Powerful Facility
Energy Conference

Decarbonized Onsite Energy with Clean Hydrogen and Today's Infrastructure

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March 16, 2023
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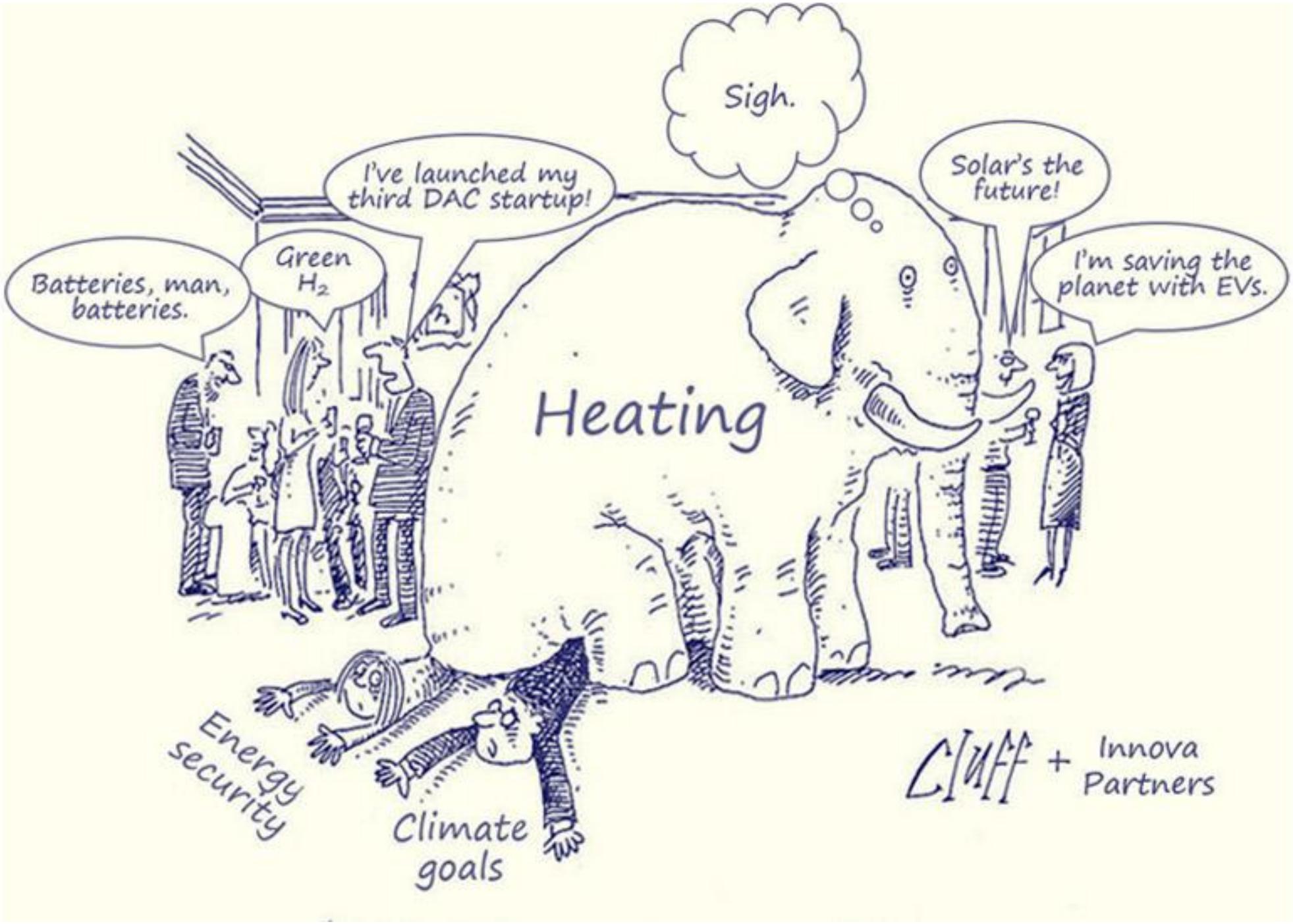
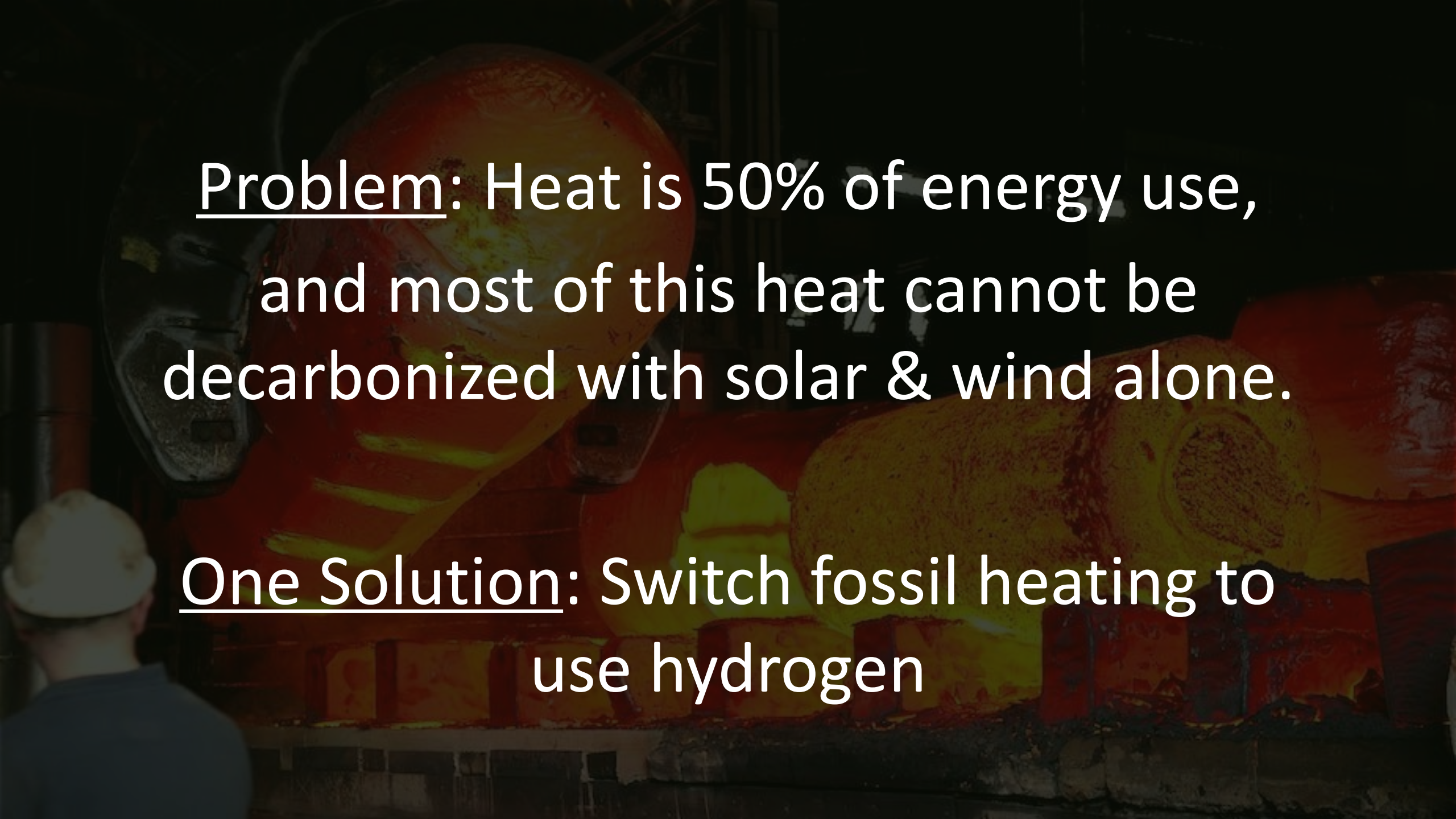
Learning Goals Today

1. What is the industrial heating landscape, and how does hydrogen fit in?
2. What are metrics to evaluate for hydrogen projects and products?
3. How is hydrogen produced today? What are alternative methods?
4. Overview of several pilot projects in the PNW with new hydrogen generation technology under new paradigm of end-of-grid pyrolysis.

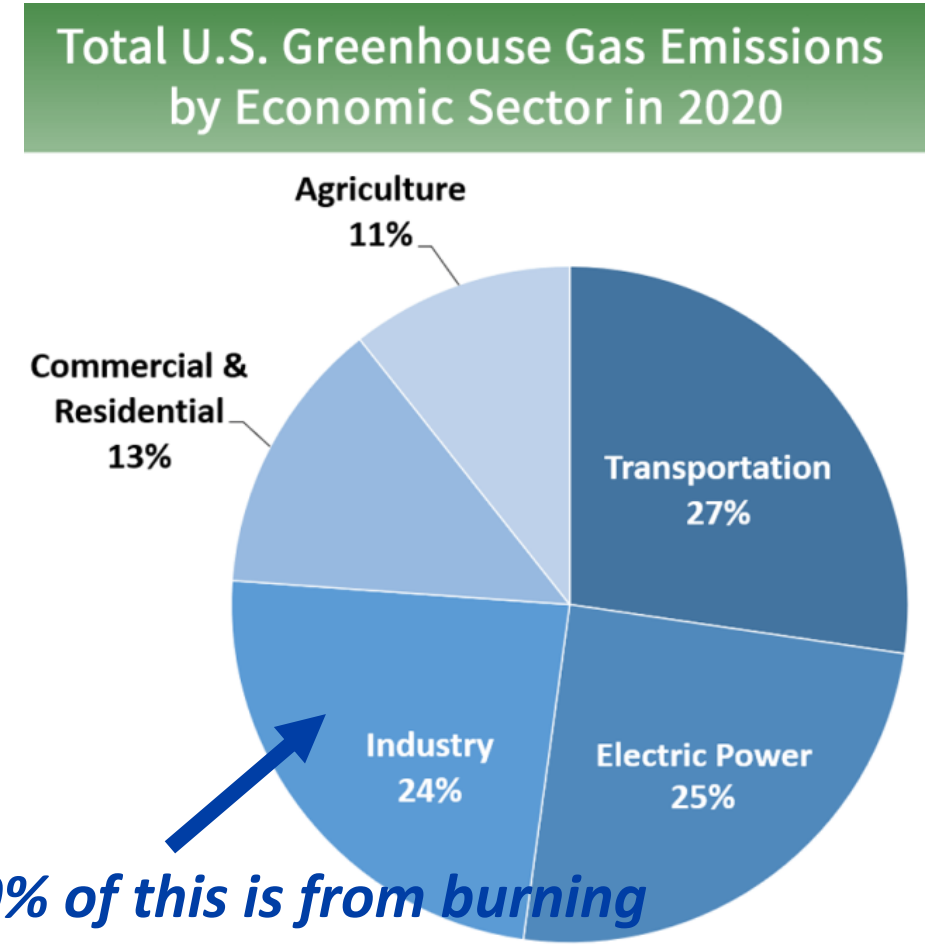

Sigh.
I've launched my third DAC startup!
Solar's the future!
Batteries, man, batteries.
Green H_2
I'm saving the planet with EVs.
Heating
Energy security
Climate goals
CIUff + Innova Partners



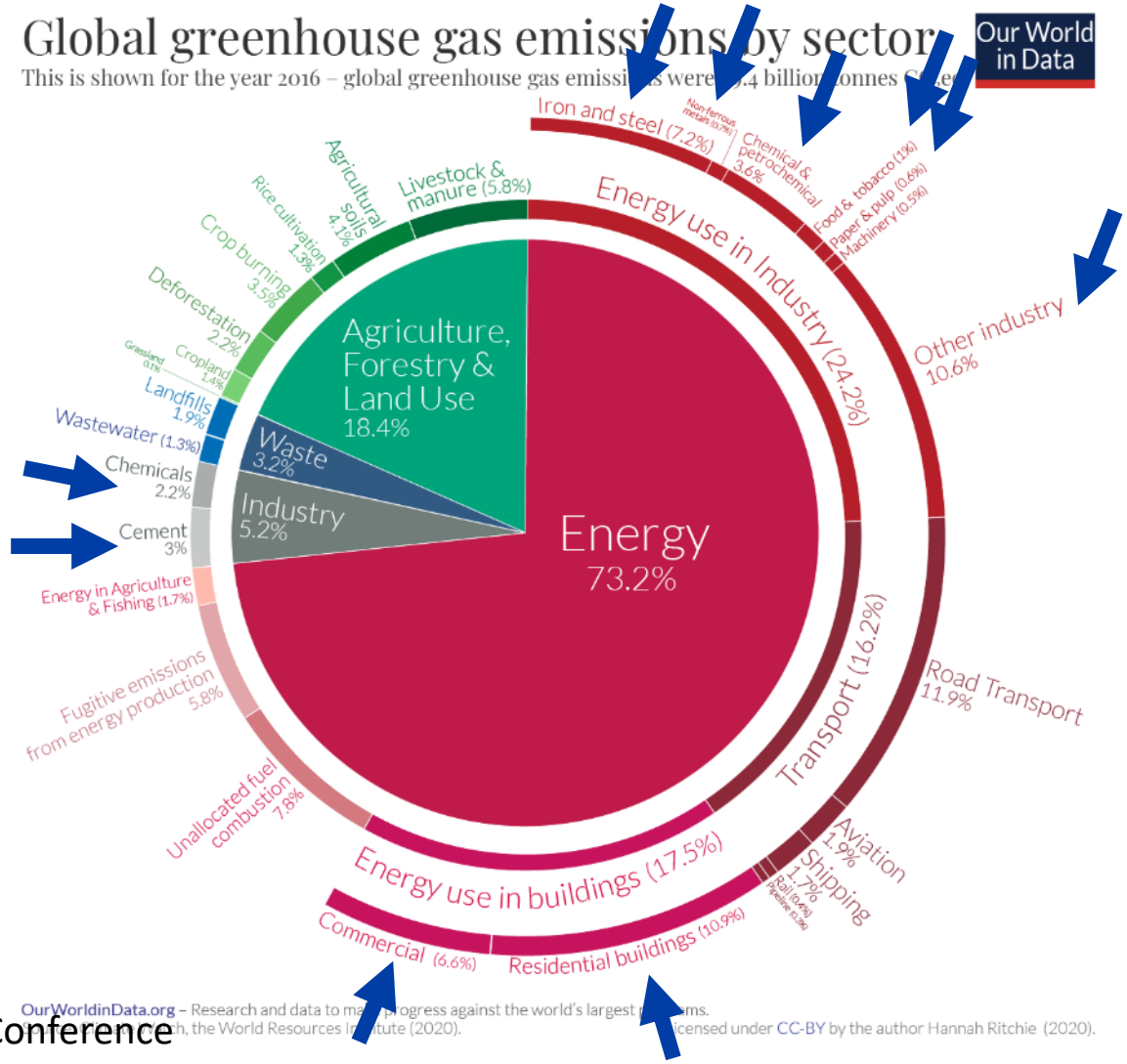
Problem: Heat is 50% of energy use, and most of this heat cannot be decarbonized with solar & wind alone.

One Solution: Switch fossil heating to use hydrogen

Industrial Heat Landscape: Emissions



>50% of this is from burning natural gas & petroleum!



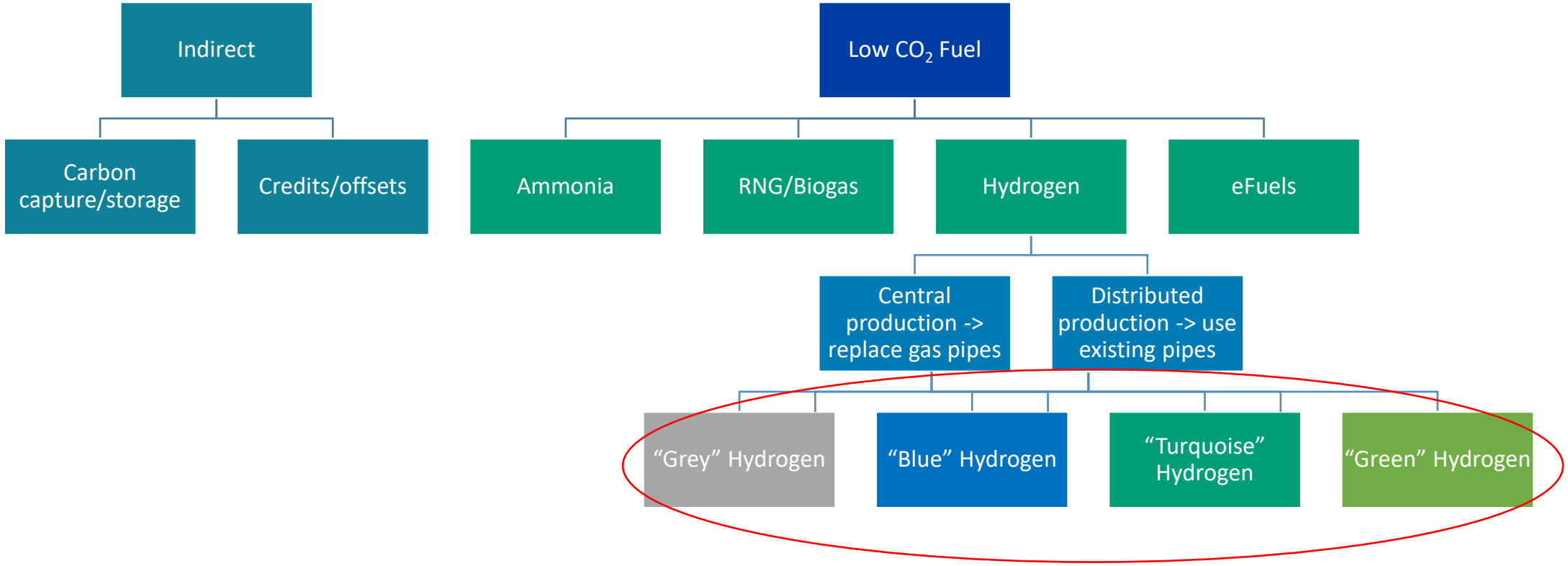
Industrial Gas Heating Landscape: Example Use Cases & Temps

	Steel	Copper	Paper & Pulp	Food & beverage	Cement	Glass	Chemicals
Typical Temp	1100°C+ (2000°F+)	950°C+ (1740°F+)	200-500°C (392-900°F)	200-500°C (392-900°F)	1000°C+ (1800°F+)	1100°C+ (2000°F+)	300-800°C+ (500-1400°F+)
Form	Direct firing	Direct firing	Steam boiler	Steam boiler	Direct firing	Direct firing	Direct firing and steam

We *could* use electric heating, but that has limitations that industrials + utilities are deeply concerned about:

1. Electricity is 3-5x more expensive than gas on a per energy basis due to 'spark spread', even for industrial rates
2. Need to swap industrial plant capex (~$100M+ investments with 30-60 year operating lives)
3. Not enough grid capacity, especially w/ T&D

Taxonomy: Options to Decarbonize when Electrification Isn't Affordable or Possible



Hydrogen (H_2) may be a wonder fuel…

H_2 STRENGTHS
Abundant
Energy dense
Burns clean & hot
Energy storage medium
Low CO_2 fuel!

…but it has many weaknesses as well.

H_2 STRENGTHS	HISTORICAL WEAKNESSES
Abundant	Traditional reforming production = high CO_2
Energy dense	Electrolysis is pricey
Burns clean & hot	Difficult to transport (can't move >20% in today's pipes)
Energy storage medium	Difficult to store
Low CO_2 fuel!	Embrittlement
	=> Expensive

Methods of Making Hydrogen

1. **Grey**
2. Blue
3. Turquoise
4. Green

"Steam Methane Reforming" (SMR)

$$CH_4 + H_2O \rightarrow CO + 3\ H_2$$

$$CO + H_2O \rightarrow CO_2 + H_2$$

- CI*: 9-11 kg CO_2 / kg H_2
- Cost: ~$1/kg H_2
- Pilot stage, works at large scale today

*CI = carbon intensity. Note that <~7 kg CO_2 / kg H_2 yields 'breakeven' GHG emissions with swapping H_2 for natural gas; higher for petrol + coal.

Methods of Making Hydrogen

1. Grey
2. **Blue**
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"Steam Methane Reforming" (SMR) **+ Carbon capture & storage**

$$CH_4 + H_2O \rightarrow CO + 3\ H_2$$
$$CO + H_2O \rightarrow CO_2 + H_2$$

Capture & sequestration/use

- CI: 1-3 kg CO_2 / kg H_2
- Cost: ~$3/kg H_2
- Established, works at largest scales

*CI = carbon intensity. Note that <~7 kg CO_2 / kg H_2 yields 'breakeven' GHG emissions with swapping H_2 for natural gas; higher for petrol + coal.

Methods of Making Hydrogen

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2. Blue
3. **Turquoise**
4. Green

Pyrolysis

CH_4 + *heat* -> C (solid) + 2 H_2

- CI: ~0-1 kg CO_2 / kg H_2
- Cost: ~$1-3/kg H_2 *projected*
- Pilot phase

Methods of Making Hydrogen

1. Grey
2. Blue
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4. **Green**

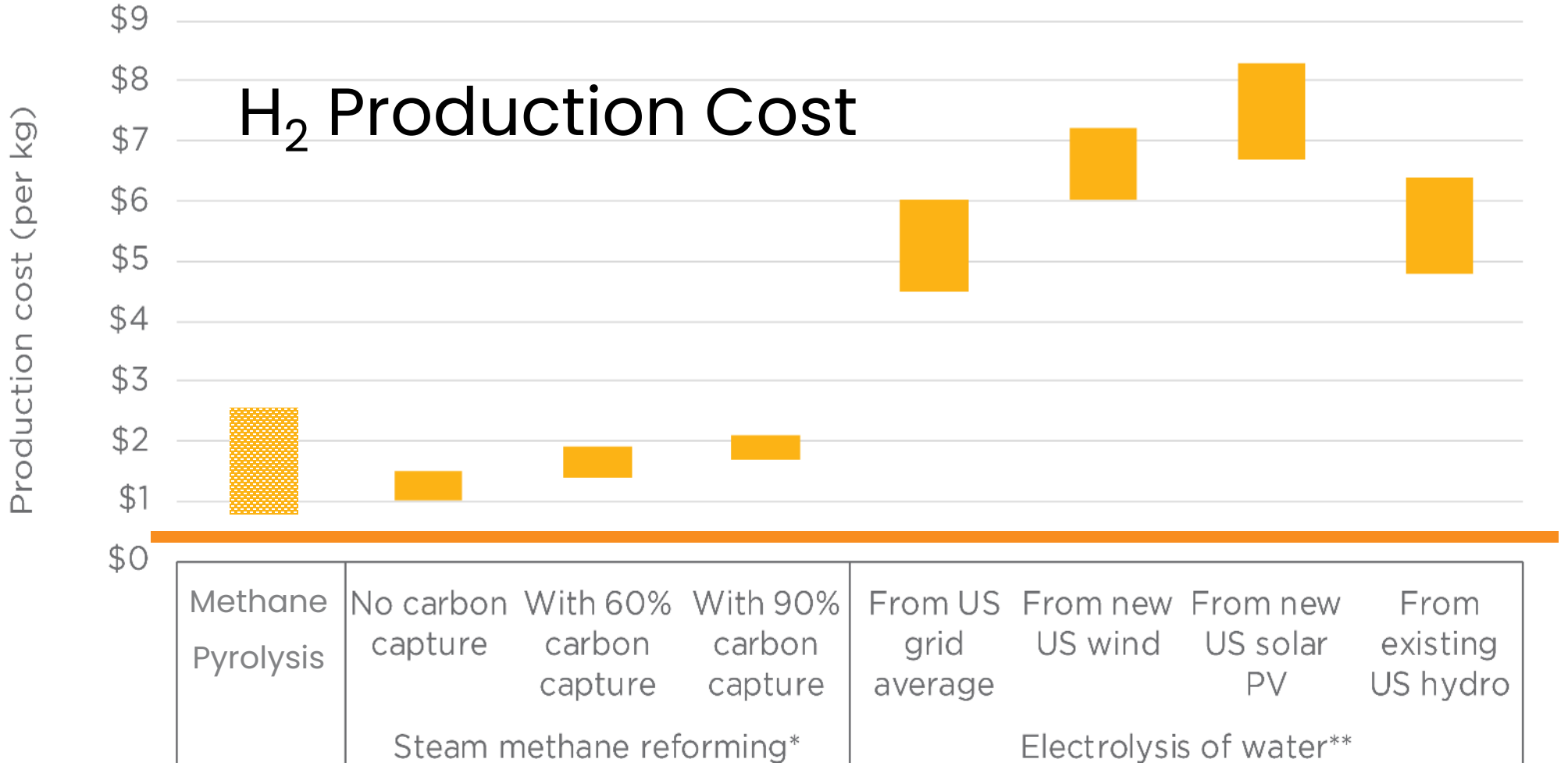
Electrolysis

$$2\ H_2O + \textit{electricity} \rightarrow O_2 + 2\ H_2$$

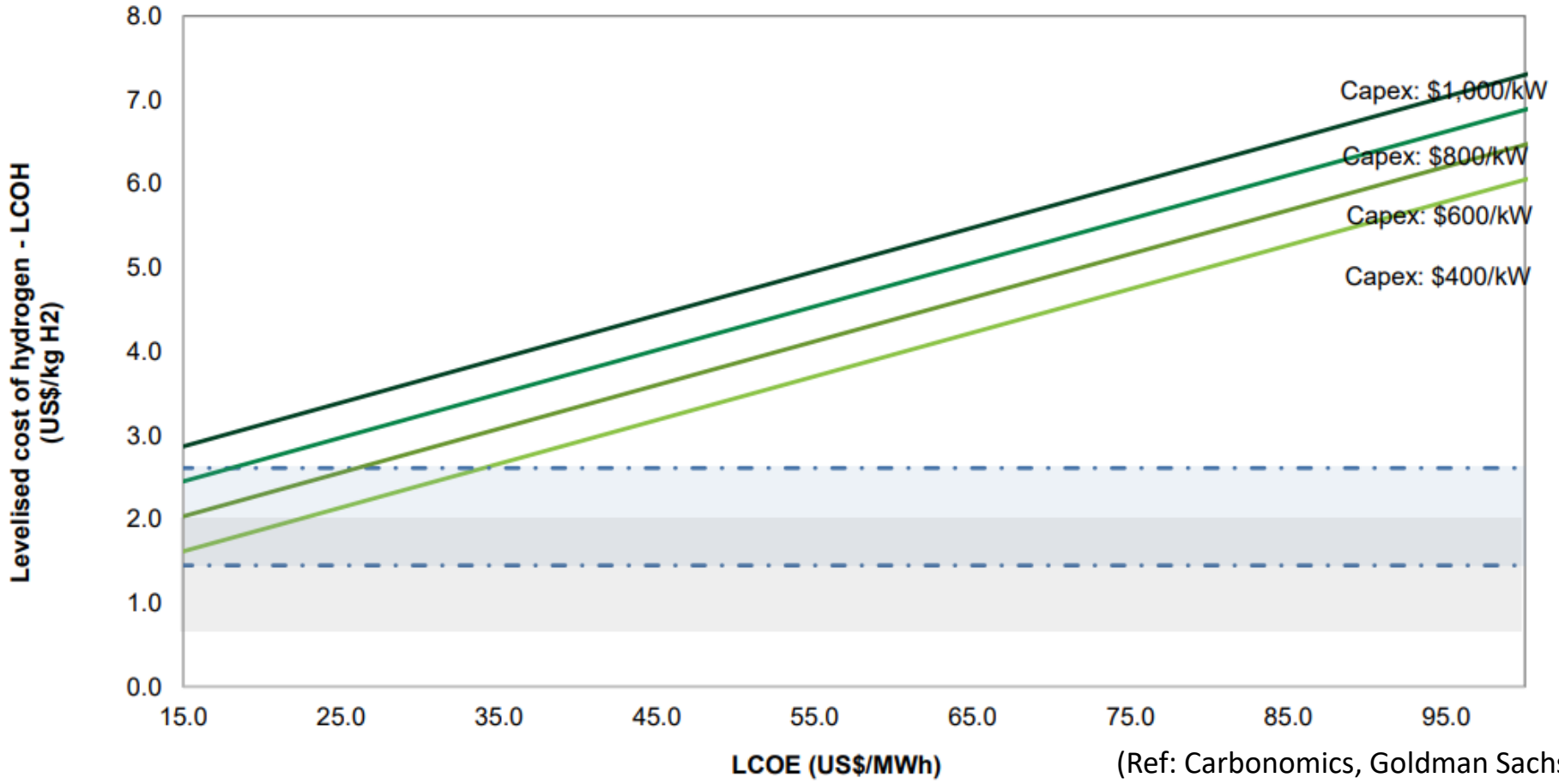
- CI: ~0-1 kg CO_2 / kg H_2
- Cost**: ~$6-10/kg H_2
- Commercially deployed at various scales, *great when electricity costs are low and renewable electricity is available at high duty*!

**Useful number to remember: electrolyzers achieve ~70 kWh/kg H_2. For example: if electricity is $0.05/kWh, that yields $3.50/kg H_2 cost contribution from electricity.

Methods of Making Hydrogen: Cost

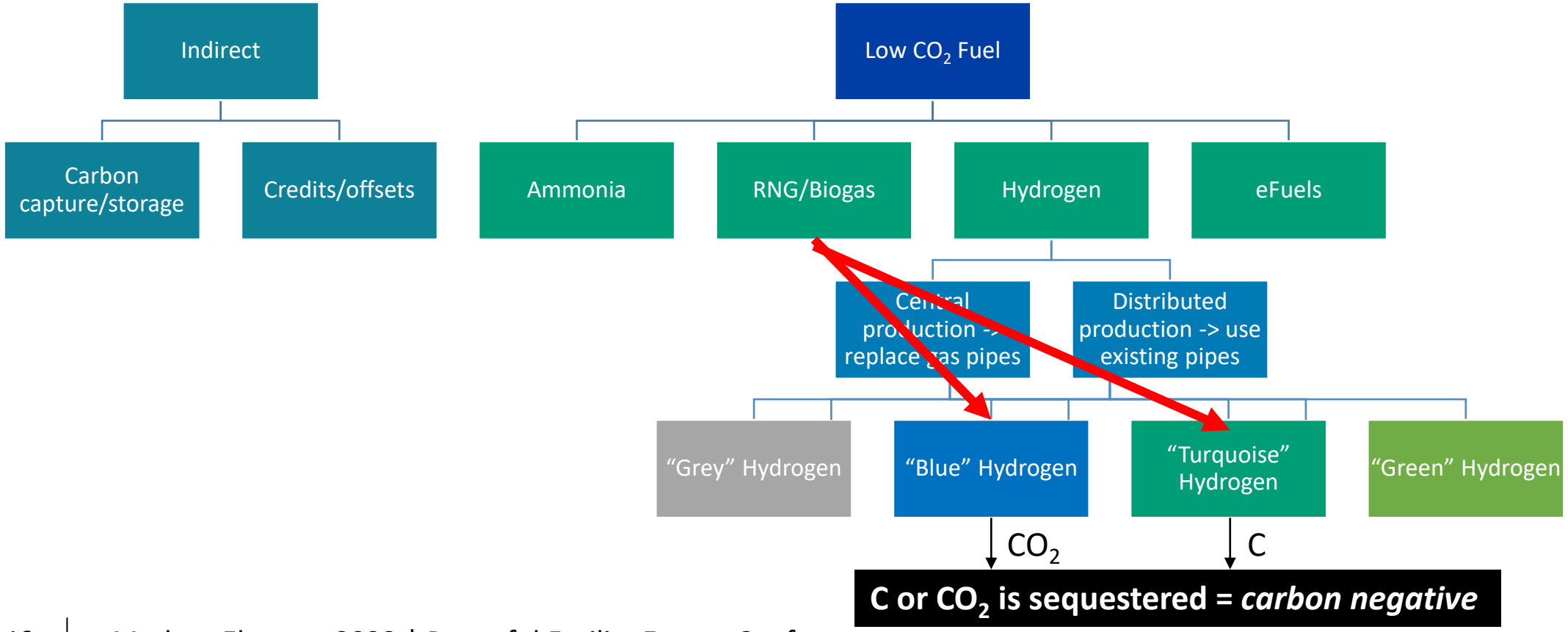


Methods of Making Hydrogen: Cost

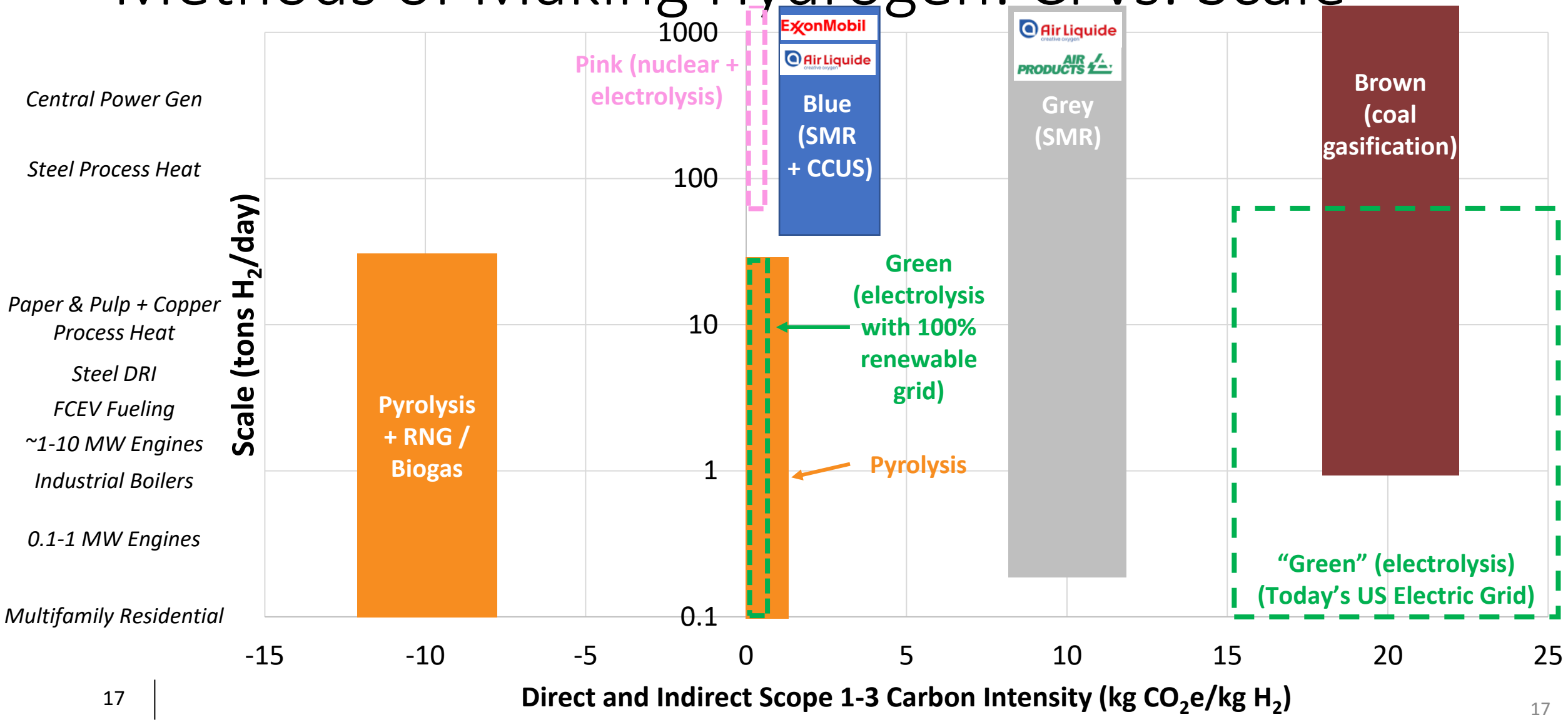


(Ref: Carbonomics, Goldman Sachs 2022)

One cool trick: combine RNG with SMR+CCUS or Pyrolysis: **NEGATIVE EMISSIONS!**



Methods of Making Hydrogen: CI vs. Scale



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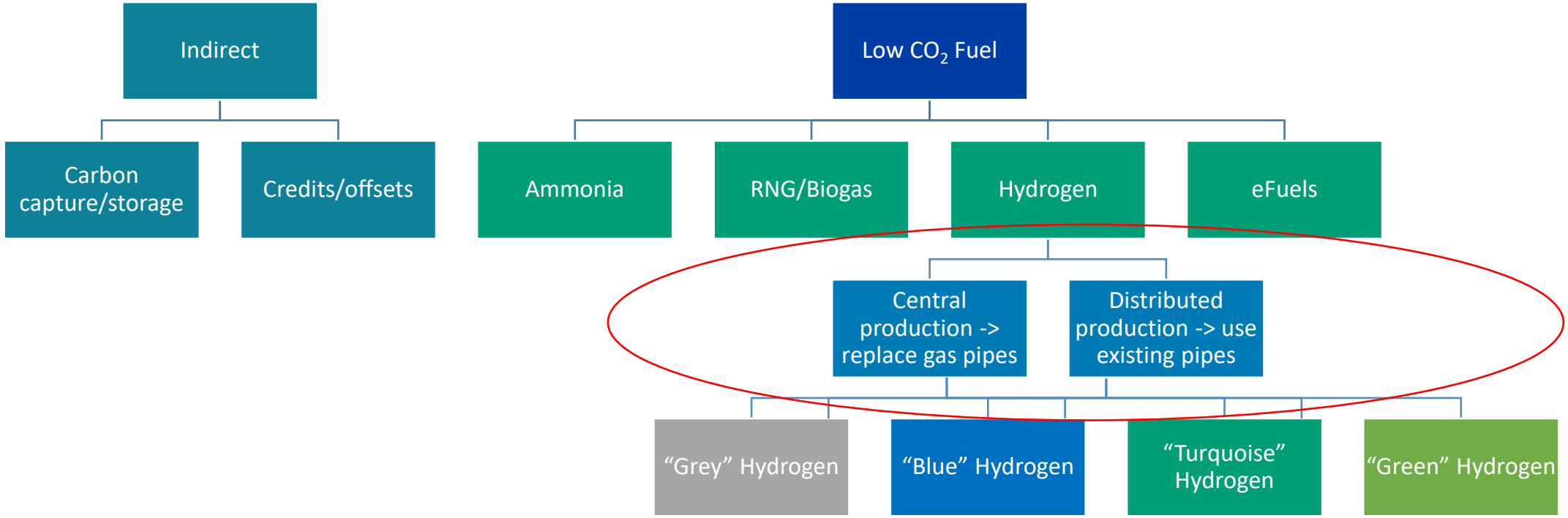
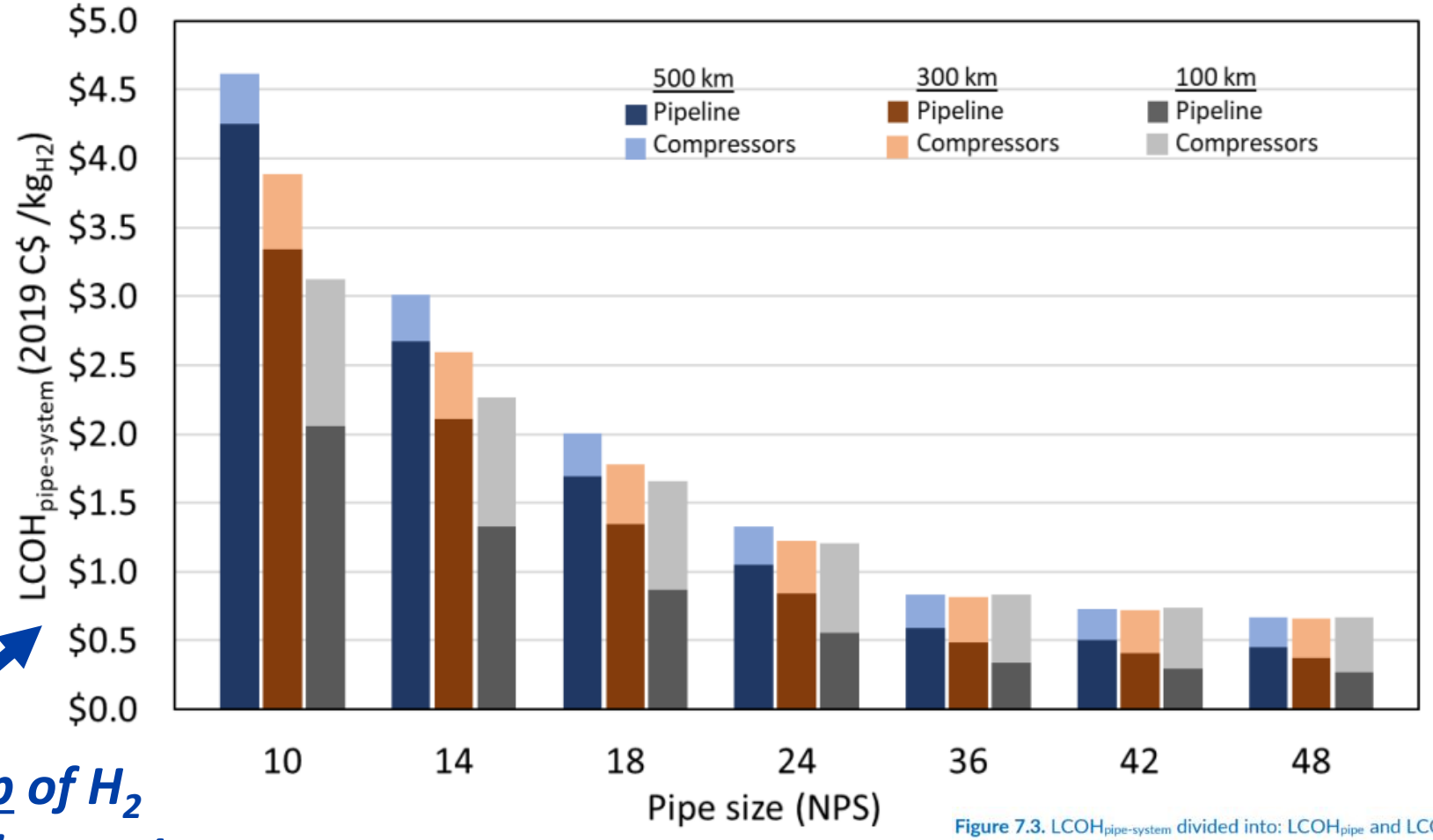
Taxonomy: Options to Decarbonize when Electrification Isn't Affordable or Possible



*"If the hydrogen has to travel a long way before it can be used, the costs of transmission and distribution could be **three times** as large as the cost of hydrogen production."*

- International Energy Agency on The Future of Hydrogen

Hydrogen Transportation Costs



On top of H_2 production costs

Figure 7.3. $LCOH_{pipe\text{-}system}$ divided into: $LCOH_{pipe}$ and $LCOH_{comp}$ versus pipe size (NPS).
Note: The cost analysis is performed for different pipe lengths (distance between compressor stations): 500 km, 300 km, 100 km. The inlet pressure was assumed to be 70 bar, outlet gas velocity of 35 m/s and the total distance is 1500 km. Other assumptions as in **Tables 6.1 and 6.2**.

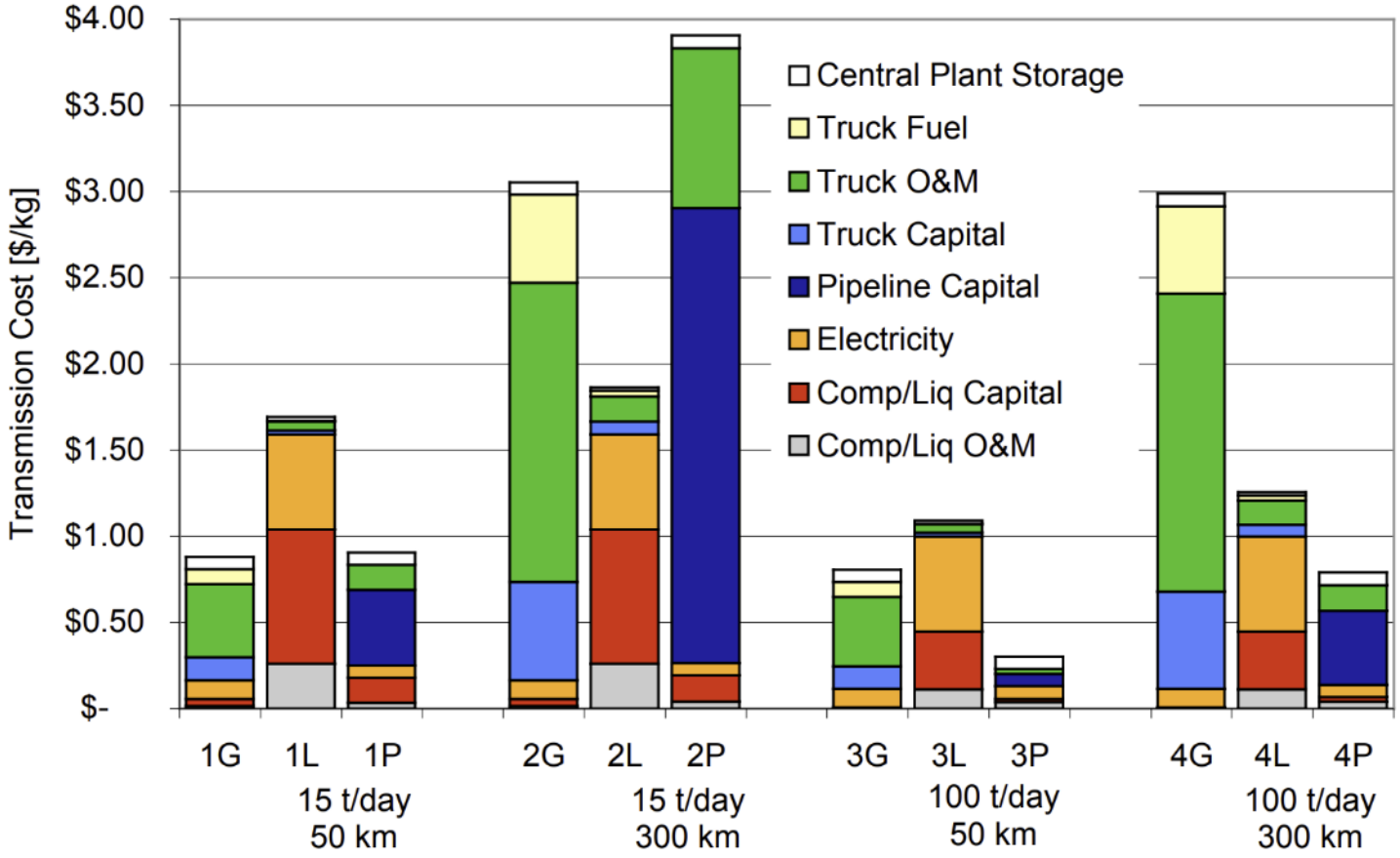
Hydrogen Transportation Costs

- (G) 

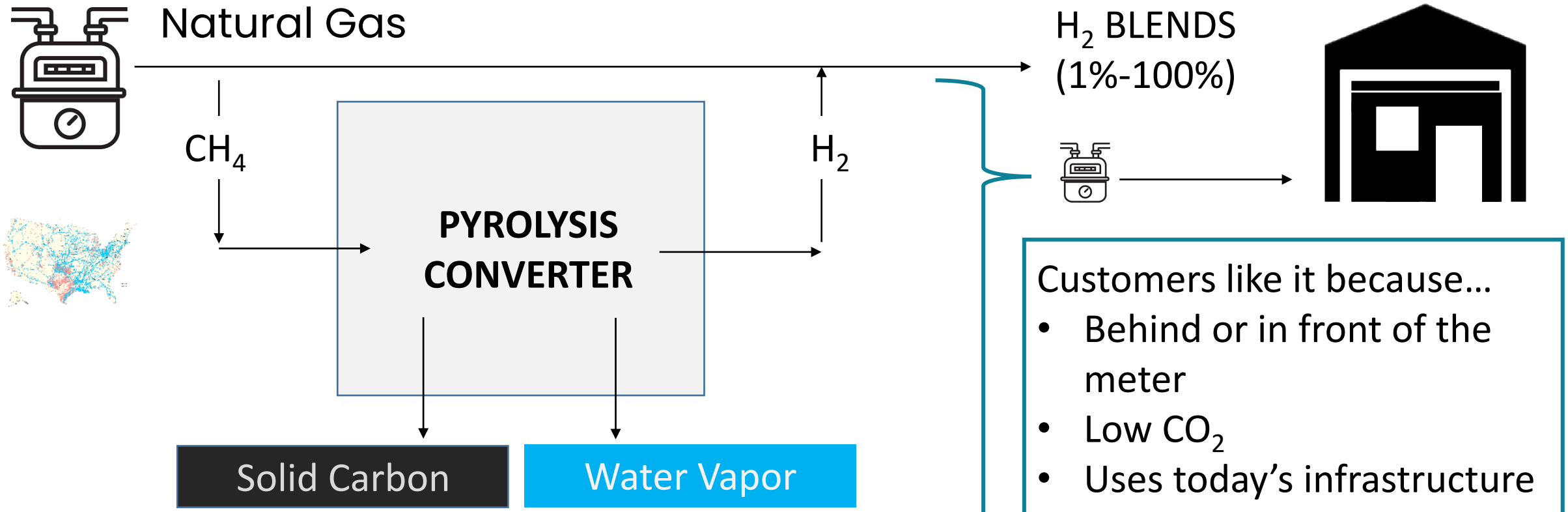
Truck Delivery, Compressed Gas
- (L) 

Truck Delivery, Liquified
- (P) 

Pipeline, Compressed Gas



New paradigm: Clean hydrogen with end of grid pyrolysis



Customers like it because…

- Behind or in front of the meter
- Low CO_2
- Uses today's infrastructure
- No H_2 logistics
- Complementary to electrolysis

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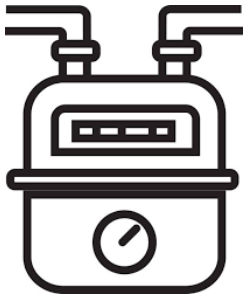
New paradigm: Clean hydrogen with end of grid pyrolysis

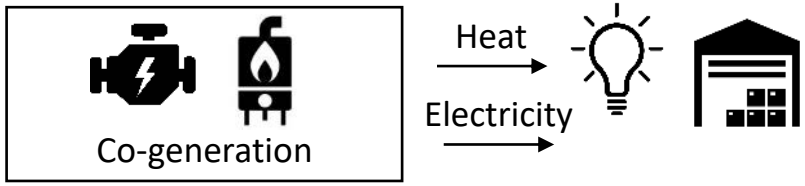


Existing Utility Infrastructure

CH_4 → **PYROLYSIS CONVERTER** → H_2

1. **Process Heating**

2. **Distributed power generation + co-gen**

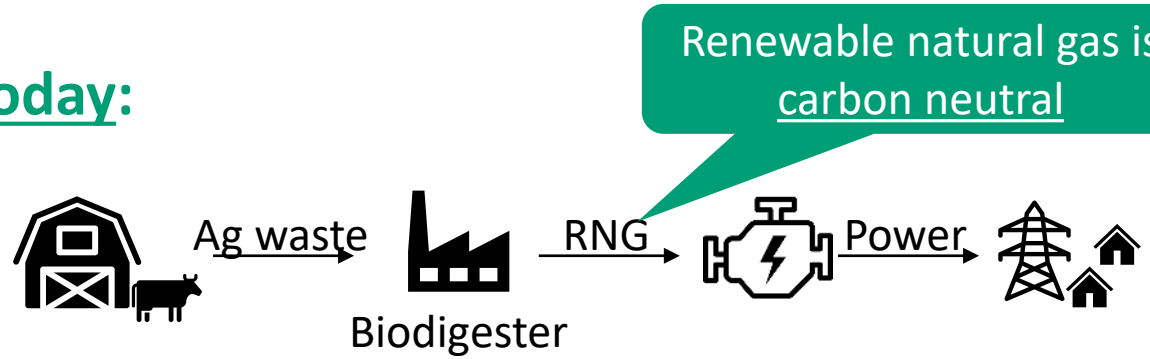


3. **Transport & fleets (FCEVs)**

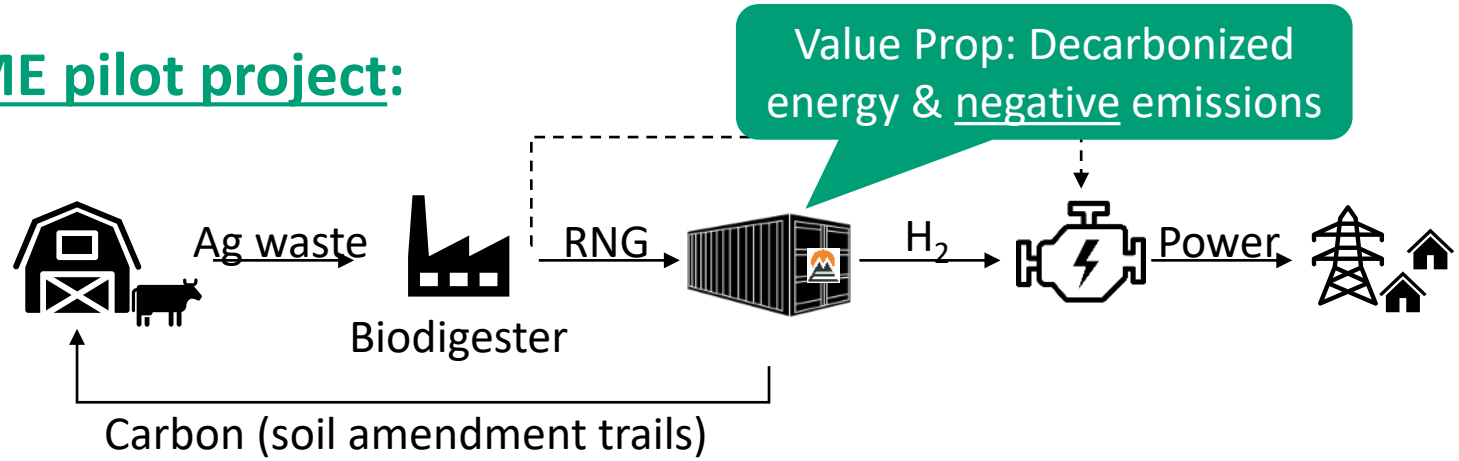
Pilot Projects in the PNW:
Qualco & Tulalip Tribes

- H_2 generated from biogas at dairy digester
- H_2 used for generator; power supplied to Snohomish PUD
- Carbon tilled back into farm soil for water retention
- **-> 'negative' emissions power gen**

Today:



ME pilot project:



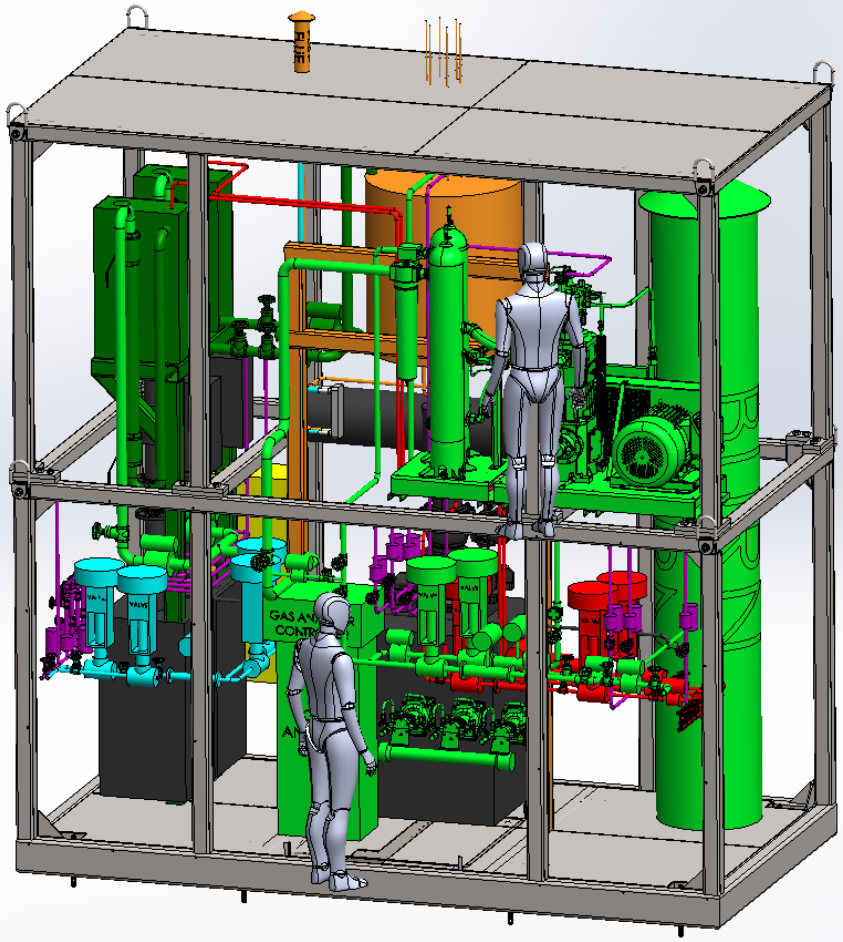
Pilot Projects in the PNW: [Anonymous]

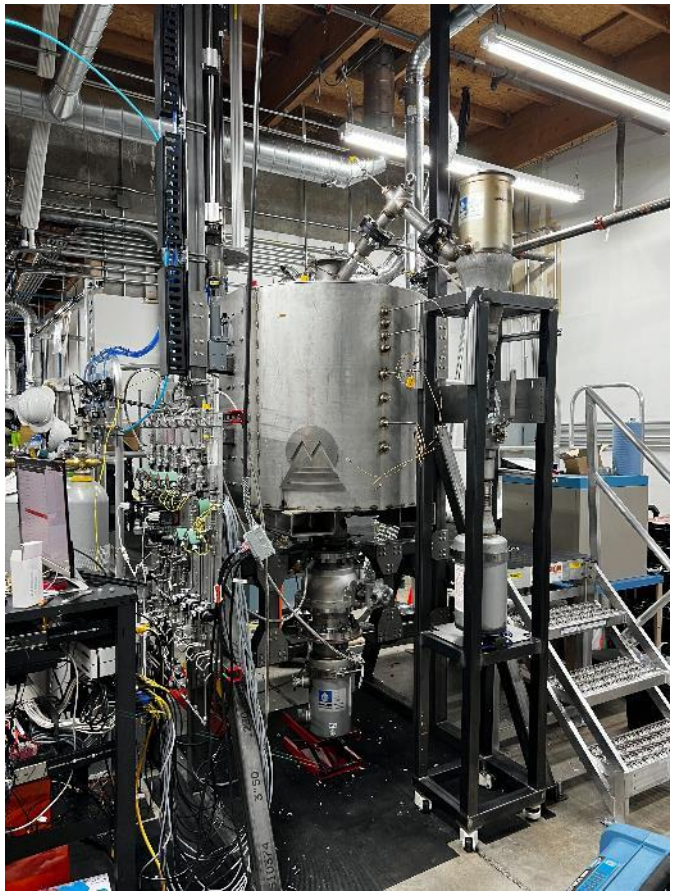
- **H_2 used feeds onsite generator that is hydrogen ready -> decarbonize building co-generation of heat and power!**

Pilot Projects in the PNW:
NW Natural

- H_2 generated at local distribution network at gate station from natural gas
- **H_2 used to help local industrials decarbonize impractical-to-electrify process heat**

Pilot Projects in the PNW

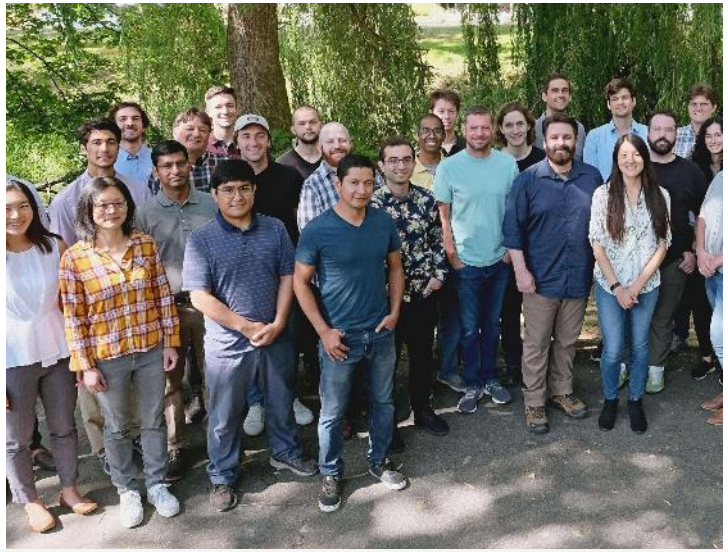




- Shipping container footprint (key for onsite use!)
- Under construction now; deploying in 2023 H_2.
- ~Weekly solid carbon removal, used for rubber, cement, & agriculture.

About Modern Electron

- Founded 2015
- Team of ~50
- $70M raised
- HQ Bothell, WA (Seattle metro)



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Learning Goals Today

- ✓What is the industrial heating landscape, and how does hydrogen fit in? Use hydrogen to decarbonize high-temp heating and difficult-to-electrify applications.
- ✓What are metrics to evaluate for hydrogen projects and products? Carbon intensity (kg CO_2e/kg H_2) and LCOH ($/kg H2), including production, feedstock, capex, AND transportation.
- ✓How is hydrogen produced today? Steam methane reforming, but this has high CI. What are alternative methods? Electrolysis, pyrolysis, and SMR+CCUS. Need to consider scale, cost of feedstock, and overall CI + LCOH when evaluating these technology options.
- ✓Overview of several pilot projects in the PNW with new hydrogen generation technology under new paradigm of end-of-grid pyrolysis. NW Natural: blend H2 in for industrial decarbonization; Qualco: negative emissions power + use C for agricultural water retention; [Anon]: decarbonize onsite building co-gen.

Thank You

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Questions?

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