AIChE® 13th SOUTHWEST PROCESS TECHNOLOGY CONFERENCE

September 30 - October 1, 2021

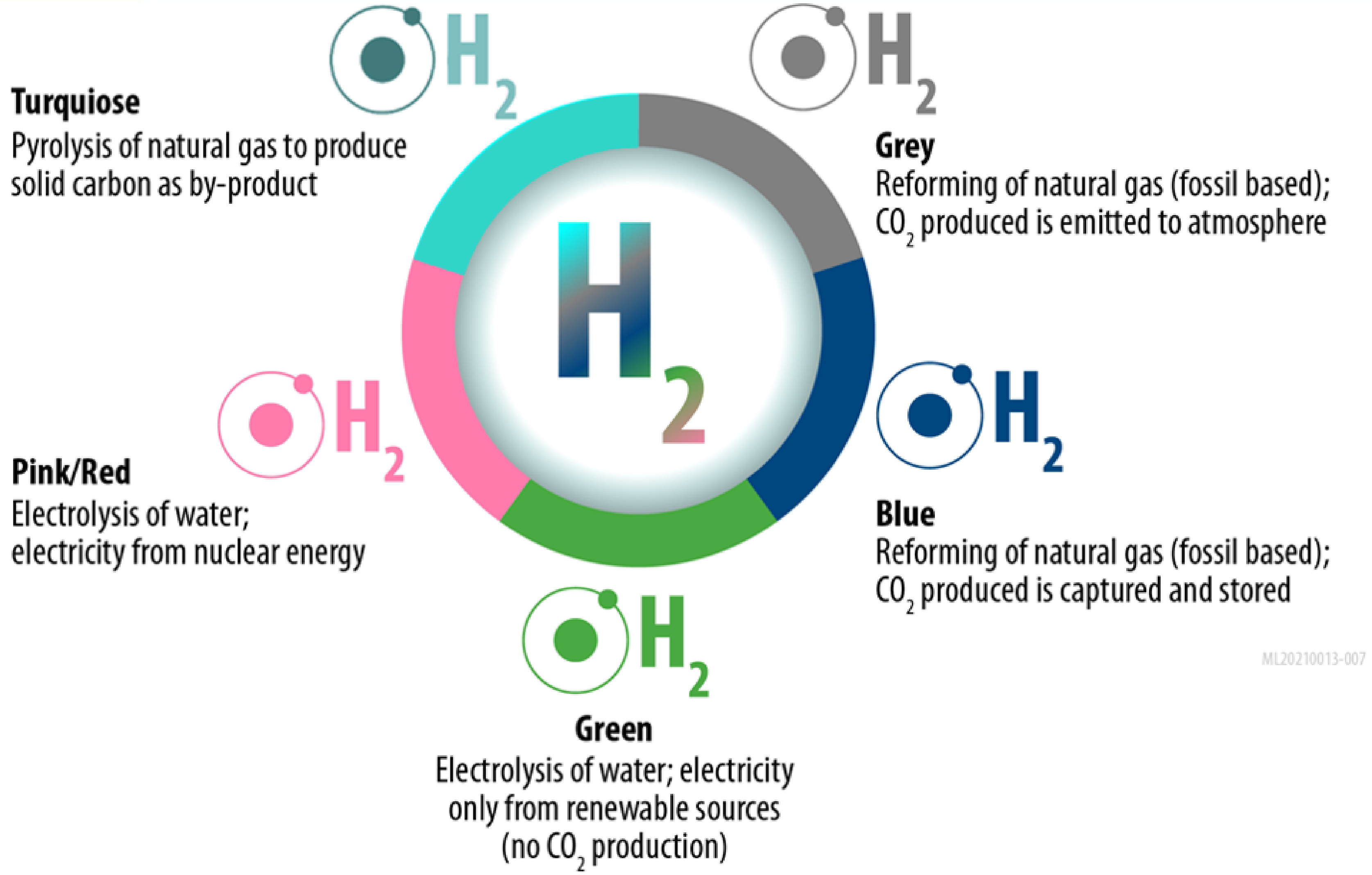
Sugar Land Marriott Town Square, Texas

There is No C in Hydrogen

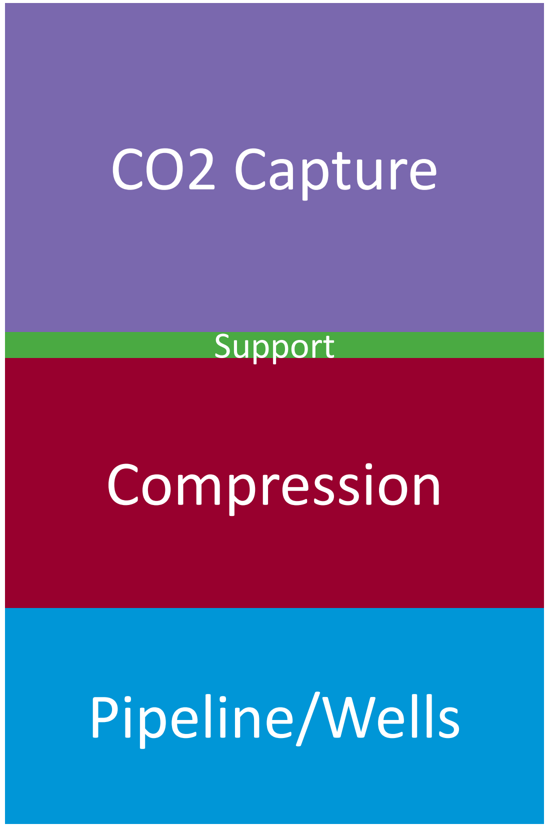
Low Carbon Footprint Hydrogen Production

Matt Reisdorf
Fluor

Colors of Hydrogen

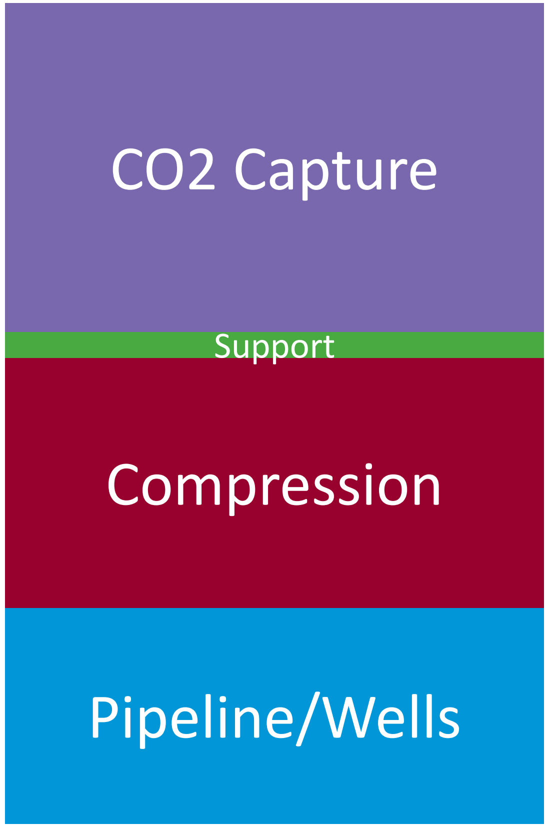


Capital Cost of Low Carbon Hydrogen: Postcombustion Blue H_2 as an Example



Basis: Precombustion amine capture from Hydrogen. Total capital cost categorized by equipment cost to yield approximate cost per category.

Capital Cost of Low Carbon Hydrogen: Ultimate Destination

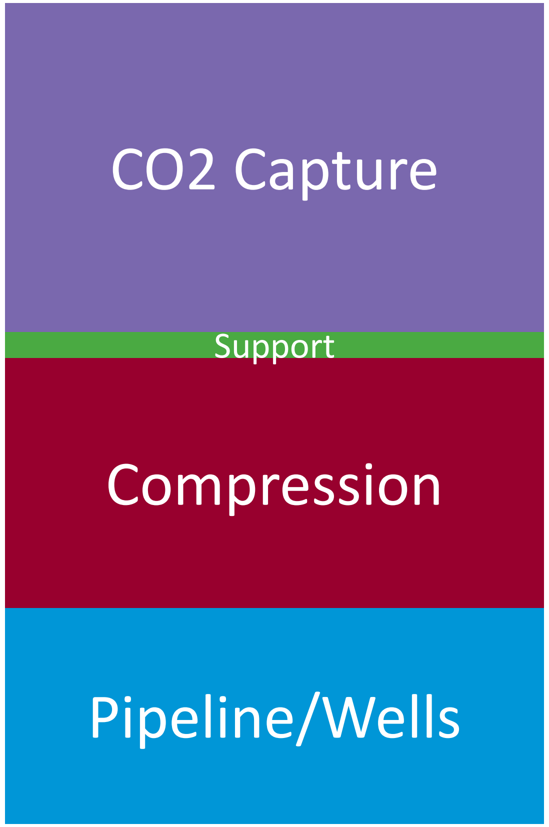


- Enhanced Oil Recovery can justify (varies with geology, geography, and oil price)
- Shared pipeline systems bring economies of scale
- Carbon Utilization initiatives seek opportunities to turn cost to value
- Geologic research has identified widespread storage opportunities

ALBERTA CARBON TRUNK LINE

CARBON TO VALUE INITIATIVE

Capital Cost of Low Carbon Hydrogen: Compression



- Capture technology can somewhat affect suction pressure…but high discharge pressures set by geology and hydraulics.
- Some carbon utilization targets do not require compression

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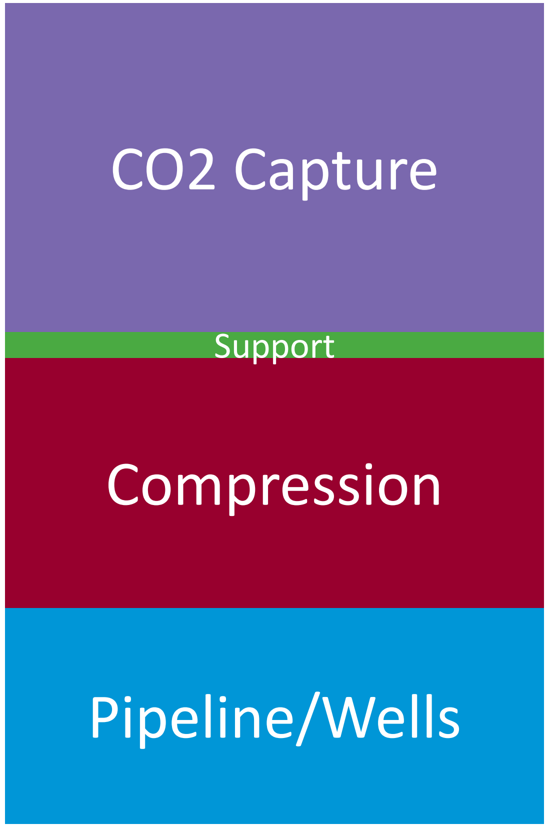
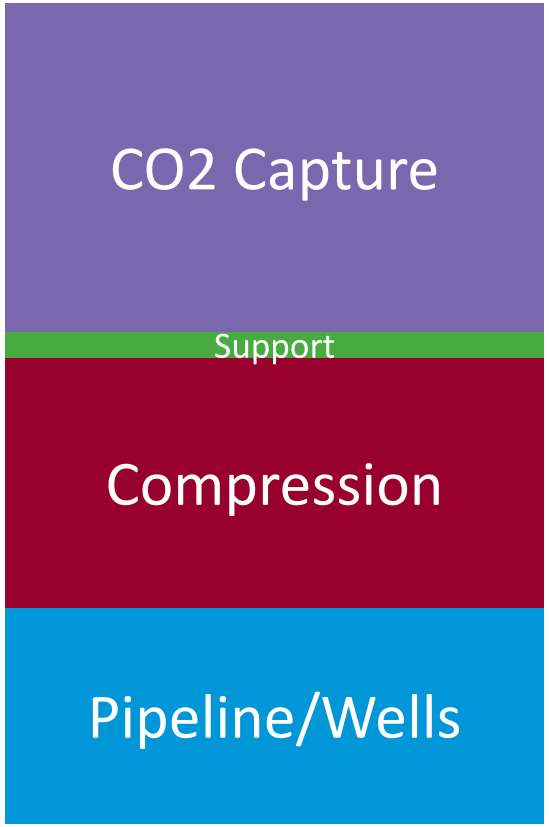
Capital Cost of Low Carbon Hydrogen: Support



- Carbon capture systems can be large users of steam, power, and cooling
- Fortunately, hydrogen plants often export steam and have other utilities available, minimizing new utility capital requirements

Capital Cost of Low Carbon Hydrogen: Carbon Capture

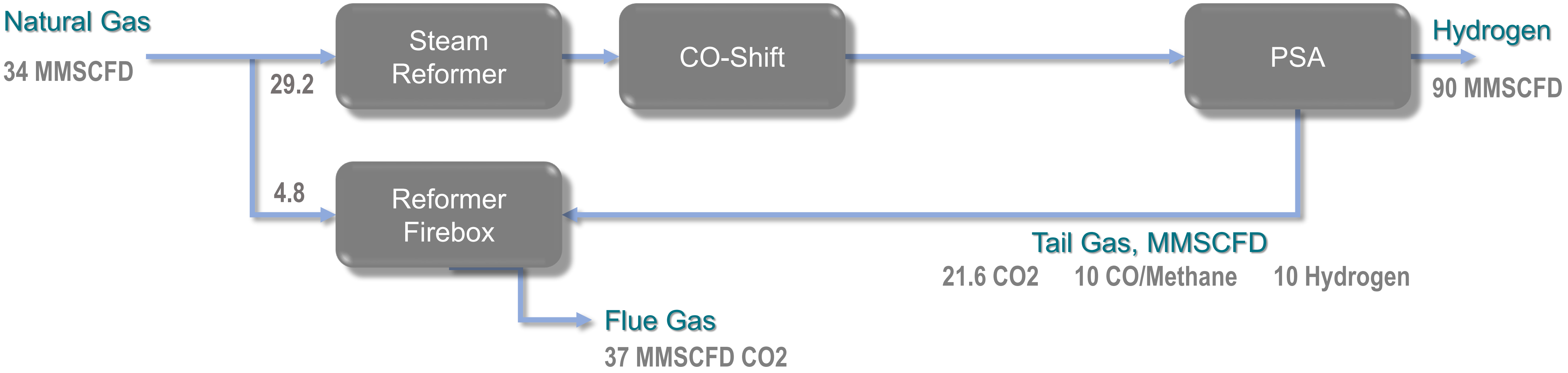


- Carbon capture costs vary with technology, but are only one piece of the total
- Reducing CO2 Capture costs by 50% affects the total cost by only 20%

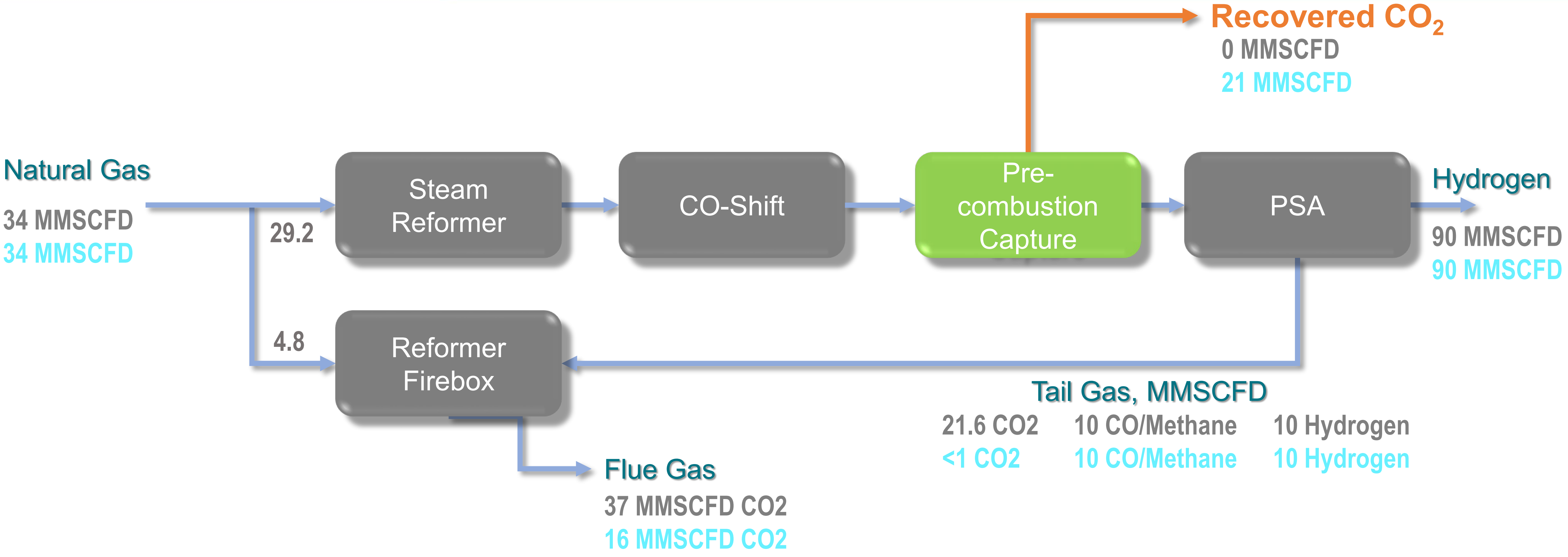
Incentives for Low Carbon Hydrogen

- Enhanced Oil Recovery: Varies, but perhaps $35/MT
- US 45Q Incentives: $35-50/MT
- Low Carbon Fuel Standard: Varies by destination, but can be $200/MT for liquid fuel producers
- Current Cap and Trade: Varies by location, but ~$20/MT
- Future regulation may significantly increase

Modern SMR Hydrogen Plant



Precombustion SMR Carbon Capture
(57% Direct Emissions Captured)



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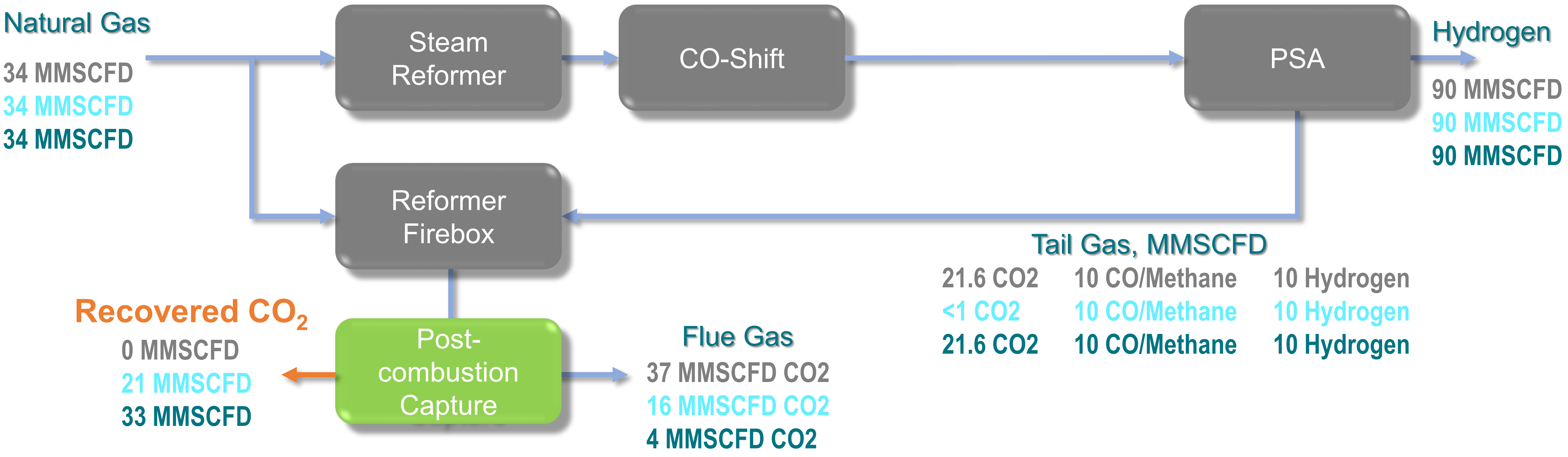
Postcombustion SMR Carbon Capture
(90% Direct Emissions Captured)



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Major Operating Costs

	Precombustion Amine	Postcombustion Amine	Physical Solvent
Steam, MT/MT CO_2	1.14	1.15	0
Power, kWh/MT CO_2	138	173	198
Cost, $/MT CO_2 ($5/1000 lb steam, $0.05/kWh)	$19.50	$21.30	$9.90

Amine utilities from actual operating facilities, public domain data, for relatively CO_2 rich sources. Solvent utilities estimated. Steam and power costs will vary with facility

Physical Solvent for Carbon Capture

	Physical Solvent	Amines
Composition	Non-Hazardous	May be Hazardous
Metallurgy	Generally Carbon Steel	Stainless Steel
Solvent Degradation	Not a concern	Significant concern
Regeneration	Simple flashing	Steam-based regenerator
Solvent Maintenance/ Reclamation System	Not Required	Required
CO_2 Captured	Highly concentrated	Highly concentrated
CO_2 Capture Percentage	>90%	>90%

Physical solvent based on Fluor Solvent

Other Routes to Blue Hydrogen

- Autothermal Reformer or POX with Carbon Capture
    - No reformer furnace loads to consider
- Adsorption
    - Vacuum Swing Adsorption by Air Products

THE SHELL BLUE HYDROGEN PROCESS

Water Electrolysis Basic Components

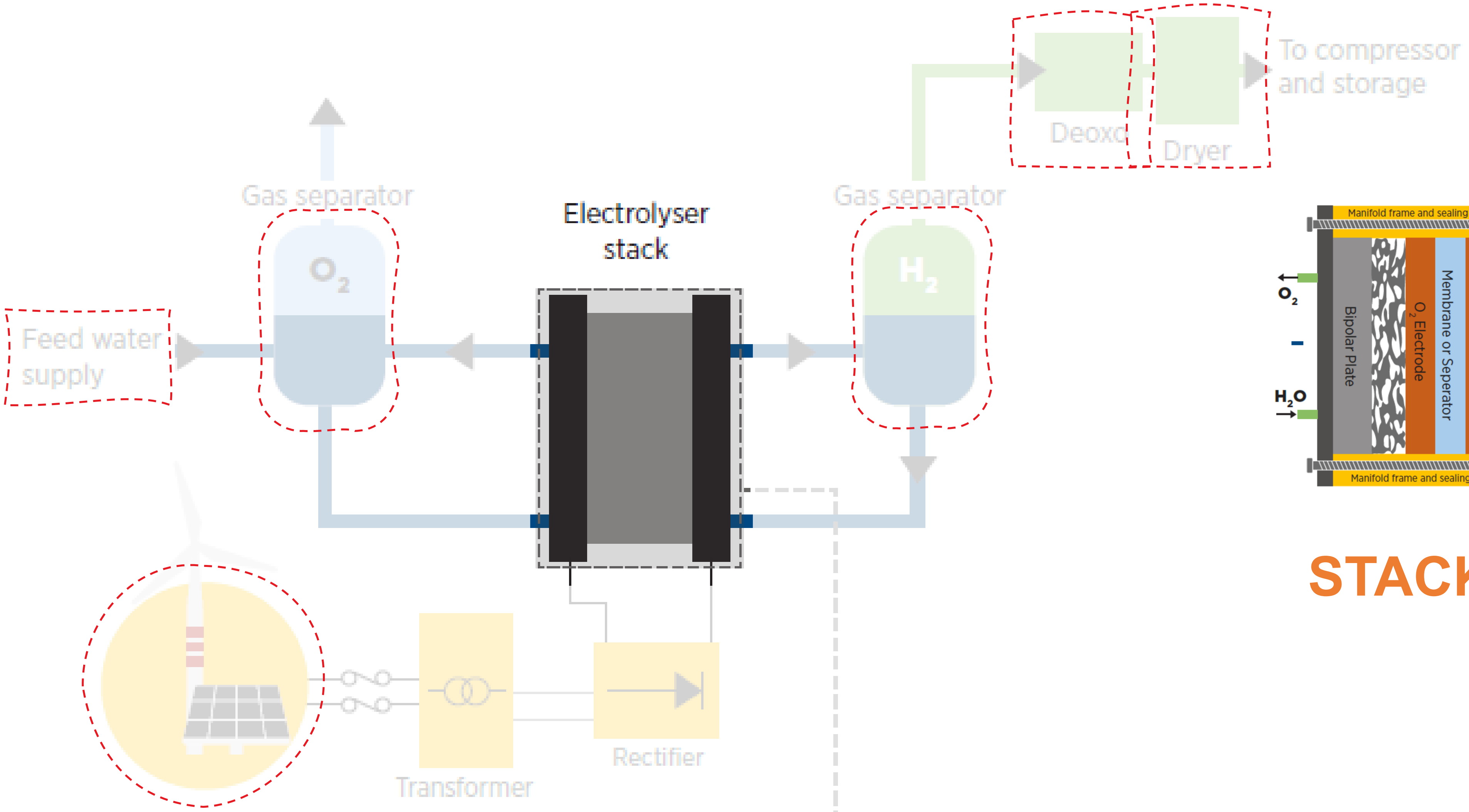
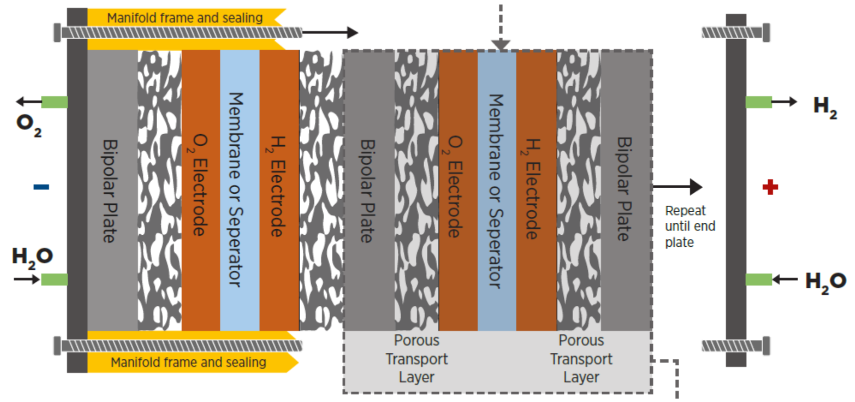


Image Credits: IRENA, Green Hydrogen Cost Reduction

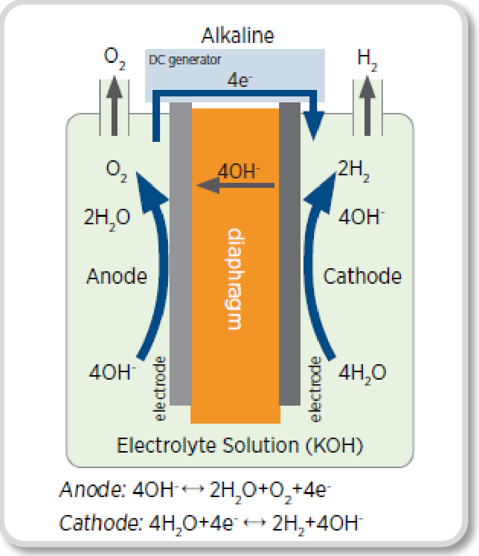


STACK

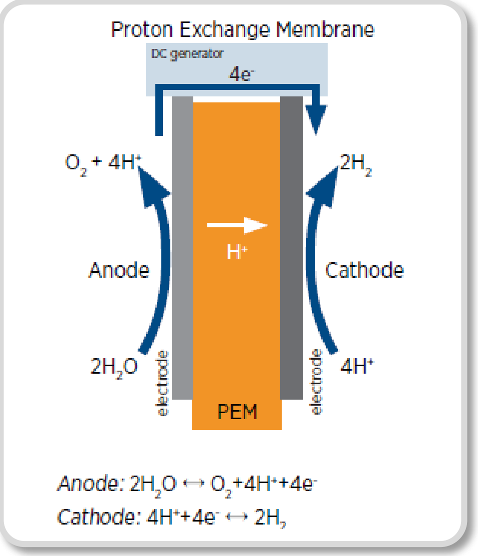
Image Credit: ITM Power

Types of Water Electrolyzers

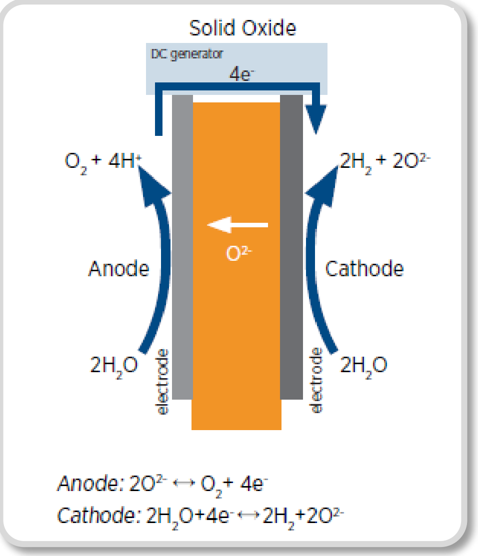
ALKALINE



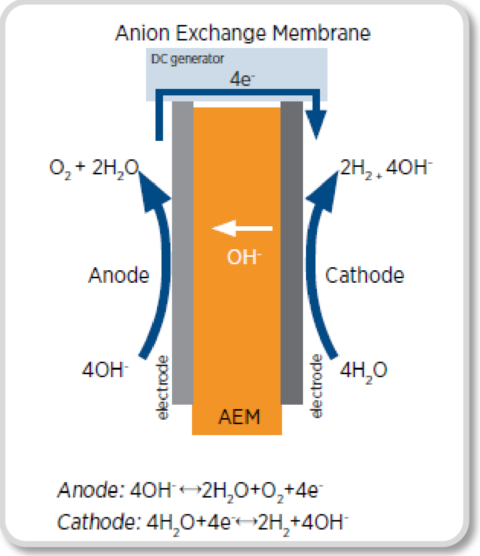
PROTON EXCHANGE MEMBRANE (PEM)



SOLID OXIDE (SOEC)



ANION EXCHANGE MEMBRANE (AEM)



Mature and Reliable

Developing Technology

Image Credit: IRENA, Green Hydrogen Cost Reduction

How Green is Blue Hydrogen?

- A recent article ("How Green is Blue Hydrogen", Howarth and Jacobson) has created recent news
- The premise that fugitive emissions is important to consider is valid, but the conclusion in the headlines needs to be considered critically


HOUSTON CHRONICLE

'Blue hydrogen,' touted as clean natural gas product, may pollute more than coal, new research finds

James Osborne

Aug. 13, 2021 | Updated: Aug. 13, 2021 11:50 a.m.

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How Green is Blue Hydrogen?

- The following analysis is based on the IEAGHG 2017-02 report, which considers:
  - A full material balance of a modern SMR hydrogen plant, with the value of produced steam converted to electricity
  - A full material balance of a conservative postcombustion carbon capture facility, with steam and power generated from the SMR excess steam
- This analysis considers the full energy impact of the hydrogen plant and onsite carbon capture

How Green is Blue Hydrogen?

	Howarth and Jacobson	Industry Experience
Energy for Carbon Capture	Separately produced without carbon capture, adds to emissions	Steam is a byproduct of SMR process and can be used to generate power
Energy Inputs for SMR	High level figure from literature	Rigorous material balance is 18% lower
Carbon Capture Rate	65-85%. Low end from cycling power plant	>=90% in steady state operation. Cyclic operation will be lower, but many hydrogen plants are steady state

Grey Hydrogen

	Value used in Howarth and Jacobson	mol Methane per mol H2 Produced
SMR Process	0.875 mol Methane / MJ H2	0.250
Fuel	0.1814 MJ Energy / mol H2	0.206
Electricity Required	Included above	
Total		0.456

First, convert the data from the article to moles to compare material balance data

Grey Hydrogen
Compare with rigorous material balance

Mol Methane / Mole H2 Produced

	Howarth and Jacobson	IEAGHG 2017-02 Base Case (1)
SMR Process	0.250	0.336
Fuel	0.207	0.059
Electricity Required	Included above	-0.02
Total	0.456	0.376

Higher as some methane is unreacted and PSA sends some H2 to furnace

Exported steam converted to power. Power converted to methane using US average natural gas power plant

Net methane requirements 18% lower

Note 1: Converted from a natural gas basis to a pure methane basis by Fluor to place on the same basis as Howarth and Jacobson

Blue Hydrogen (Postcombustion) Material Balance

Mol Methane / Mole H2 Produced

	Howarth and Jacobson Grey H2	IEAGHG 2017-02 Base Case (Grey H2)	IEAGHG 2017-02 Case 3 (Blue H2)
SMR Process	0.250	0.336	0.336
Fuel	0.206	0.059	0.10
Electricity Required	Included above	-0.02	0
Total	0.456	0.376	0.437

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CO2 Emissions

Assume 3.5% Fugitive Emissions, 20 Year Life

	Howarth and Jacobson		IEAGHG 2017-02	
	Grey	Blue	Grey	Blue
Direct Emissions, mol CO_2/mol H_2	0.46	0.21	0.40	0.05
Fugitive Emissions, mol CO_2 Equiv/ mol H_2	0.50	0.62	0.41	0.48
Upstream Emissions	0.03	0.04	0.03	0.03
Total, mol CO_2/mol H_2	0.99	0.87	0.84	0.56
Reduction		12%		33%

CO2 Emissions

Assume 1.75% Fugitive Emissions, 20 Year Life

	Howarth and Jacobson		IEAGHG 2017-02	
	Grey	Blue	Grey	Blue
Direct Emissions, mol CO_2/mol H_2	0.46	0.21	0.40	0.05
Fugitive Emissions, mol CO_2 Equiv/ mol H_2	0.25	0.31	0.21	0.24
Upstream Emissions	0.03	0.04	0.03	0.03
Total, mol CO_2/mol H_2	0.74	0.57	0.63	0.32
Reduction		24%		50%

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How Green is Blue Hydrogen?

- Fugitive emissions from natural gas add a “base load” of GHG emissions that carbon capture cannot adjust
- Assumptions of time horizon and fugitive methane emissions strongly affect GHG intensity of natural gas
- It is important to consider the full energy balance of hydrogen production and CO2 capture in the overall system
- For an existing facility, operating with carbon capture should always improve GHG emissions vs operating without

Low Carbon Hydrogen Use Cases

Retrofit of Existing Facilities

- Ability of a solution to integrate with existing facility is key
- Destination of CO_2 is important; carbon utilization can provide options if local storage not available

New Facilities with H_2 as a Feedstock

- May be able to adjust facility location and process for CO_2 capture and storage
- Energy source for hydrogen production affects product carbon intensity

New Facilities with H_2 as an Energy Source

- Energy source for hydrogen production is key
- Steady state vs intermittent energy production is a key variable for the process and its integration