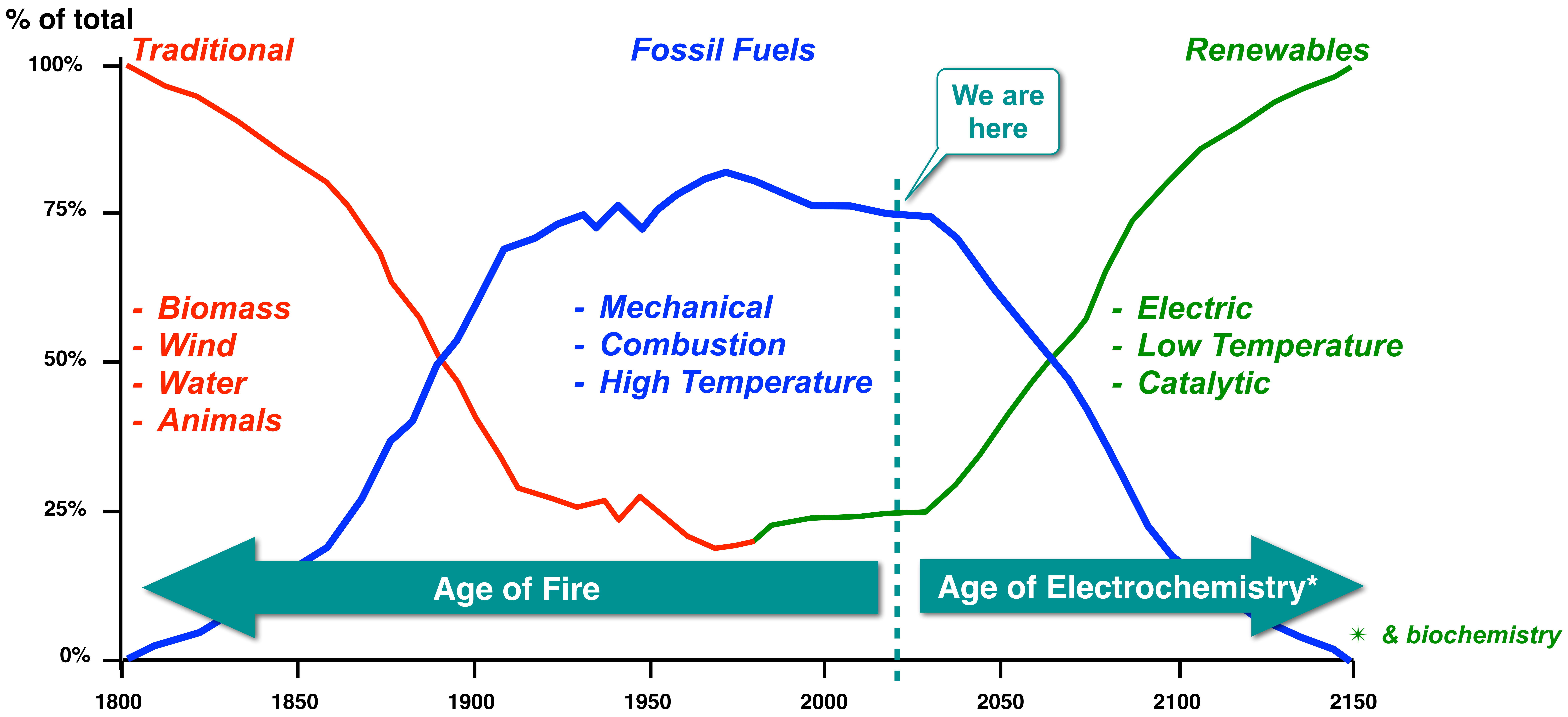
3G&S Technologies Pte Ltd

Low-Cost Green Hydrogen from Biomass

California Bioresource Alliance Symposium

9-10 NOVEMBER, 2022

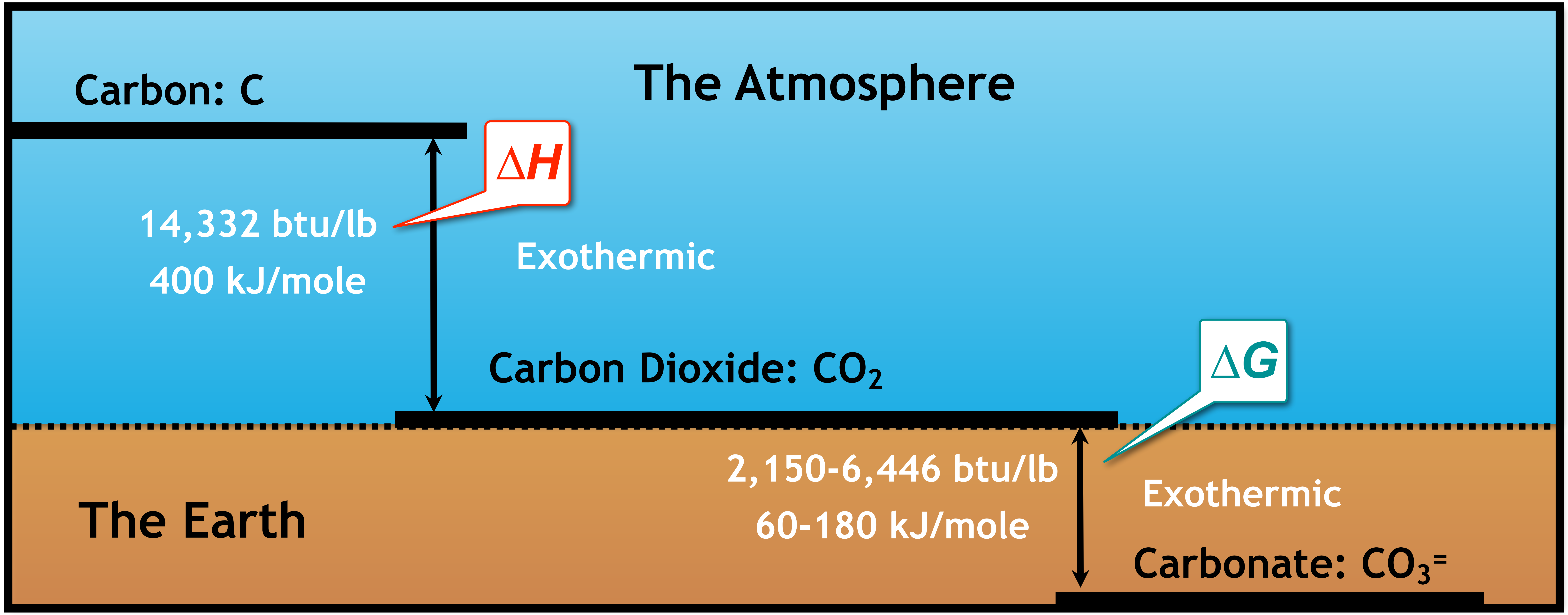
The History & Future of Energy - according to Shell



Source: Ewald Breunesse, Shell Netherlands, 14th IAMA Conference, Montreux, 14 June 2004

Pat Grimes observed that…

… the ground state of carbon is a mineral carbonate…



…and Carnot is leaving a lot of energy on the table.

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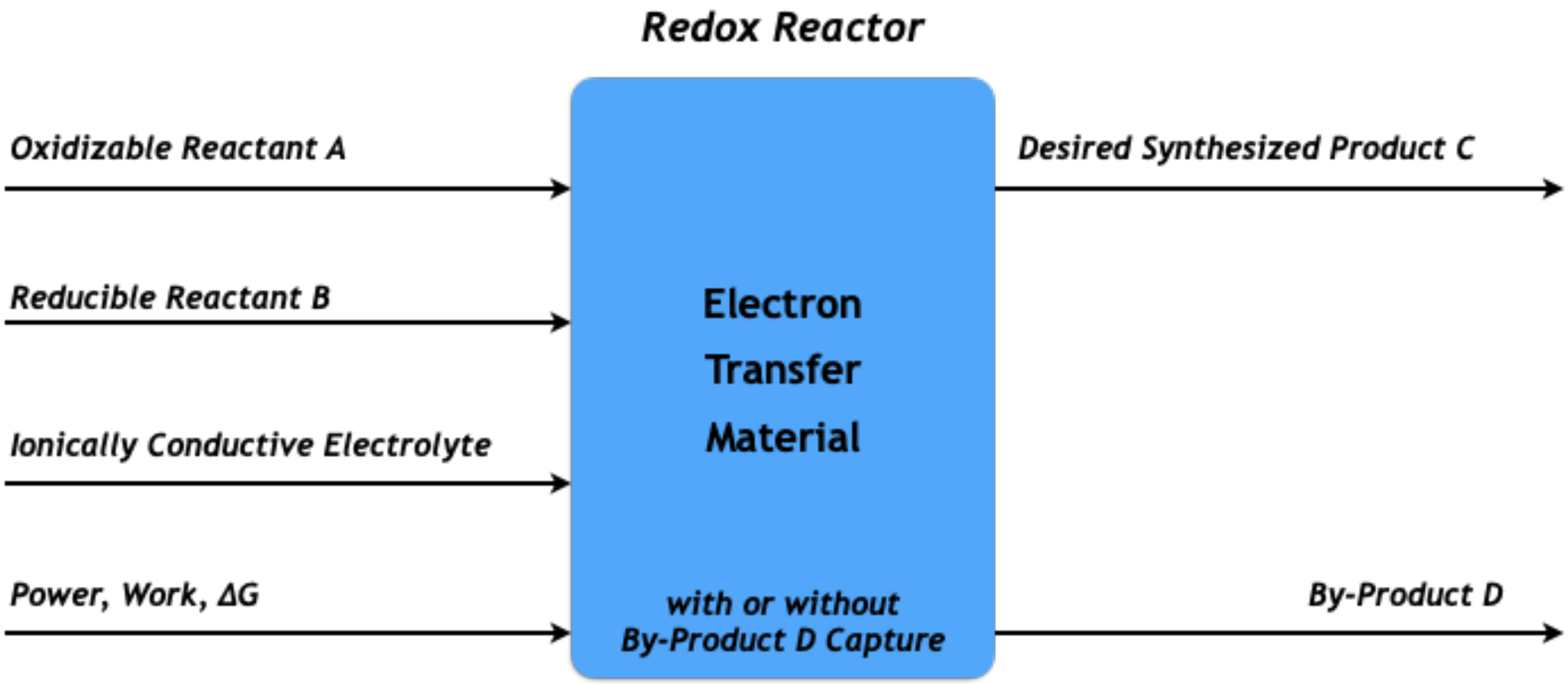
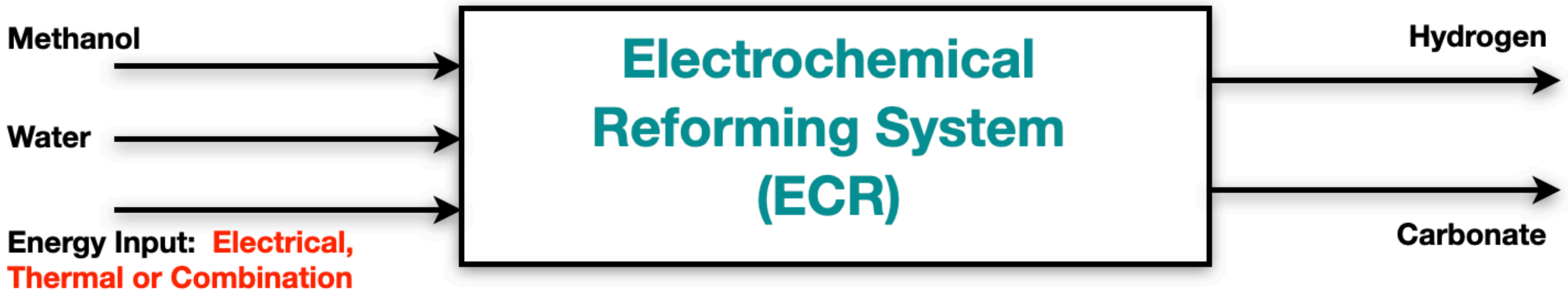
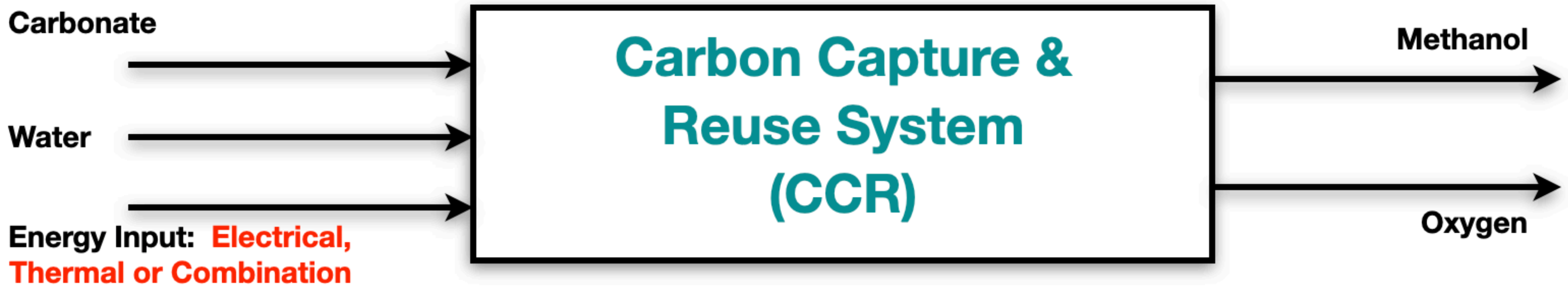
What are Grimes' Processes ?

Free Energy Driven Process
($\Delta G = \Delta H - T\Delta S$)
Occurs in Acidic, Neutral & Basic Systems
Reactant A + Reactant B + Energy, Power, ΔG => Desired Product C + By-Product D



Grimes industrializes naturally occurring processes





ECR – Electrochemical reformer is a proprietary technology that can convert multiple carbonaceous feedstocks into low-cost **Green Hydrogen**

- low-temperature
- liquid-phase
- recover Gibbs Available Energy (ΔG)
- built in of pre-combustion carbon capture
- carbon can be captured at its source
- lower energy consumption
- higher efficiency
- captured carbon can be recycled as valuable hydrocarbons and oxygen

CCR - Carbon Capture and Reuse system is a proprietary system that can capture atmospheric or post-combustion CO_2 and convert into **Hydrocarbons**

- low-temperature
- liquid-phase
- recover Gibbs Available Energy (ΔG)
- capable of atmospheric and post combustion carbon capture
- carbon can be captured at its source
- lower energy consumption
- higher efficiency
- captured carbon can be recycled as valuable hydrocarbons and oxygen

Example: Electrochemical Reforming (ECR)

Fossil industry’s “Blue Hydrogen”:

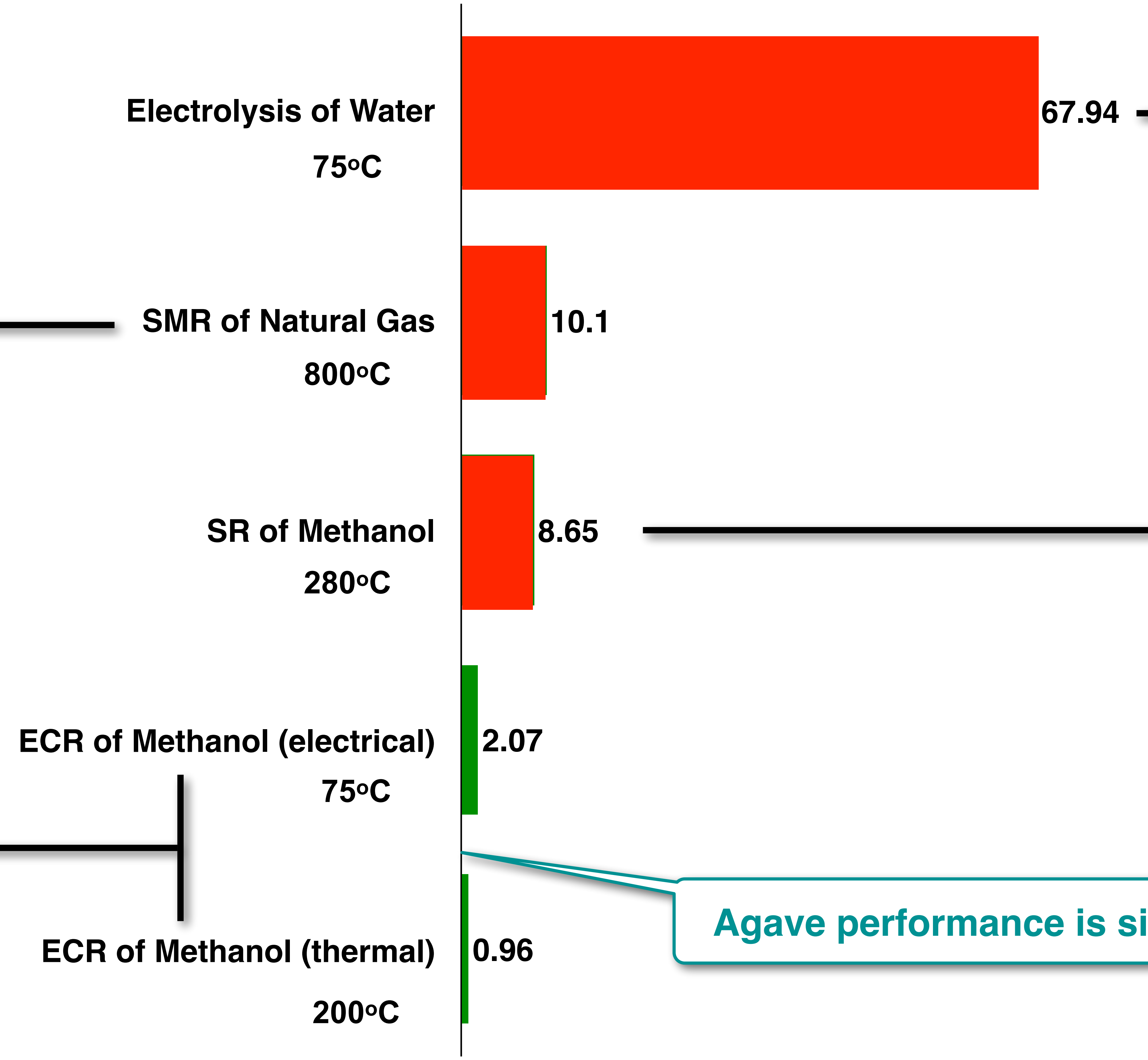
- 50% lower yield than ECR
- Energy penalty associated with CCUS
- **1.5x higher delivered costs** in Singapore than ECR of agave juice

Methanol was initial feedstock chosen by COP for ECR development:

- Logistic compatible fuel
- Bio-sourced methanol cost-competitive
- Sugar from agave has similar thermodynamics

Energy Required to produce H_2

(kcal/mole - 1 mole = 2.02 grams)



Agave performance is similar to Methanol

Green Hydrogen through he electrolysis of water:

- Intermittent source (solar & wind)
- 33x more energy than ECR
- **3x higher delivered costs** in Singapore than ECR of agave juice

Lowest cost option - Green Methanol:

- **3x higher delivered costs** in Singapore than ECR of agave juice

Problem with Hydrogen

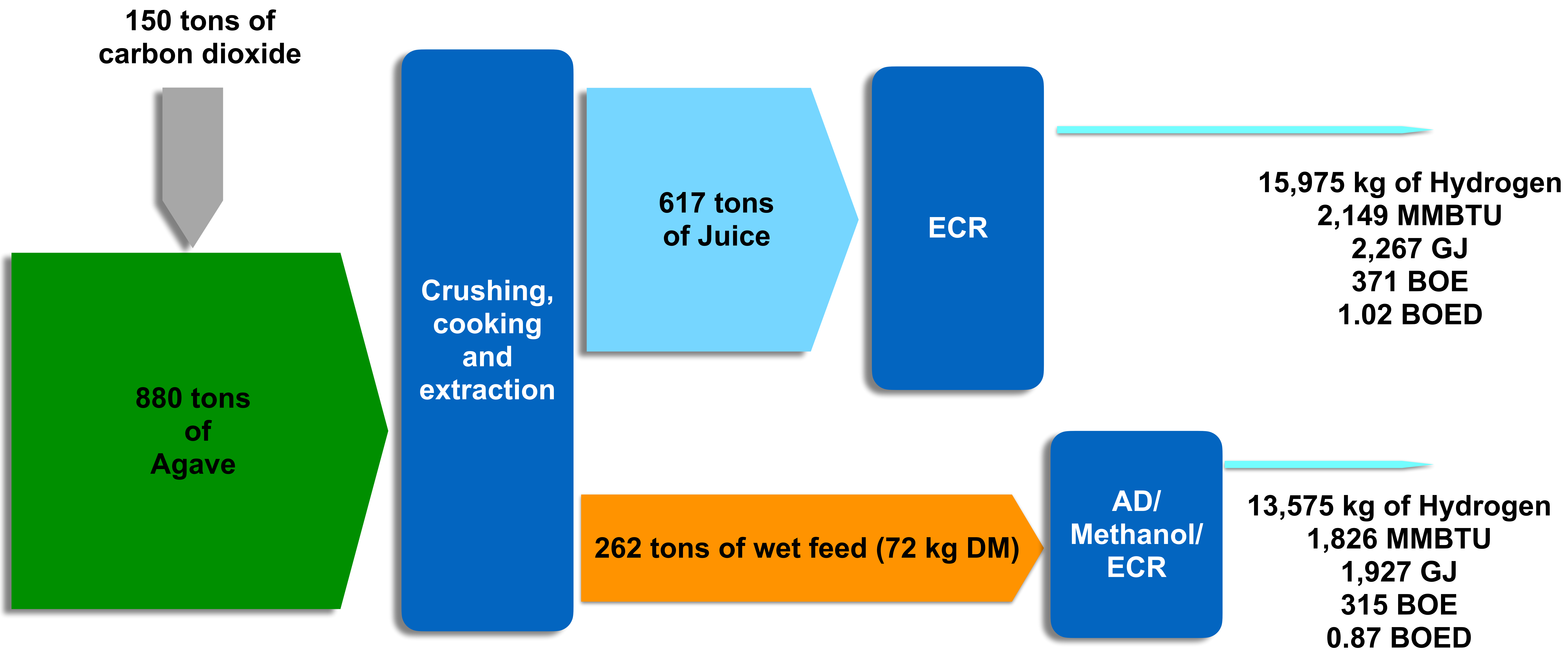
1. Energy intensive to produce
2. Expensive to compress or liquefy
3. Expensive and difficult to transport
4. Storage is hazardous and needs physical security

Solution

1. Never transport or store hydrogen, only produce it on demand
2. Transport and store benign bio-derived sugar juice or methanol instead
3. Use an order of magnitude less energy to produce each kg of hydrogen
4. Distribute such production capacity close to end users

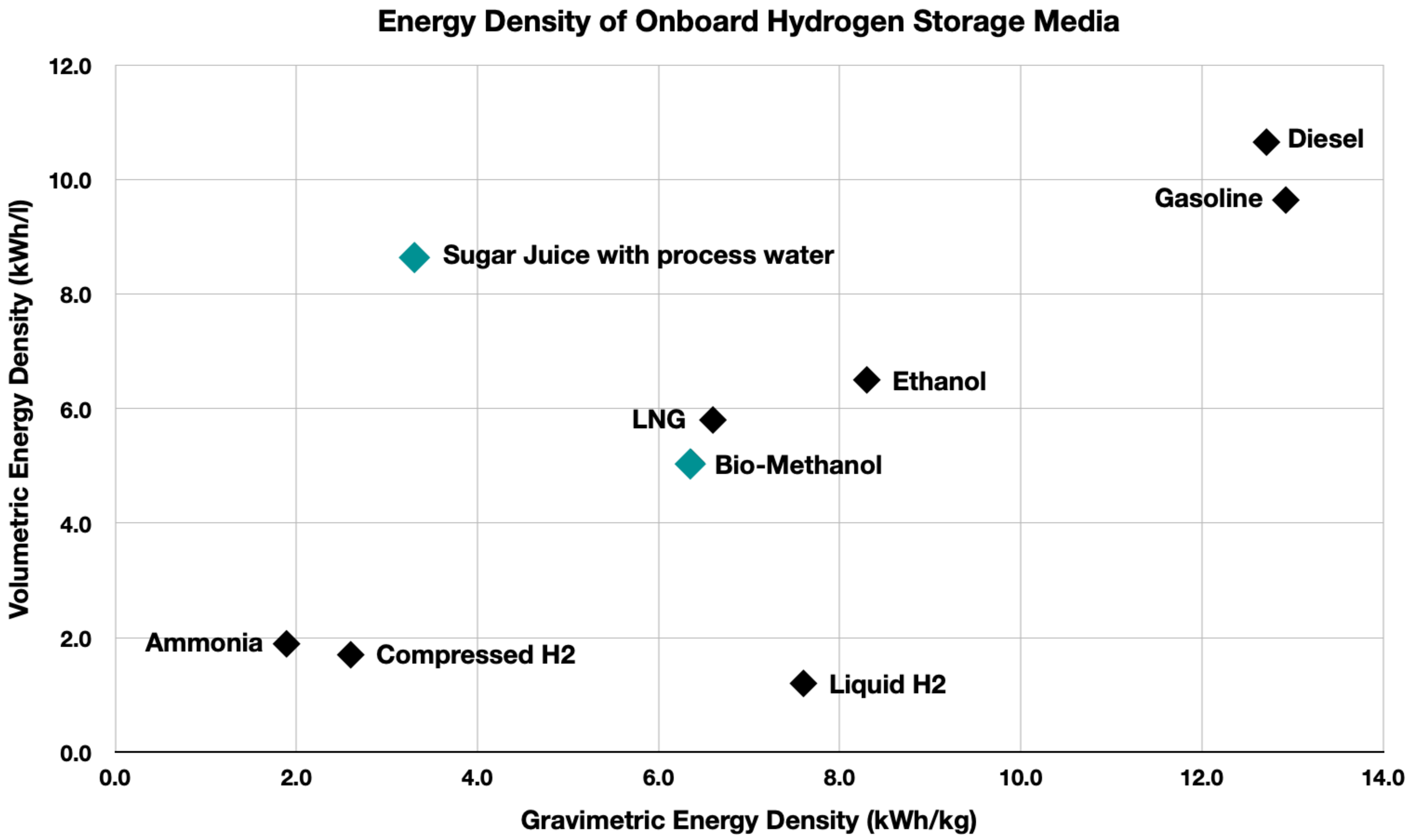
What are Grimes' Processes ?

Products from 1 ha of Agave



20% of Singapore's total energy = 5.5x its area

Energy Density



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Tanker Comparison

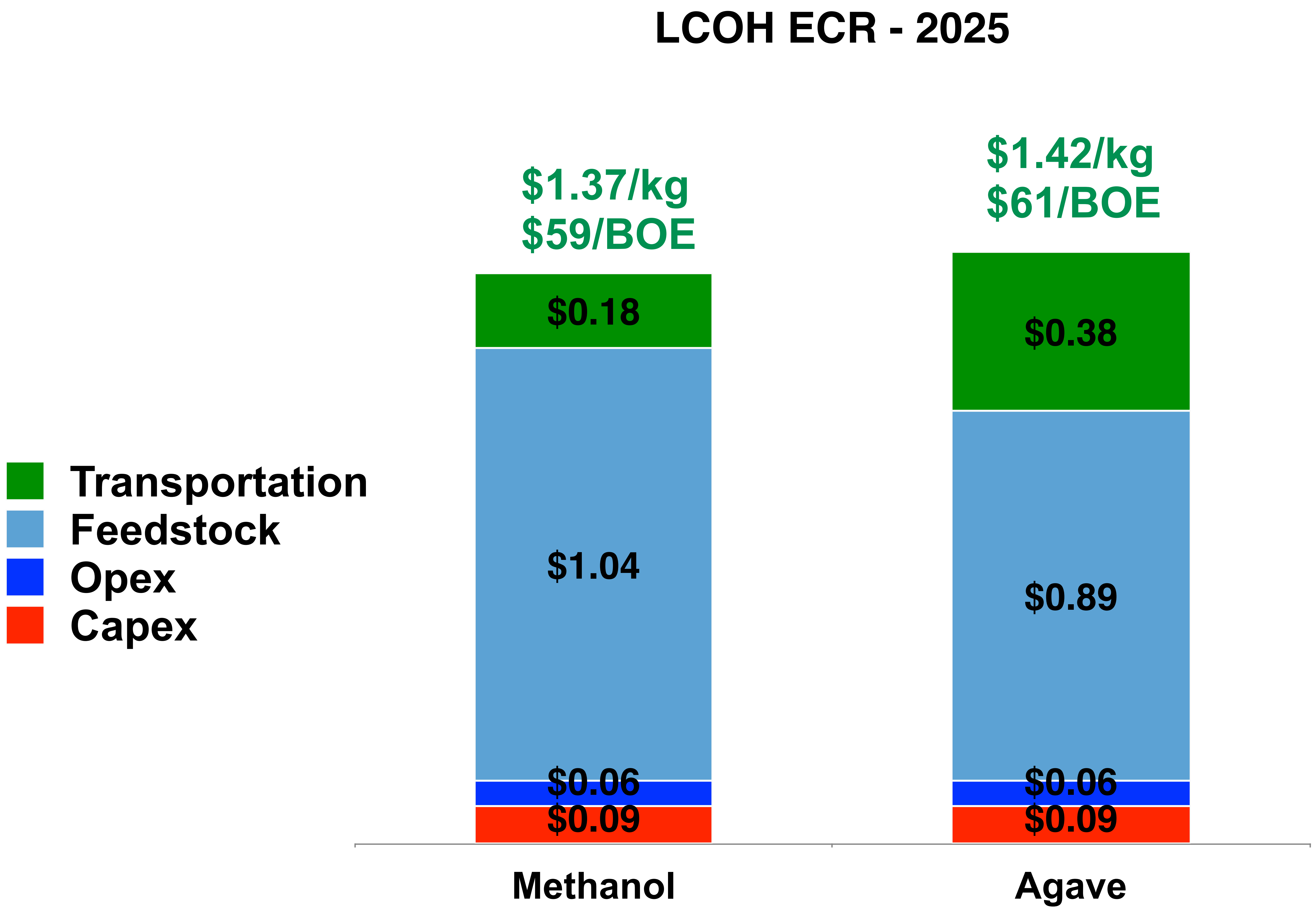
Liquid Hydrogen Tanker

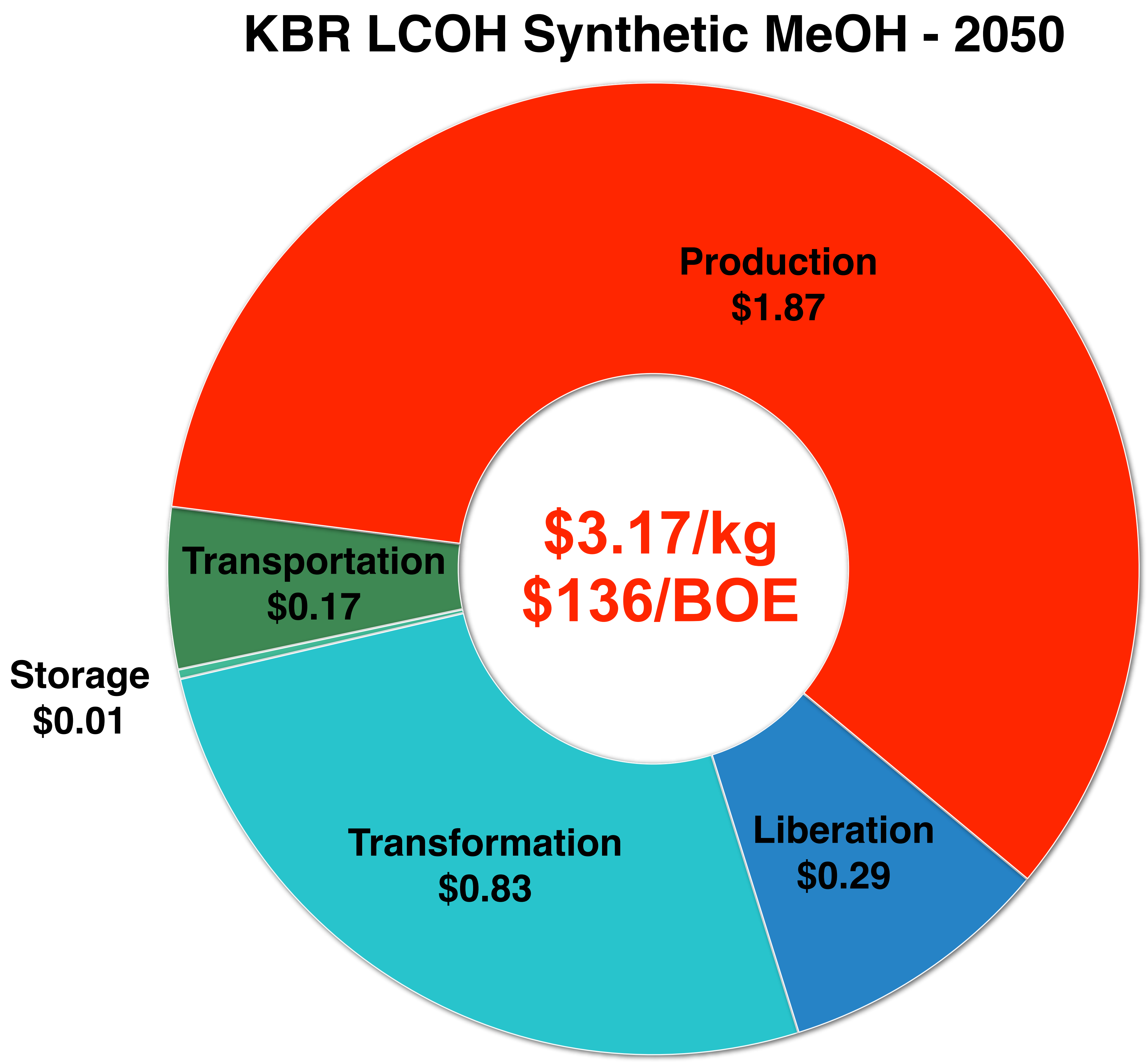
Capacity: 11,400 tons of Hydrogen
Length: 1,100 feet
Temperature: -253 degrees Celsius
Cost: US$ 302M (projected 50% reduction)

Sugar Juice Tanker

Capacity: 28,480 tons of Hydrogen
Length: 1,100 feet
Temperature: Ambient
Cost: US$ 120M

LCOH Comparison: KBR Singapore 2050 v ECR 2025





Notes: *Electricity cost* *= $0.030/kWh*
Green Methanol cost *= $164/ton*

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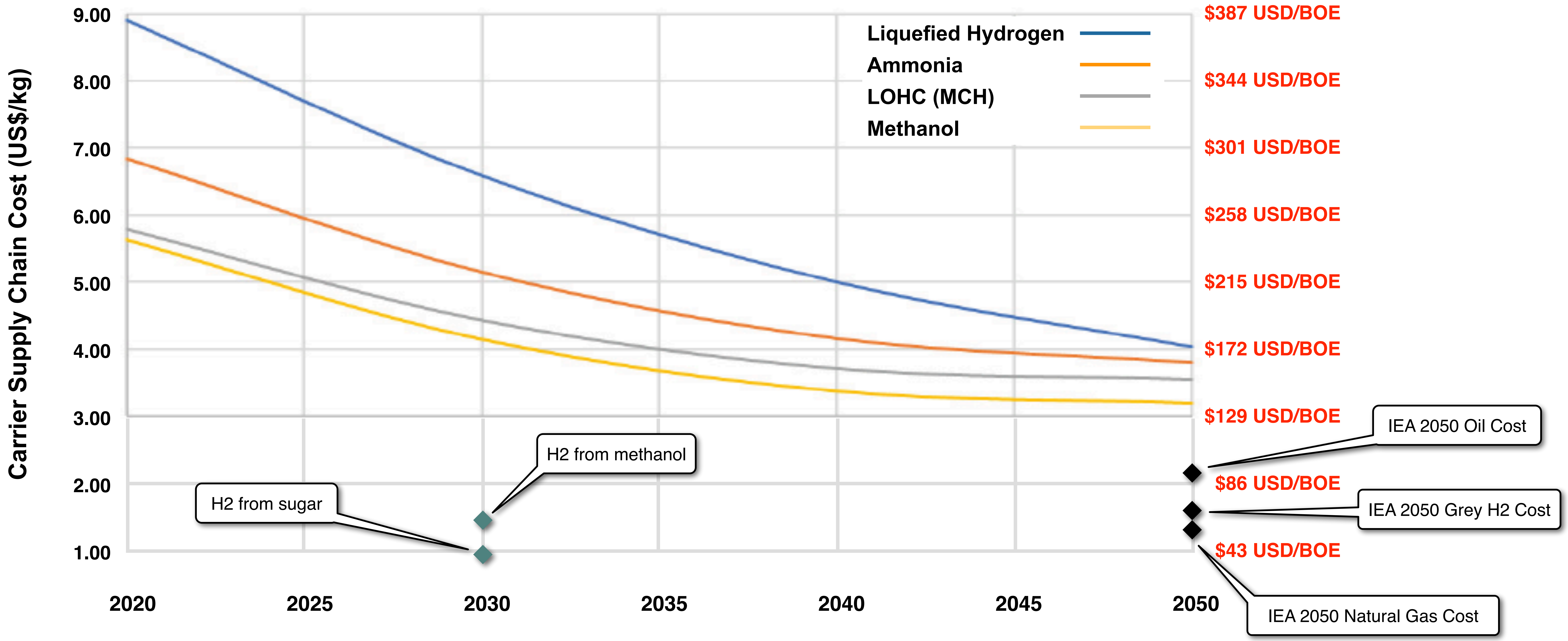
Comparison of LCOH to Fossil Fuels



Predicted Cost Improvements of Each Carrier Supply Chain from 2020 - 2050

Source: Study of Hydrogen Imports & Downstream Applications for Singapore, Figure 5.14 - KBR - 2020

Cost of Green H_2 from Agave Juice & Methanol (CI# = 0)

880 tons

1 ha agave

Vendor Quotes

203 tons fertilizer

73 Mm^3 biogas

Cost of Hydrogen

Feedstock $/ton juice	Feedstock $/kg H2	Capex $/kg H2	Opex $/kg H2	Total $/kg H2
$ 25	$ 0.30	$ 0.09	$ 0.06	$ 0.44

Cost of Methanol

Feedstock $/m³ biogas	Feedstock $/ton MeOH	Capex * $/ton MeOH	Opex $/ton MeOH	Total $/ton MeOH
$ 0.03	$ 23.78	$ 95.12	$ 44.64	$ 163.54

in-house cost

* *100% debt over 10 year term @ 5.5%*

Vendor Quotes

235 tons Methanol
295,226 liters
1,859 BPD

26.28 Mm^3

tailgas

Vendor Quotes

6,501 MWh(e)
< $0.03/kWh

161.48 tons CO_2

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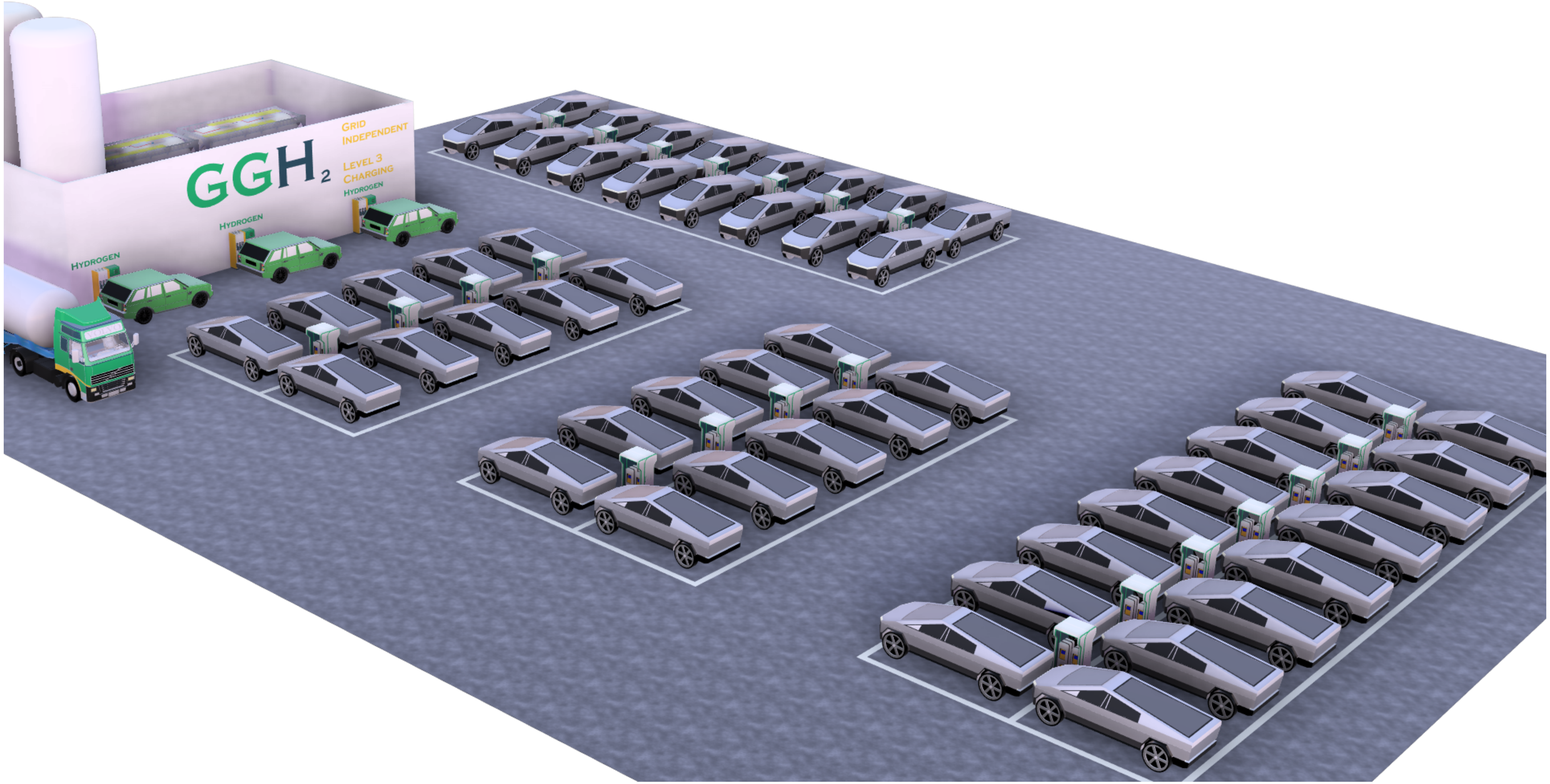
Market Strategy

1. Focus on utility users who have already committed to hydrogen in NGCC plants (from 20% to 70%) and repowering of older thermal plants.

2. Offer green hydrogen that is cost-competitive with fossil fuels for vehicles and make additional hydrogen to power grid-independent charging stations for electric vehicles

3. Options for California,
   a) import cane juice from the southern US & Caribbean
   b) grow agave in the southern half of the state and central valley
   c) ship sugar juice from Australia and other countries to be converted into hydrogen for power generation at a landed cost of ~$1.25/kg by 2030
   d) convert bagasse from the sugar juice sources into bio-methanol and ship to Singapore and other countries to produce hydrogen on demand for a cost of $2.00/kg by 2027.

First California Market - Grid Independent Charging



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