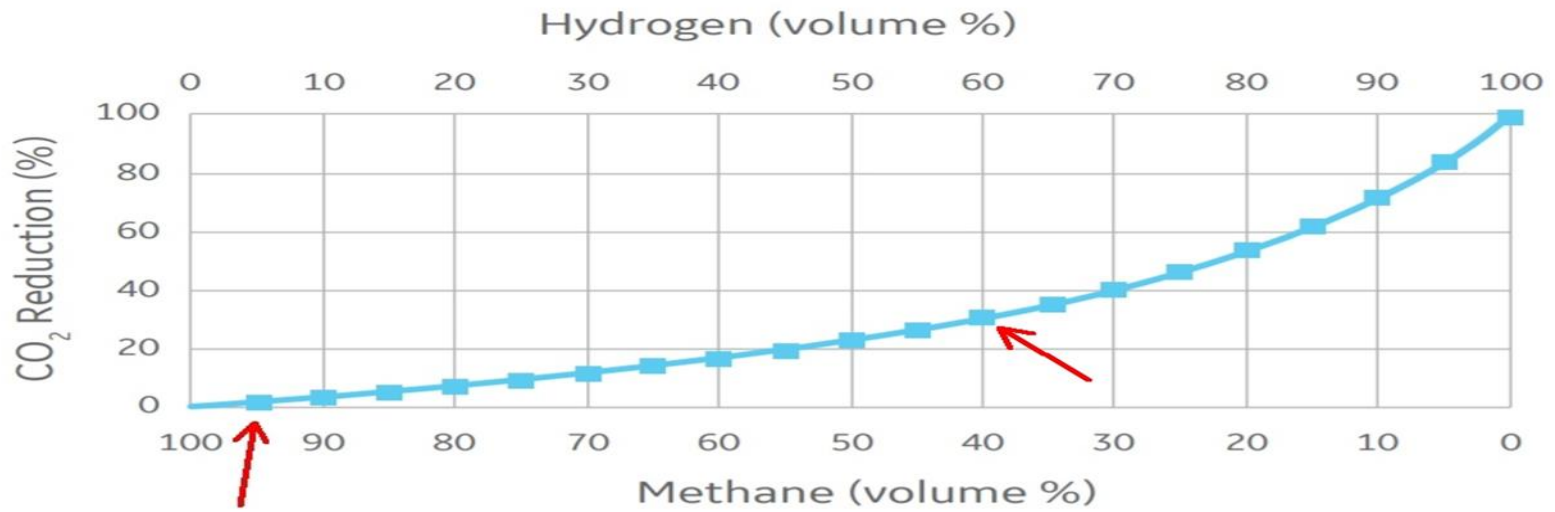


FIGURE 5: Relationship between CO₂ emissions and hydrogen/methane fuel blends (volume %)

H₂ is poor replacement for CH₄..

@ 50/50= only 24 % reduction ;... H₂ 93%= 80% reduction

QUESTIONS ?

- 'We are not sure green hydrogen cost will fall to €5/kg any time soon': senior German government official
- Green-hydrogen-powered trucks will require four times as much renewable energy as battery equivalents: study

*** US producers of clean H₂ products face stiff competition from countries such as Australia, Chile, Morocco, Saudi Arabia, and Spain.**

JAPAN:.. Burn NH3 for power: Green NH3= \$\$

* **Japan's largest power generation company JERA --** has reached an agreement with Exxon Mobil to development of the oil major's planned project in Texas to produce "blue" hydrogen with carbon capture....

... an estimated 900,000 metric tons of low-carbon hydrogen and more than 1 million metric tons of ammonia each year

* **Plagen South Korea:** to transform the Taebaek City former coal mining city into a clean energy industrial. The project is expected to eventually cover 20% of the domestic green methanol (100,000 tons) production target by 2030.

An abundance of forest residues and renewable energy infrastructure, wind power in particular. the green methanol produced there as fuel for ships on the US-Korea Green Shipping Corridor.

JAPAN:.. Burn NH3 for power: Green NH3= \$\$

*** US-based GE Vernova and Japanese IHI Corp. have JV:**

--New gas turbine utilizing ammonia NH3 as a viable fuel for power generation by 2030

*** JV Tokyo electric & Chubu electric-**

- to shift Massive coal burning fleet to 100 % ammonia by 2050

GREEN NH₃

- Danish firms: Topsoe, Skovgaard Energy and Vestas first green ammonia plant in the world, in Denmark..
- capable of producing 5,000 tons of [green ammonia](#) / yr.. entirely from solar and wind energy. this effort will prevent 8,200 tons of carbon dioxide emissions annually.
- It received support more than US\$12 million from the Danish Energy Technology Development
- ...Gray ammonia production accounts for about 1.2% of all carbon dioxide emissions. ..
-

*** “book-and-claim” accounting methods,**

***Which allow H2 producers to sign contracts with RNG:**

- landfills; manure; WasteWater Treatment in another part of the country to offset the fossil gas they’re using to make hydrogen

-Treasury’s guidance does contain some provisions for RNG to be used to make hydrogen that can earn 45V tax credits.

-- Allows one particular use of RNG: .. RNG that’s directly transported from landfills to hydrogen production sites.

Other methods of using it may be permitted later, but only after further study.