HydrogenNowCast

COLORADO
HYDROGEN
NETWORK

Podcast

www.colorado-hydrogen.org

Video Podcast

The Big Picture Cost of Hydrogen Sourcing and Transporting

May 2024

To Replace Petroleum . . .

. . . we need to consider the numbers

- Target price for hydrogen to:
  - Replace gasoline & diesel for transportation
    - Same cost-per-mile for the user
  - To replace natural gas for industry & utilities
    - Same cost-per-BTU for the user
- Cost of the likely *Clean* sources
  - Electrolysis of water
  - Natural hydrogen wells
  - Underground hydrogen generation (ProtonTechnology https://protonh2.com)

A Cost – Price Analysis

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Energy Definitions

- “Clean” Energy
  - Zero GHG (Greenhouse Gas)
    - No emissions
  - GHG neutral
    - Use may emit GHG
    - Production absorbs an amount equal to emission
  - GHG negative
    - If the use of a fuel emits GHG
    - Production of that fuel removes more GHG from the atmosphere than emitted
- Renewable energy
  - Source is replenished by natural processes
  - Is not depleted

All Renewable Energy is Clean
Not all Clean Energy is renewable

“Clean” and “Renewable” are Separate Characteristics

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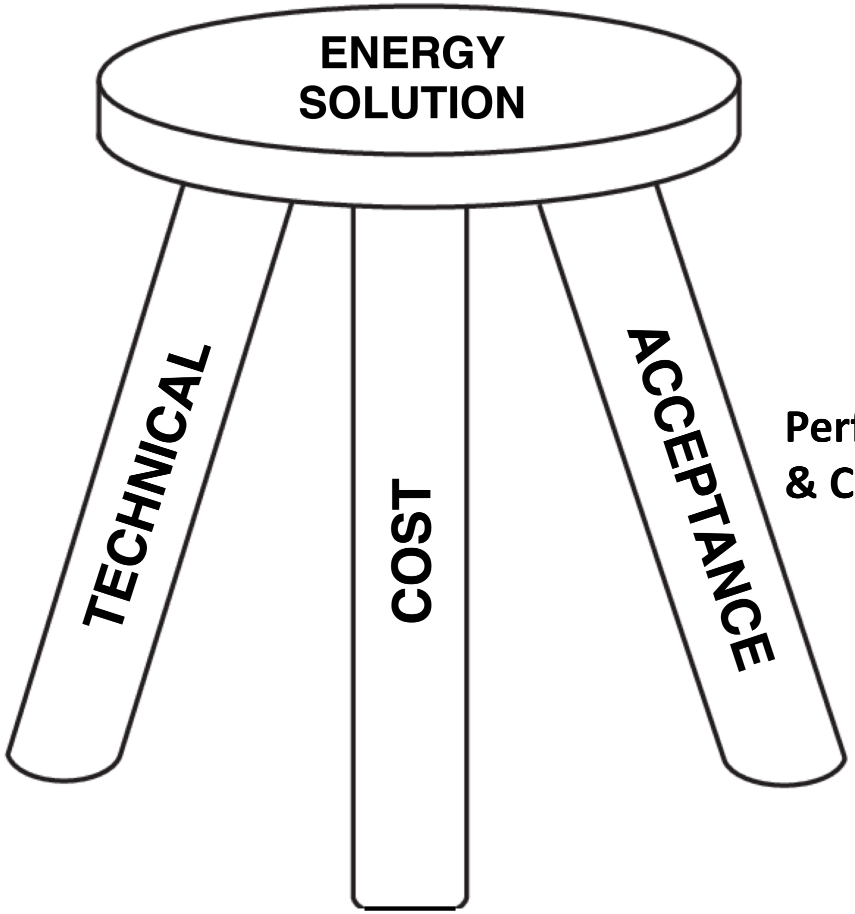
Energy Solutions Must Meet 3 Criteria



Performance
& Convenience

Why Hydrogen?
To Replace Fossil Fuels
We Need All The Functions That Fossil Fuels Provide

	Energy Source	Energy Carrier	Storability		Fast Transfer to Vehicles	Hi-Temp for industry (Steel, Cement Glass making)	Long-Distance Energy Transport	High Energy Density (Ships & Planes)
			Short Term	Long Term				
Fossil Fuels	X	X	X	X	X	X	X	X

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To Replace Fossil Fuels We Need All The Functions That Fossil Fuels Provide

	Energy Source	Energy Carrier	Storability		Fast Transfer to Vehicles	Hi-Temp for industry (Steel, Cement Glass making)	Long-Distance Energy Transport	High Energy Density (Ships & Planes)
			Short Term	Long Term				
Fossil Fuels	X	X	X	X	X	X	X	X
Wind, Solar Geothermal	X							

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To Replace Fossil Fuels We Need All The Functions That Fossil Fuels Provide

	Energy Source	Energy Carrier	Storability		Fast Transfer to Vehicles	Hi-Temp for industry (Steel, Cement Glass making)	Long-Distance Energy Transport	High Energy Density (Ships & Planes)
			Short Term	Long Term				
Fossil Fuels	X	X	X	X	X	X	X	X
Wind, Solar Geothermal	X							
Electric Grid		X					X	

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To Replace Fossil Fuels We Need All The Functions That Fossil Fuels Provide

	Energy Source	Energy Carrier	Storability		Fast Transfer to Vehicles	Hi-Temp for industry (Steel, Cement Glass making)	Long-Distance Energy Transport	High Energy Density (Ships & Planes)
			Short Term	Long Term				
Fossil Fuels	X	X	X	X	X	X	X	X
Wind, Solar Geothermal	X							
Electric Grid		X					X	
Batteries		X	X					

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Hydrogen Picks Up
Where the Grid and Batteries Leave Off

	Energy Source	Energy Carrier	Storability		Fast Transfer to Vehicles	Hi-Temp for industry (Steel, Cement Glass making)	Long-Distance Energy Transport	High Energy Density (Ships & Planes)
			Short Term	Long Term				
Fossil Fuels	X	X	X	X	X	X	X	X
Wind, Solar Geothermal	X							
Electric Grid		X					X	?
Batteries		X	X					
Hydrogen	X	X	X	X	X	X	X	

- Geological hydrogen (wells)
- Underground Hydrogen Generation From Petroleum
- Hydrogen from Biomass

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The Complete Energy Transition Picture

	Energy Source	Energy Carrier	Storability		Fast Transfer to Vehicles	Hi-Temp for industry (Steel, Cement Glass making)	Long-Distance Energy Transport	High Energy Density (Ships & Planes)
			Short Term	Long Term				
Fossil Fuels	X	X	X	X	X	X	X	X
Wind & Solar	X							
Electric Grid		X					X	
Batteries		X	X					
Hydrogen	X	X	X	X	X	X	X	
Biofuel	X	X	X	X	X		X	X

- “Clean” and “Renewable”, but not zero emissions
- Uses the atmosphere to exchange CO_2 between use and source

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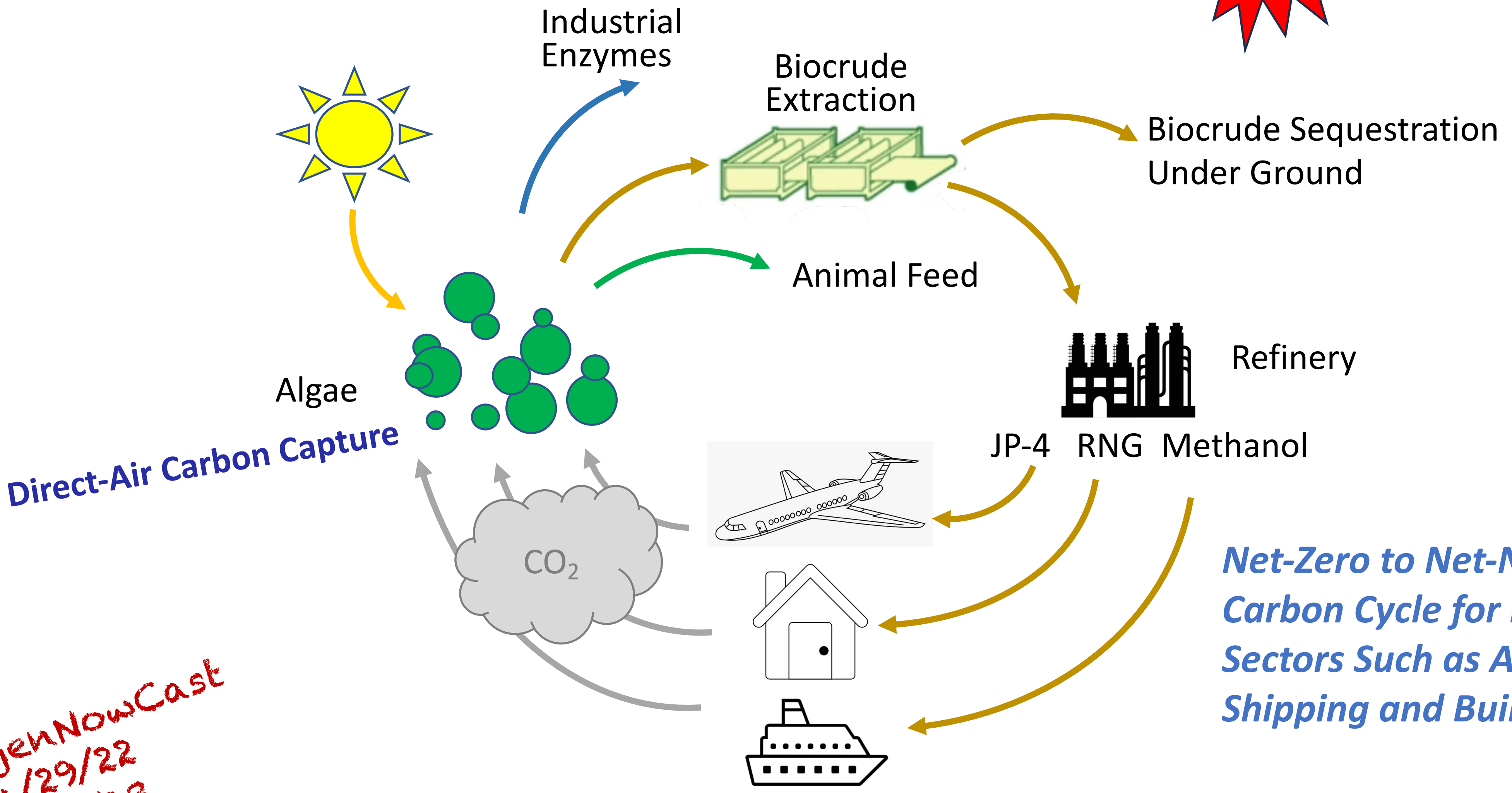
Biofuel From Algae

New



Net-Zero to Net-Negative Carbon Cycle for Hard to Abate Sectors Such as Aviation, Shipping and Building Heating

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2/10/23

Clean Hydrogen Sourcing

- Hydrogen needs to be *Clean* (zero greenhouse gases)
  - If it weren't for the need to eliminate greenhouse gases the world wouldn't bother using hydrogen
- Sources of *Clean* hydrogen
  - Electrolysis of water
  - Natural Hydrogen Wells
  - Generated Underground (GU) Hydrogen (Proton Technology* process)

***https://protonh2.com.**

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Gasoline & Diesel Replacement H_2 Price Target

New

- Goal: Price hydrogen at the same or better cost-per-mile as petroleum
  - To entice users to switch from petroleum to hydrogen vehicles
- Cost-per-mile is based on vehicle efficiency
  - Hydrogen vehicles are more efficient than petroleum . . . but that varies by Class
- Energy Economy Ratio (EER)
  - Ratio of MPKg-to-MPG
  - For similar size and weight vehicles

Class	LD/MD Gas	LD/MD Diesel	HD Diesel Local	HD Diesel Highway
Petrol. $/gal	$3.50	$4.00	$4.00	$4.00
EER	2.5	1.9	1.5	1.1
Target Price $/kg	**$8.75**	**$7.60**	**$6.00**	**$4.40**

Price Per kg is Highly Dependent on Vehicle Class and Comparison to Gasoline vs Diesel

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Cost to Transport Hydrogen

50-mile delivery
LH_2 Delivered
LOHC Delivered
Ammonia Delivered
On-Site Electrolysis

Cost to Transport Hydrogen

50-mile delivery	CAPEX
LH_2 Delivered	\$3.8 M
LOHC Delivered	\$4.3 M
Ammonia Delivered	\$7.0 M
On-Site Electrolysis	\$3.2 M

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Cost to Transport Hydrogen

50-mile delivery	CAPEX	CAPEX debt service ($/kg)
LH_2 Delivered	$3.8 M	$2.40
LOHC Delivered	$4.3 M	$2.73
Ammonia Delivered	$7.0 M	$4.43
On-Site Electrolysis	$3.2 M	$4.23

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Cost to Transport Hydrogen

50-mile delivery	CAPEX	CAPEX debt service ($/kg)	OPEX ($/kg)
LH_2 Delivered	$3.8 M	$2.40	$2.04
LOHC Delivered	$4.3 M	$2.73	$3.13
Ammonia Delivered	$7.0 M	$4.43	$2.78
On-Site Electrolysis	$3.2 M	$4.23	$4.52

Cost to Transport Hydrogen

50-mile delivery	CAPEX	CAPEX debt service ($/kg)	OPEX ($/kg)	Transport Cost
LH_2 Delivered	$3.8 M	$2.40	$2.04	$4.44
LOHC Delivered	$4.3 M	$2.73	$3.13	$5.87
Ammonia Delivered	$7.0 M	$4.43	$2.78	$7.21
On-Site Electrolysis	$3.2 M	$4.23	$4.52	

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Cost to Transport Hydrogen

50-mile delivery	CAPEX	CAPEX debt service ($/kg)	OPEX ($/kg)	Transport Cost	H2 Cost at well
LH_2 Delivered	$3.8 M	$2.40	$2.04	$4.44	$0.30
LOHC Delivered	$4.3 M	$2.73	$3.13	$5.87	$0.30
Ammonia Delivered	$7.0 M	$4.43	$2.78	$7.21	$0.30
On-Site Electrolysis	$3.2 M	$4.23	$4.52		

Cost to Transport Hydrogen

50-mile delivery	CAPEX	CAPEX debt service ($/kg)	OPEX ($/kg)	Transport Cost	H2 Cost at well	Total Cost ($/kg)
LH_2 Delivered	$3.8 M	$2.40	$2.04	$4.44	$0.30	**$4.74**
LOHC Delivered	$4.3 M	$2.73	$3.13	$5.87	$0.30	**$6.17**
Ammonia Delivered	$7.0 M	$4.43	$2.78	$7.21	$0.30	**$7.51**
On-Site Electrolysis	$3.2 M	$4.23	$4.52			**$8.75**

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Price-Cost Comparison

Hydrogen Target Price			
Class	LD/MD Gas	LD/MD Diesel	HD Diesel
Petrol. $/gal	$3.50	$4.00	$4.00
EER	2.5	1.9	1.1
Target Price $/kg	**$8.75**	**$7.60**	**$4.40**

Cost for Transport and Generation					
50-mile delivery	**Transport CAPEX debt service ($/kg)**	**Transport OPEX ($/kg)**	**Transport Total Cost**	**H_2 Cost at well**	**Total Cost ($/kg)**
LH_2 Delivered	$2.40	$2.04	$4.44	$0.30	**$4.74**
LOHC Delivered	$2.73	$3.13	$5.87	$0.30	**$6.17**
Ammonia Delivered	$4.43	$2.78	$7.21	$0.30	**$7.51**
On-Site Electrolysis	$4.23	$4.52			**$8.75**

			Target Price ($/kg)		
	✓ = Price ≥ Cost		LD/MD Gas	LD/MD Diesel	HD Diesel
			$8.75	**$7.60**	**$4.40**
Cost ($/kg)	LH_2	**$4.74**	✓	✓	(✓)
	LOHC	**$6.17**	✓	✓	
	Ammonia	**$7.51**	✓	✓	
	Electrolysis	**$8.75**	✓		

Although Hydrogen for Heavy-Duty Transportation is a Compelling Idea
A Competitive Source for the Hydrogen is Challenging

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Natural Gas Cost-Price Comparison

New

Price Target	
Item	**Value (at H_2 Source)**
CH_4 cost per 1,000 SCF	$9.60
BTU per 1,000 SCF	922,740
BTU per kg H_2 (LHV)	114,887
kg H_2 equiv. to 1,000 SCF CH_4	8.03
Price per kg H_2 equiv. to CH_4	**$1.20**

Cost Analysis	
Item	**$ per kg**
Hydrogen Cost at source	$0.30
Pipeline cost OPEX + ROI	$0.20 to $0.80
Total cost per kg	**$0.50 to $1.10**

Cost less than target price

Hydrogen Can Compete With Natural Gas if the Source is Priced at 30¢ to 40¢ per kg

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Take-Aways

New

Hydrogen can compete with petroleum for transportation

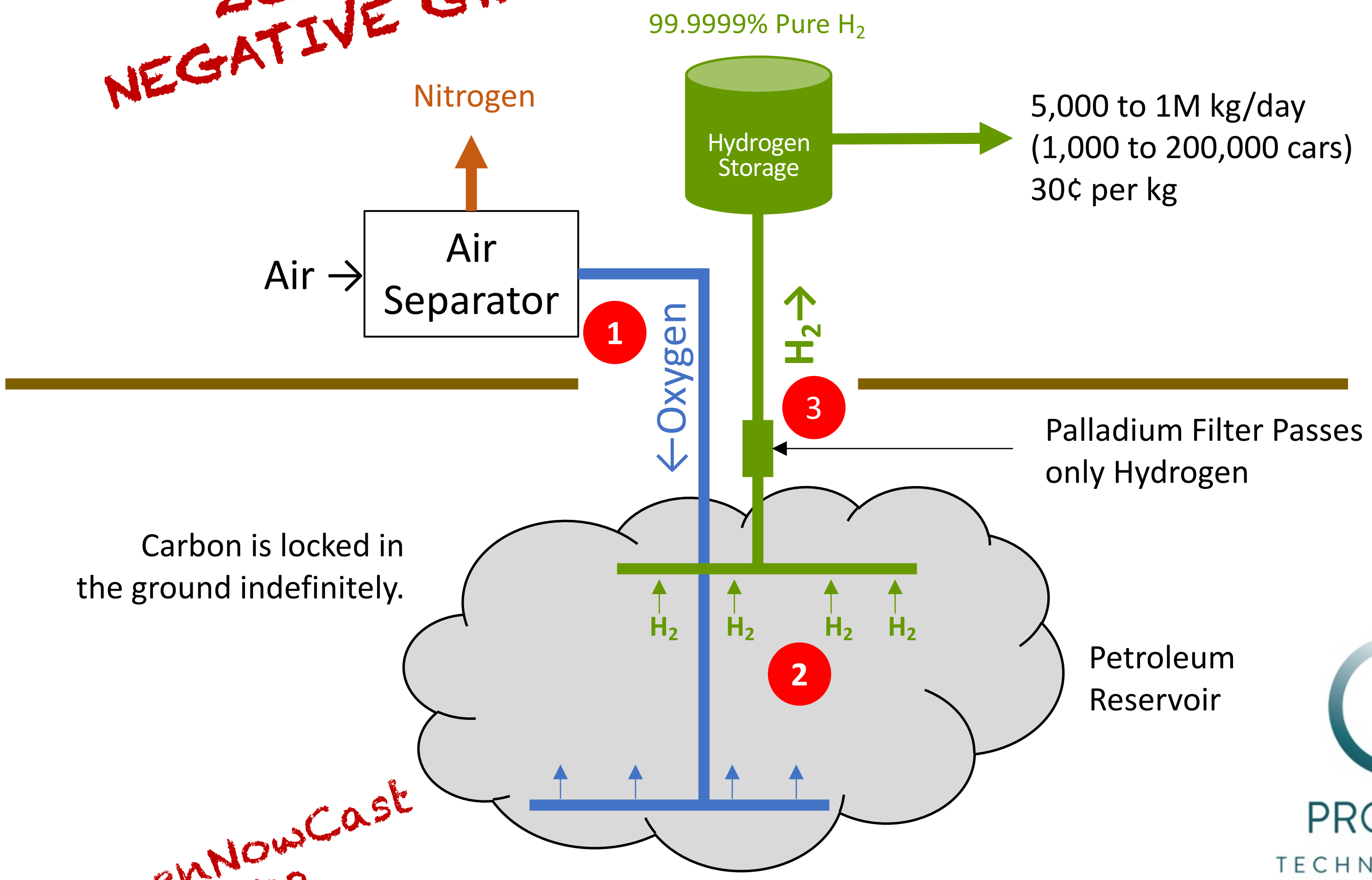
- On-site electrolysis is competitive with light-duty gasoline
- For other classes of vehicles
  - Sources of 30¢ per kg hydrogen is needed
    - Natural hydrogen wells
    - Generated Underground (GU) Hydrogen using petroleum reservoirs
  - Liquid hydrogen transport is the lowest cost

Hydrogen can compete with Nat. Gas for industry & utilities

- Pipelines will be needed
  - Quantities too great for tanker transport
  - With a hydrogen source cost of 30¢ per kg (wells and generation underground)
  - And 20¢ to 80¢ per kg pipeline cost

Zero GHG Hydrogen From Petroleum Wells

Zero to NEGATIVE GHG



1. Oxygen is injected into wells to free the hydrogen
   – "Fire Flood" effect
2. Hydrogen is released underground
3. Pure Hydrogen is brought out of the well through a palladium filter

- Works well with abandoned, spent wells
- Additionally, this process can sequester 3 times the CO_2 as hydrogen generated

PROTON TECHNOLOGIES

https://protonh2.com

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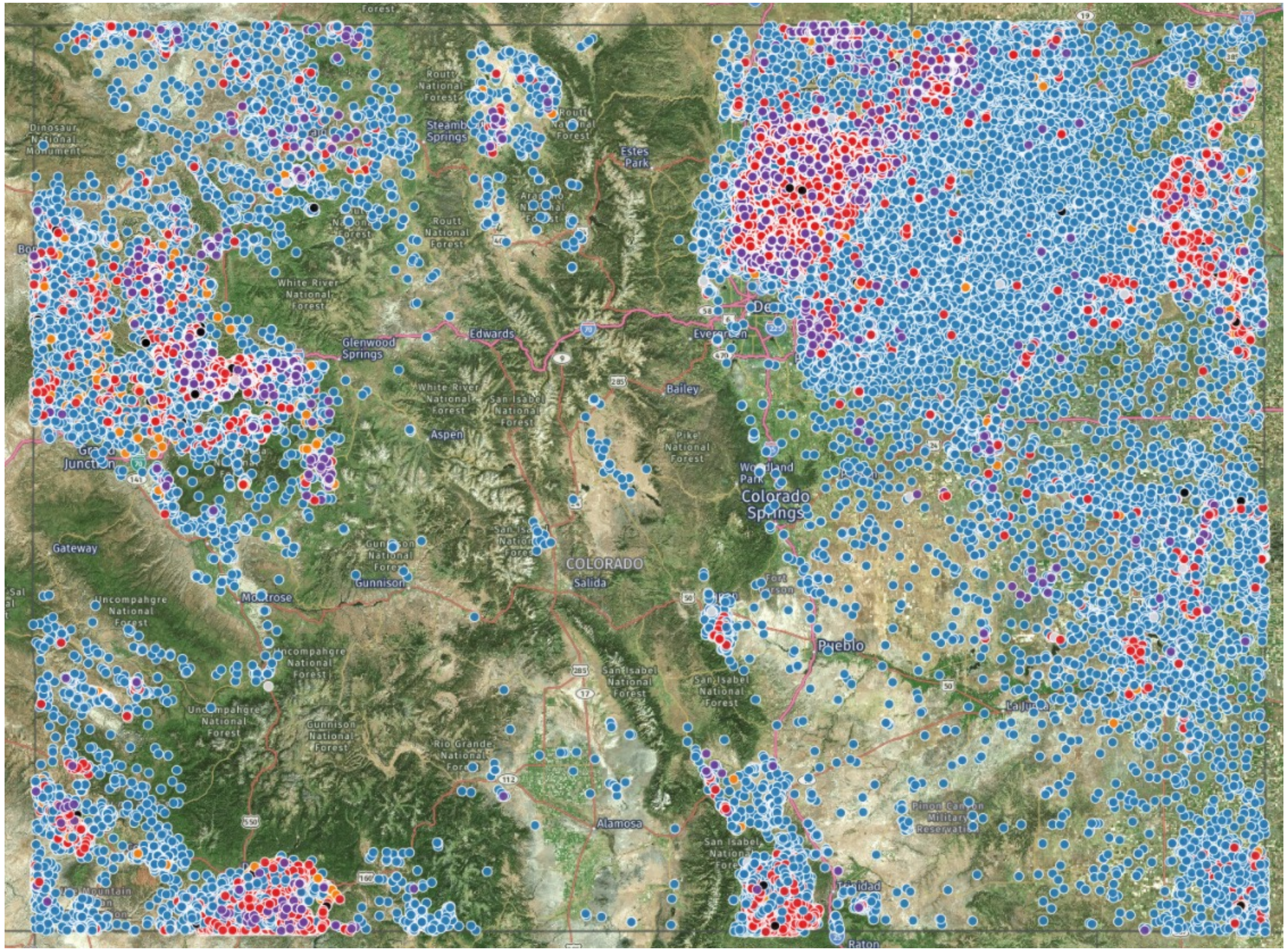
Petroleum Wells in Colorado



- Red are active
- Blue are abandoned
- Colorado has over 20,000 abandoned wells
- Many of the abandoned wells can be used to produce hydrogen

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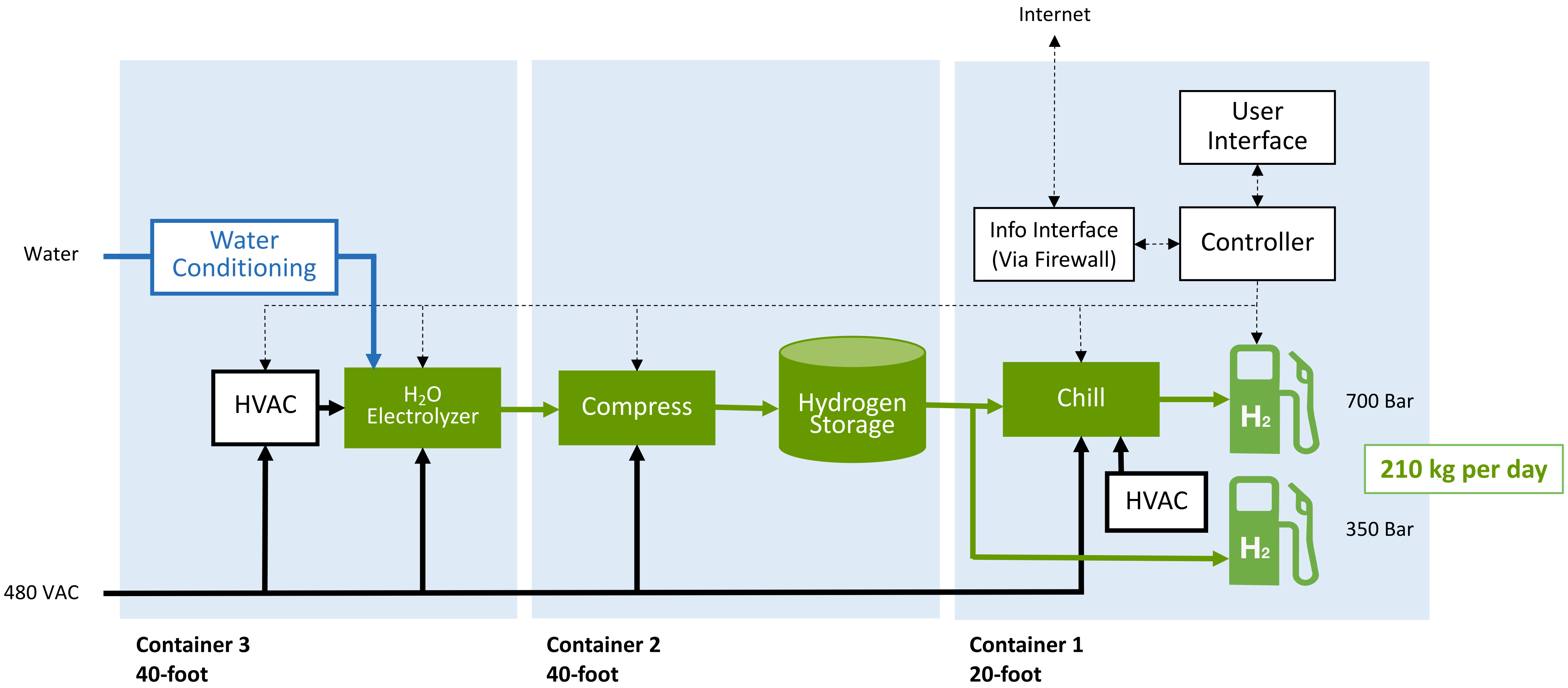
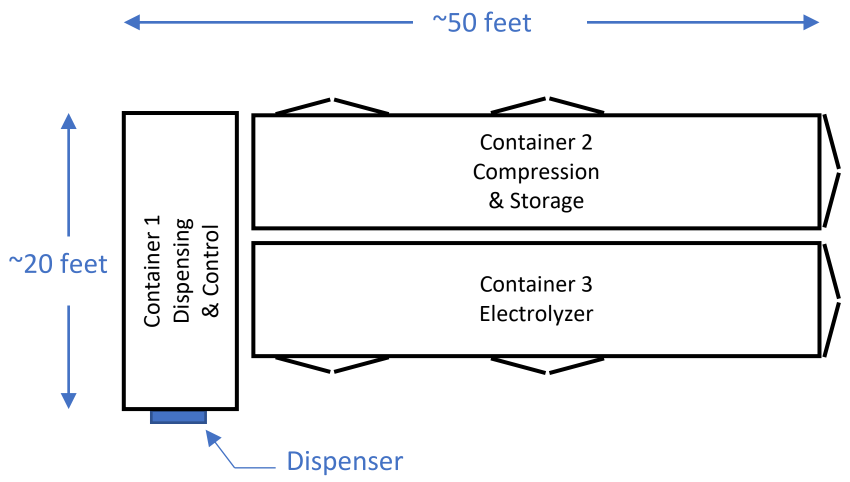
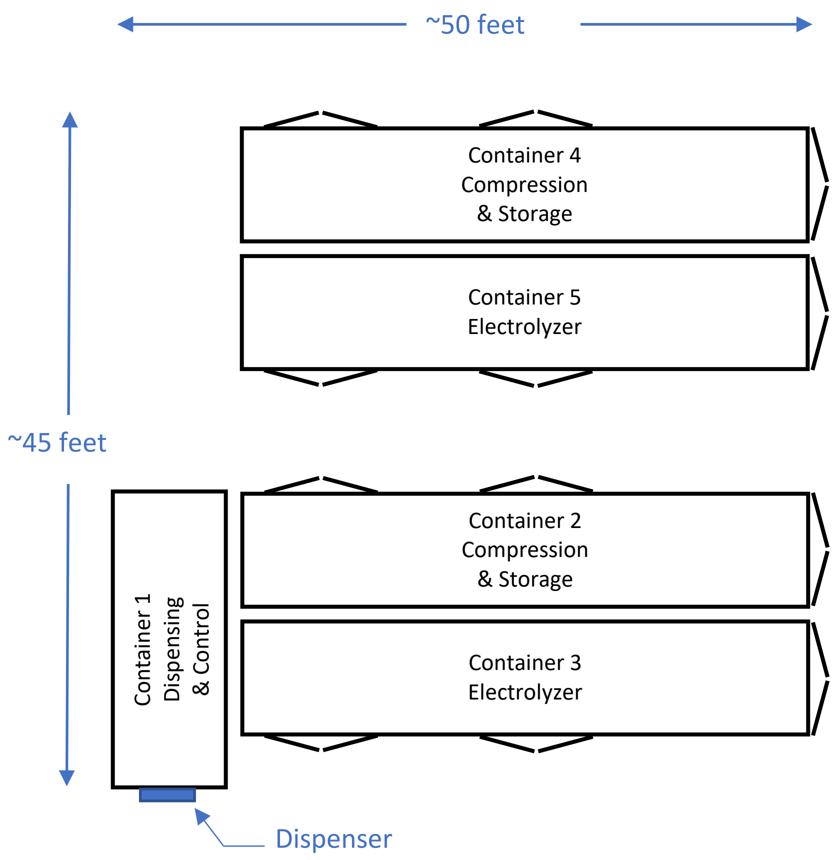
On-Site H2 Generation 210 kg/day



On-site Hydrogen Fuel Station Footprints

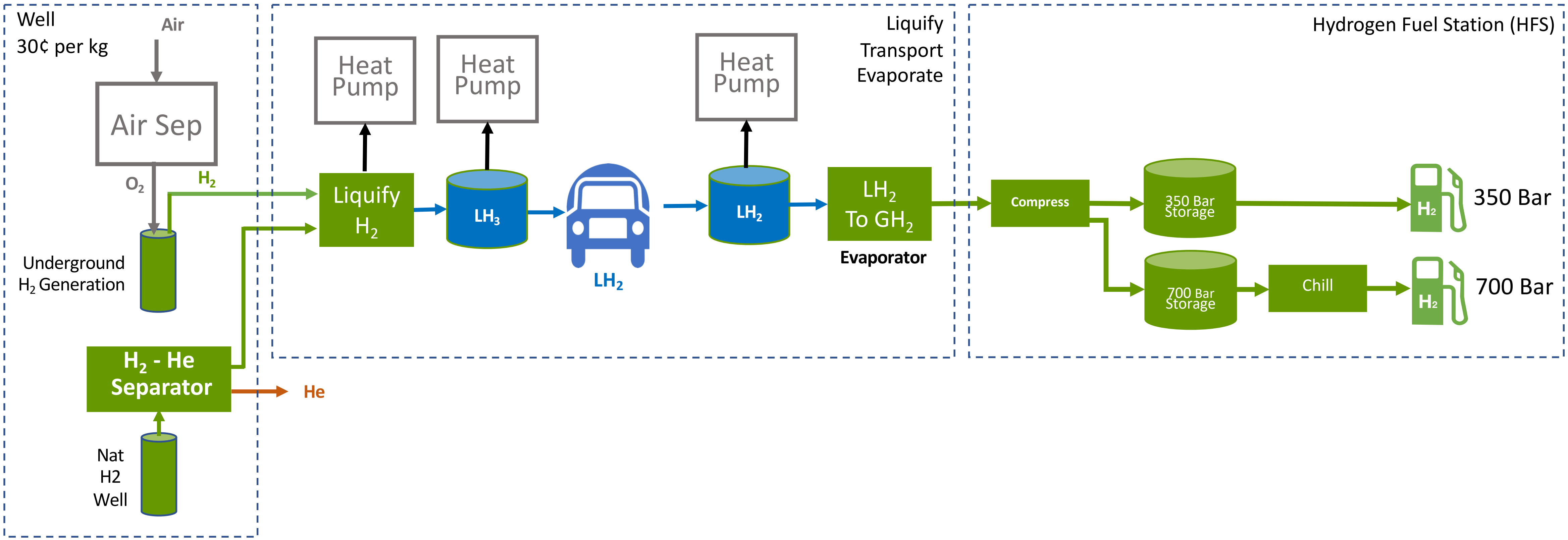


Up to 210 kg per day

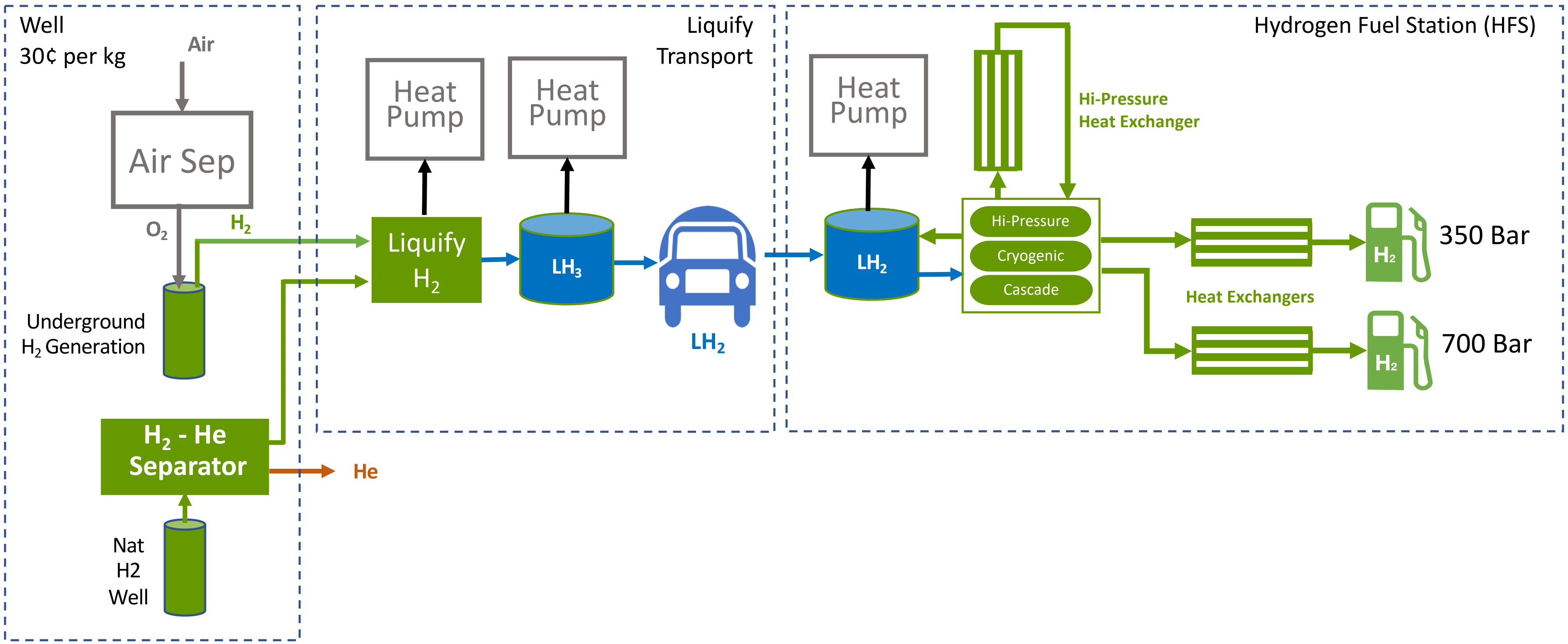


Up to 420 kg per day

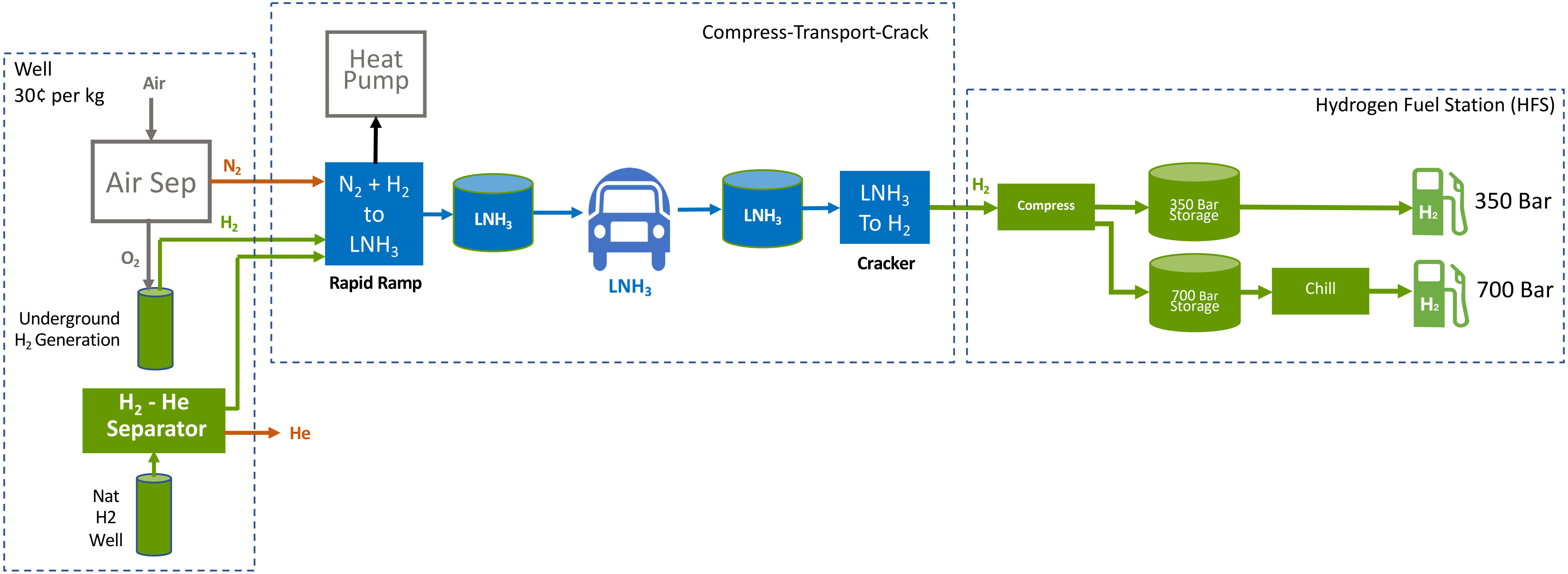
Moving Hydrogen as a Liquid



Moving Hydrogen as a Liquid – Self Pressurizing



Moving Hydrogen as Ammonia



Moving Hydrogen Using Liquid Organic Hydrogen Carrier (LOHC)