Methane Pyrolysis Overview

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What is Turquoise Hydrogen?

Hydrogen is often referred to by its "color."

Turquoise hydrogen is made by the process of decomposing methane (methane pyrolysis), which can be either fossil or biological in origin.

Turquoise hydrogen is considered low carbon because it creates a solid carbon (carbon black) that can easily be separated from the process. Since the carbon falls out in a solid form, there is no CO2 released during production.

Source: Applied Economics Clinic

The Colors of Hydrogen

GREEN
Hydrogen produced by electrolysis of water, using electricity from renewable sources like wind or solar. Zero CO_2 emissions are produced.

BLUE
Hydrogen produced from fossil fuels (i.e., grey, black, or brown hydrogen) where CO_2 is captured and either stored or repurposed.

GRAY
Hydrogen extracted from natural gas using steam-methane reforming. This is the most common form of hydrogen production in the world today.

PURPLE/PINK
Hydrogen produced by electrolysis using nuclear power.

TURQUOISE
Hydrogen produced by thermal splitting of methane (methane pyrolysis). Instead of CO_2, solid carbon is produced.

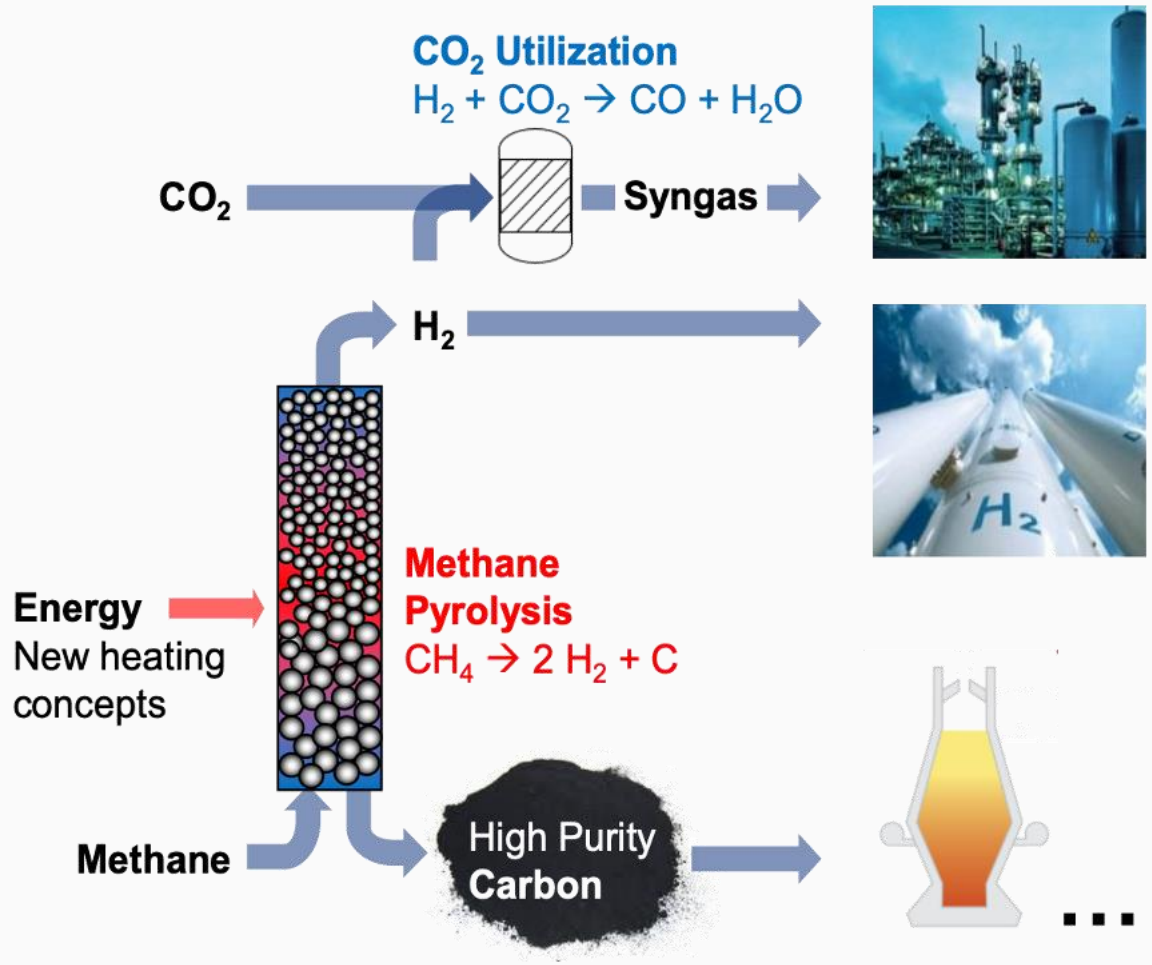
BROWN/BLACK
Hydrogen produced by electrolysis using nuclear power.

YELLOW
Hydrogen produced by electrolysis using grid electricity from various sources (i.e., renewables and fossil fuels).

WHITE
Hydrogen produced as a byproduct of industrial processes.
Also refers to hydrogen occurring in its (rare) natural form.

Methane Pyrolysis Reaction

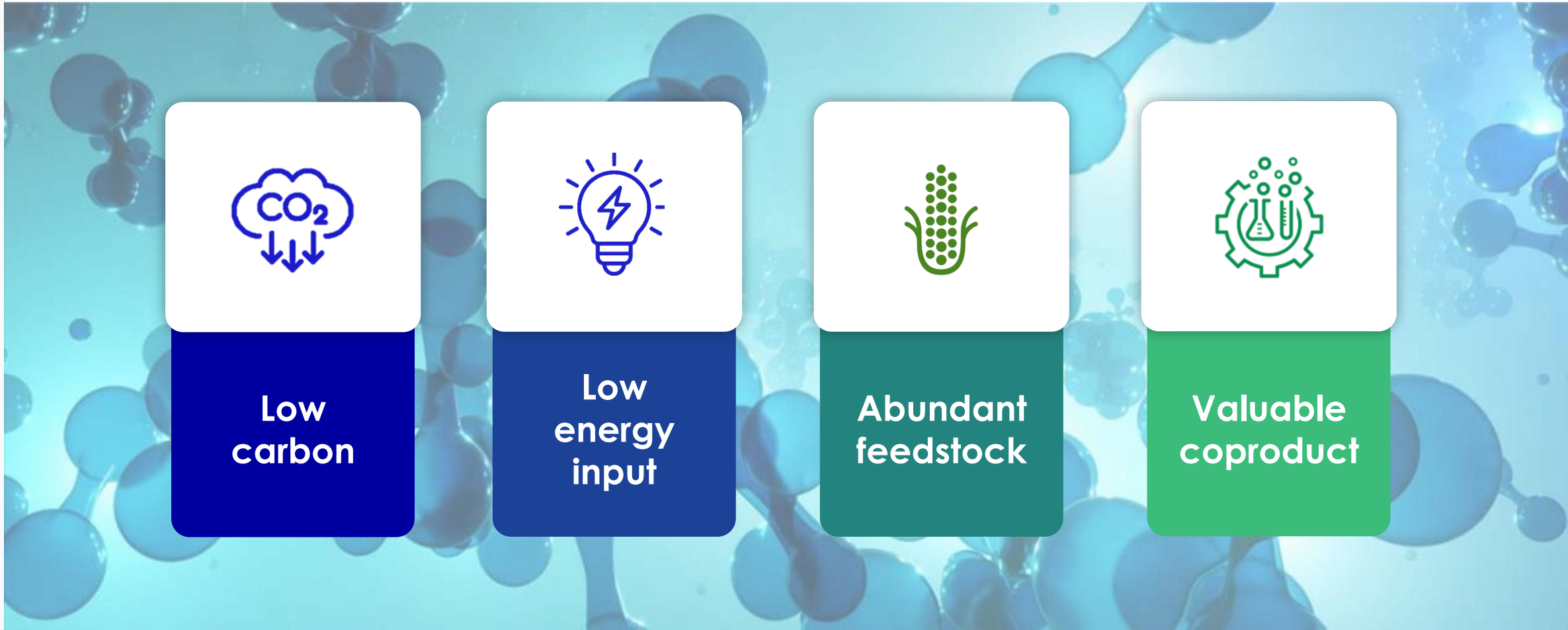
Methane pyrolysis uses high heat in a reactor without oxygen to break down CH4 (methane) to elemental hydrogen (H2) and solid carbon (C).



Source: Dr. William Daloz, BASF, December 10, 2019

Turquoise Hydrogen Advantages

Methane pyrolysis has several potential advantages compared with other hydrogen production methods:



Turquoise Hydrogen Advantages

Methane pyrolysis produces a solid carbon byproduct (carbon black), which can be permanently sequestered. Therefore, turquoise hydrogen is a low carbon energy carrier.

If biogas is used as a feedstock instead of fossil natural gas, the carbon intensity of the hydrogen is negative.

Mixing biogas and fossil natural gas is possible to produce zero carbon hydrogen.

Turquoise Hydrogen: Low Energy Input

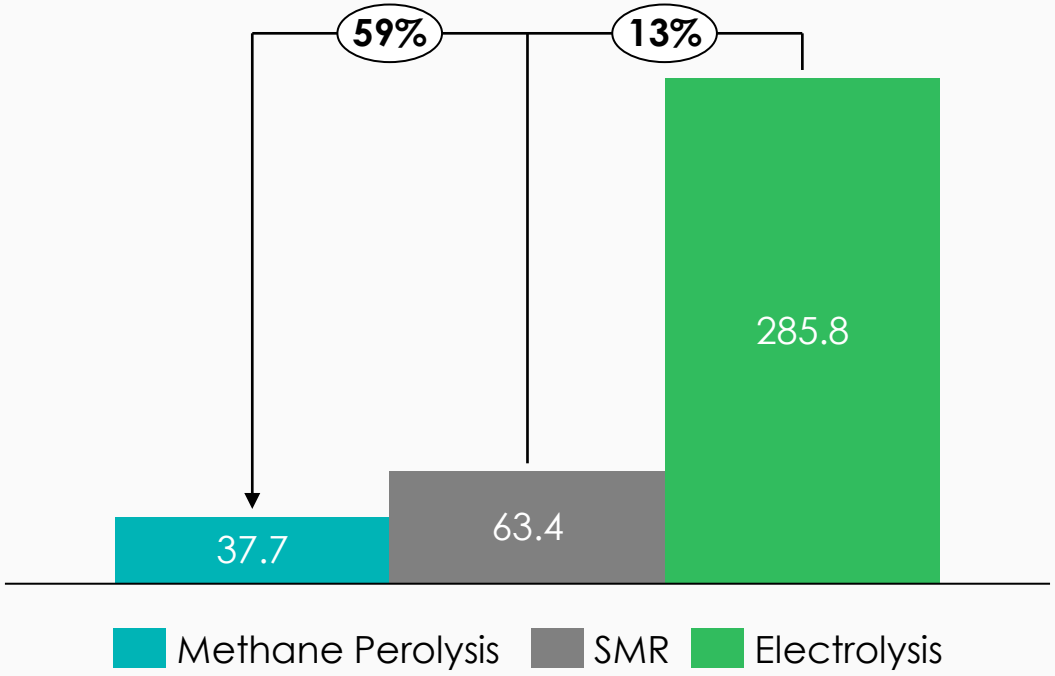
Methane pyrolysis is an energy efficient way to produce H2.

Methane pyrolysis requires:

~**59%** the energy of steam methane reforming and just

~13% of the energy of electrolysis

Energy requirements (kJ/mol H2)



Methane Pyrolysis for Zero-Emission Hydrogen Production: A Potential Bridge Technology from Fossil Fuels to a Renewable and Sustainable Hydrogen Economy

Nuria Sánchez-Bastardo, Robert Schlögl, and Holger Ruland
Industrial & Engineering Chemistry Research **2021** *60* (32), 11855-11881
DOI: 10.1021/acs.iecr.1c01679

Turquoise Hydrogen: Feedstock

Methane pyrolysis uses natural gas to produce hydrogen.

Natural gas is abundant in many regions of the world and existing infrastructure can be leveraged to deliver feedstock to methane pyrolysis projects.

Biogas from anaerobic digestion from landfills, wastewater, and animal manure can also be used as feedstock.

Turquoise Hydrogen: Valuable Coproduct

Carbon black has many industrial uses.

Several industrial markets currently use carbon black, which use different grades.

The price of the lower grades of carbon black range from $1000 to $1350/MT.

Specialty grades require further processing.

Turquoise Hydrogen Challenges

Technological Readiness

Technology not proven at scale; several technological approaches exist, but none are commercially proven

Cost

Estimates for methane pyrolysis economics look promising, but have not been proven at scale and often rely on co-product value

Methane Leakage

Methane is a powerful greenhouse gas; leakage can be detrimental to environmental benefits

Carbon Black Markets

Large scale methane pyrolysis could produce more carbon black than existing markets could handle

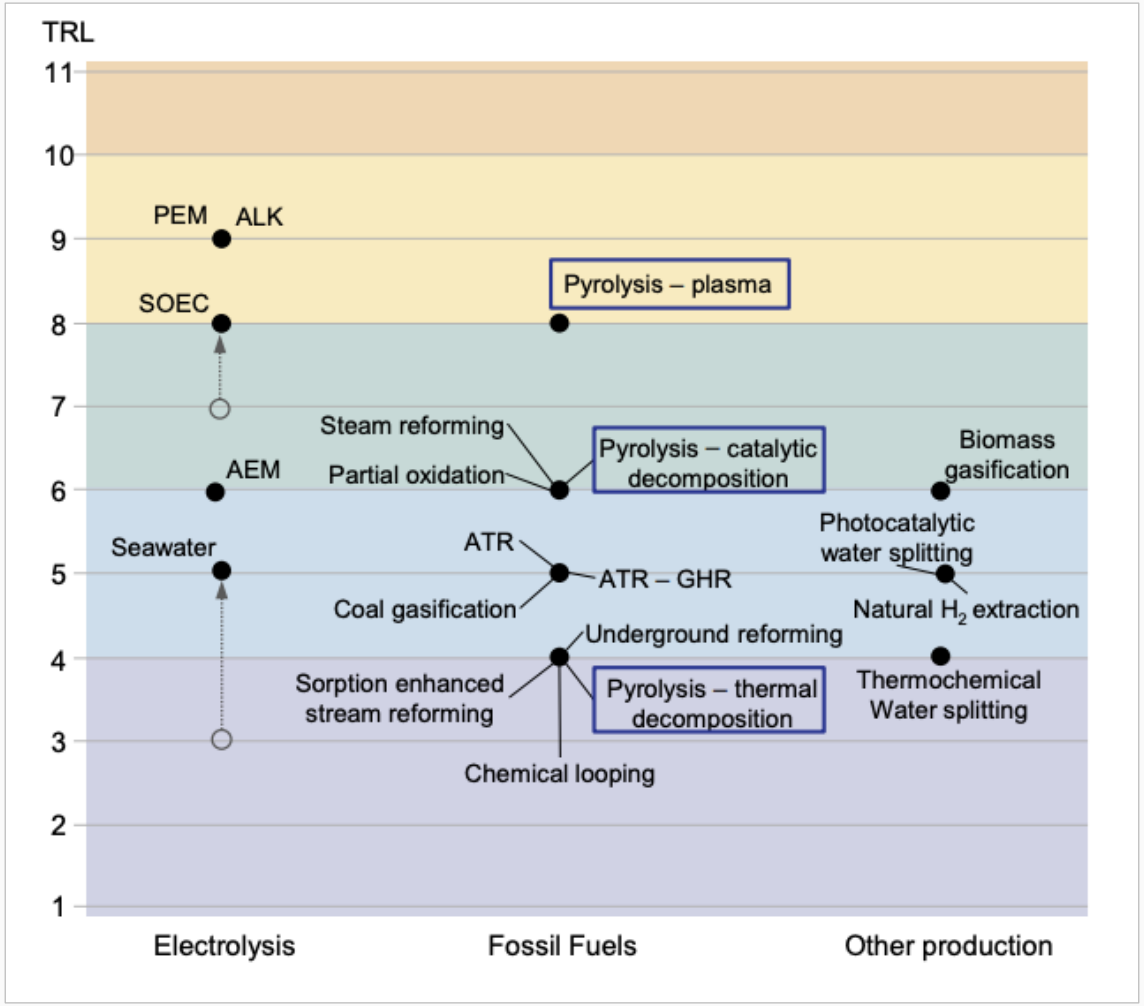
Challenge: Technological Readiness

There are several approaches to methane pyrolysis.

Plasma pyrolysis is the most advanced and is currently at TRL 8 - first of its kind commercial.

Monolith Corporation operates the only commercial scale methane pyrolysis plant in the world in Nebraska, USA.

Other technologies for methane pyrolysis are under development at pilot scale or benchtop scale.



Source: Compiled by Mizuho Bank Industry Research Department based on IEA, Global Hydrogen Review 2023.

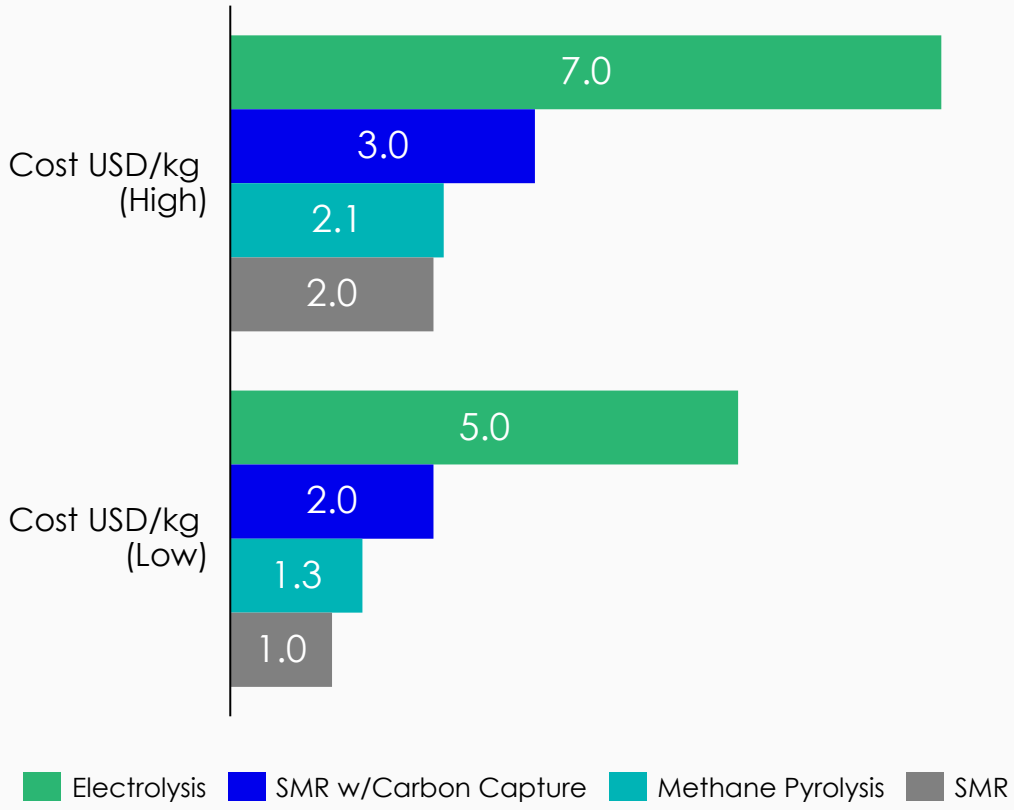
Turquoise Hydrogen: Realizing Economics

Methane pyrolysis could be a cheap way to produce clean hydrogen, but:

Actual pricing data does not exist because there are no operating commercial plants. Process economics at pilot or demo scale may not translate to commercial operations.

Frequently the price of turquoise hydrogen projects include a price for carbon black, but the economics of those markets are unproven.

Price of H2 from different technologies*



*Pricing without subsidies or a carbon tax
Data from: The Bulletin of Atomic Scientists
https://thebulletin.org/2022/01/whether-green-blue-or-turquoise-hydrogen-needs-to-be-clean-and-cheap

Turquoise Hydrogen: Methane Leakage

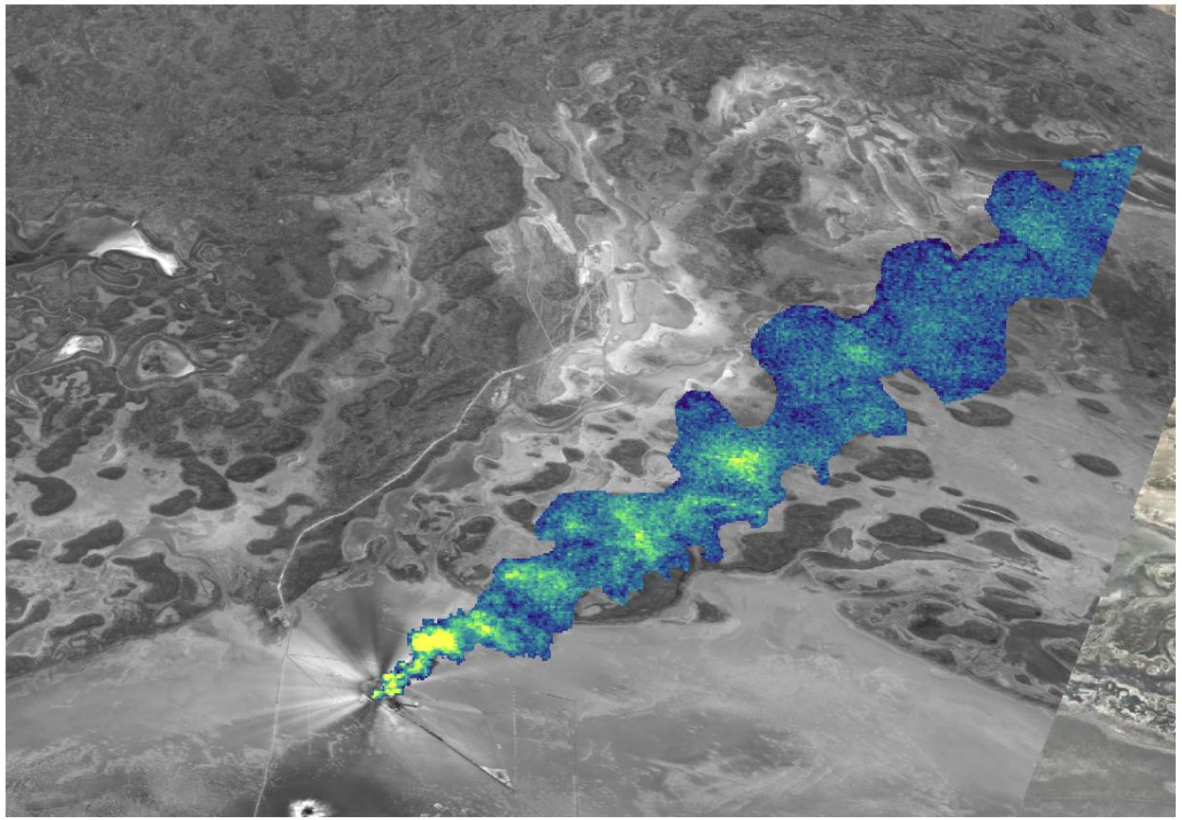
Methane pyrolysis uses natural gas to produce hydrogen.

Methane is a powerful greenhouse gas, 28x more potent than CO_2[1]

Many believe that methane leakage in lifecycle assessments is underreported[2]

Large methane pyrolysis projects may attract greater scrutiny, and reveal questions about sustainability

1)https://www.epa.gov/gmi/importance-methane
2)https://www.sciencedirect.com/science/article/abs/pii/S0959652619307875



A methane plume in eastern Kazakhstan observed by satellite on July 23. *Source: Kayrros SAS. Data generated by Kayrros under a license from ASI Original PRISMA Product - © Italian Space Agency (ASI) - (2023)*

Turquoise Hydrogen: Realizing Economics

Significant questions remain about the markets for carbon black.

Methane pyrolysis produces ~3kg of carbon black/kg of hydrogen.

If 50% of 2030 EU demand for hydrogen came from methane pyrolysis, ~30MMT of carbon black would be produced.

The 2021 global market size for carbon black was just 20MMT. Adding that much new product without additional outlets would dramatically lower carbon black pricing.

New bulk markets for carbon black are possible (cement, soil amendment, etc.), but are not developed.

The LEC Take

- Methane pyrolysis offers some unique attributes:
  - Low carbon
  - Potentially low cost
  - Abundant feedstock
  - Good feedstock logistics

- However, a lack of commercial projects means that technologies and economics need to be proven at scale

Pete Rocha, MBA

About the author

Pete Rocha is a Project Director at LEC Partners and Lead Consultant for LEC's Low Carbon Hydrogen Center of Excellence. Pete has worked on a number of hydrogen technologies and hydrogen derivatives. His former roles include, co-founder of Hydrogen Works, a solid oxide electrolyzer technology company, co-founder of Phoenix Hydrogen, a methane pyrolysis company, Director, Corporate Development at Chevron Renewable Energy Group, and Associate at Booz Allen Hamilton.

Pete holds an MBA in Finance from the University of Chicago's Booth School of Business, and a BA in International Relations from Cornell University.

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