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Technologies for turquoise hydrogen production

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World Hydrogen Leaders – Blue & Turquoise Hydrogen

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Introduction to Stephen B. Harrison and sbh4 consulting

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Stephen B. Harrison is the founder and managing director at sbh4 GmbH in Germany. His work focuses on decarbonisation and greenhouse gas emissions control. Hydrogen and CCUS are fundamental pillars of his consulting practice. He is also the international hydrogen expert and team leader for two ADB projects related to renewable hydrogen deployment in Pakistan and Palau in Asia.

With a background in industrial and specialty gases, including 27 years at BOC Gases, The BOC Group and Linde Gas, Stephen has intimate knowledge of hydrogen and carbon dioxide from commercial, technical, operational and safety perspectives. For 14 years, he was a global business leader in these FTSE100 and DAX30 companies.

Stephen has extensive buy-side and sell-side M&A due diligence and investment advisory experience in the energy and clean-tech sectors. Private Equity firms and investment fund managers and green-tech startups are regular clients.

As a member of the H2 View and **gas**world editorial advisory boards, Stephen advises the direction for these international publications. Working with Environmental Technology Publications, he is a member of the scientific committees for AQE 2021 and CEM 2023 - leading international conferences for Air Quality and Continuous Emissions Monitoring.

Hydrogen today – from fossil fuels. Coal gasification to syngas. Lu'an, Shanxi province, China.

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Reforming: SMR plus ATR for natural gas to syngas. Kaveh, Iran.

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- Most hydrogen produced today is from reforming of natural gas
- Coal and petcoke gasification is also a high-volume hydrogen production process
- Hydrogen production must transition to low carbon processes

Methane pyrolysis (cracking/splitting) for turquoise hydrogen production

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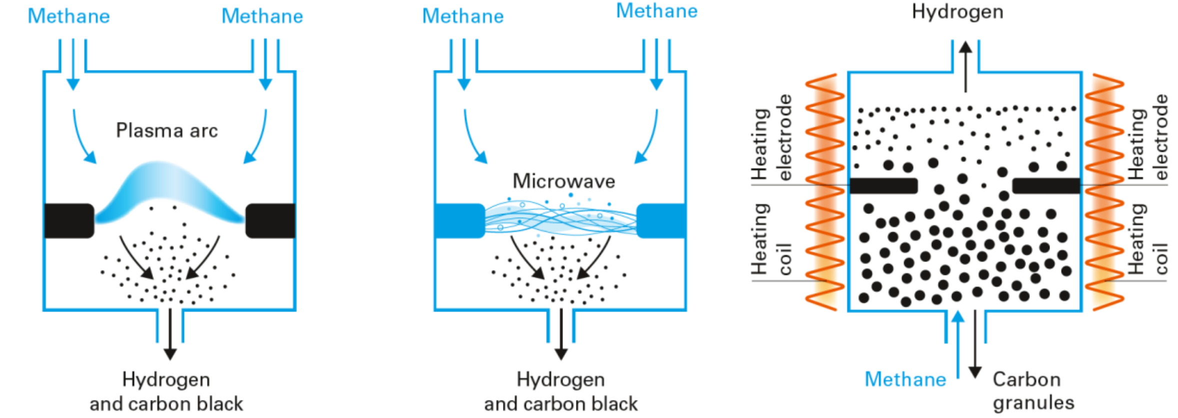
Notes:

- Unreacted methane can be separated from the hydrogen using PSA and recycled to the reactor
- The size of the carbon granules is influenced by operating conditions and the residence time of the carbon in the reactor
- Heat may be from renewable electricity
- Methane can be from natural gas or biogas



	Plasma Methane Pyrolysis	Microwave Plasma Methane Pyrolysis	Moving Carbon Bed Methane Pyrolysis
Process shown	Monolith Materials	Atlantic Hydrogen	BASF
Hydrogen content as reactor outlet	~95%	~95%	~92%
Carbon production	Carbon black	Carbon black	Carbon granules
Catalyst required	No	No	No
Heating mechanism	Direct heating with argon gas electrical plasma	Direct heating with microwave energy	Electrodes to heat the carbon bed and indirect heat applied around the reactor
Reactor temperature	1650 °C	1200 to 1500 °C	1000 to 1400 °C
Reactor pressure	Close to atmospheric pressure	Close to atmospheric pressure	Close to atmospheric pressure

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Electric arc, gas plasma methane pyrolysis

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Image copyright Monolith Materials, Nebraska

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Microwave plasma methane pyrolysis

Image copyright Atlantic Hydrogen, New Brunswick

Moving carbon bed methane pyrolysis

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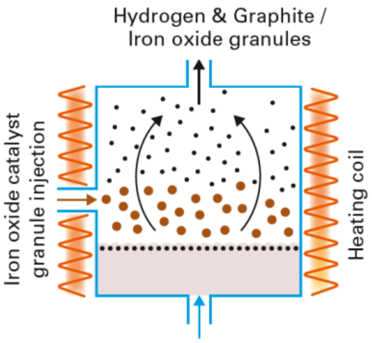

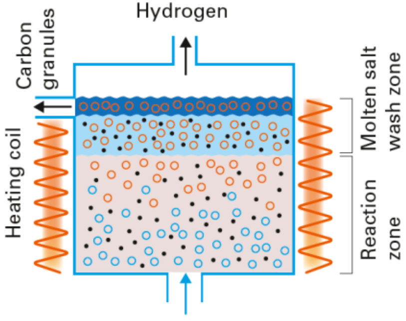

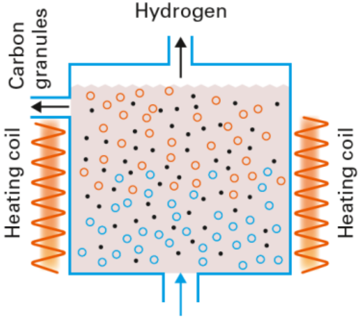

	Fluidised Bed Methane Pyrolysis	Molten Metal Methane Pyrolysis	Molten Salt Methane Pyrolysis
Process shown	Hazer	TNO EMBER	C-Zero
Hydrogen content as reactor outlet	~92%	~95%	~95%
Carbon production	80 to 95% graphite encapsulating catalyst dust particles	Carbon granules	Carbon granules
Catalyst required	Iron oxide granules	Molten 27% Nickel - 73% Bismuth	Molten Manganese Chloride
Heating mechanism	Indirect heat applied around the reactor	Indirect heat applied around the reactor	Indirect heat applied around the reactor
Reactor temperature	900 °C	1100 °C	650 °C
Reactor pressure	Close to atmospheric pressure	Up to 5 bar	Up to 5 bar

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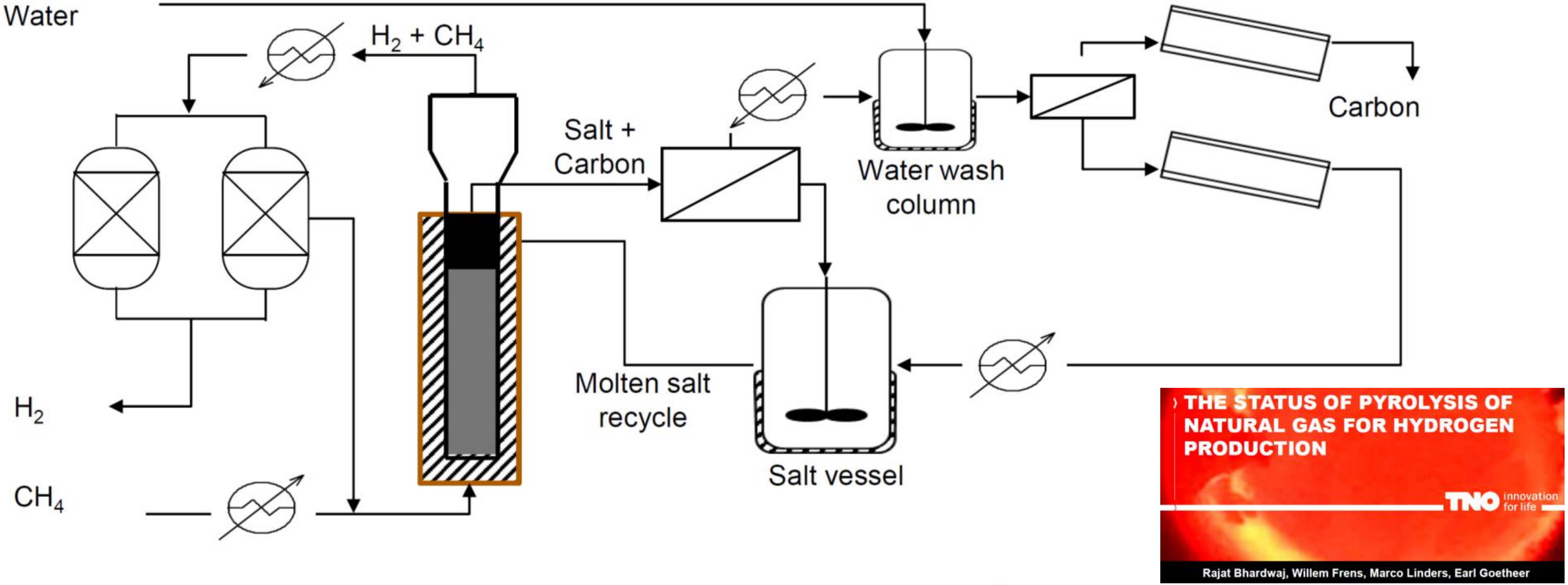
Iron oxide catalysed methane pyrolysis

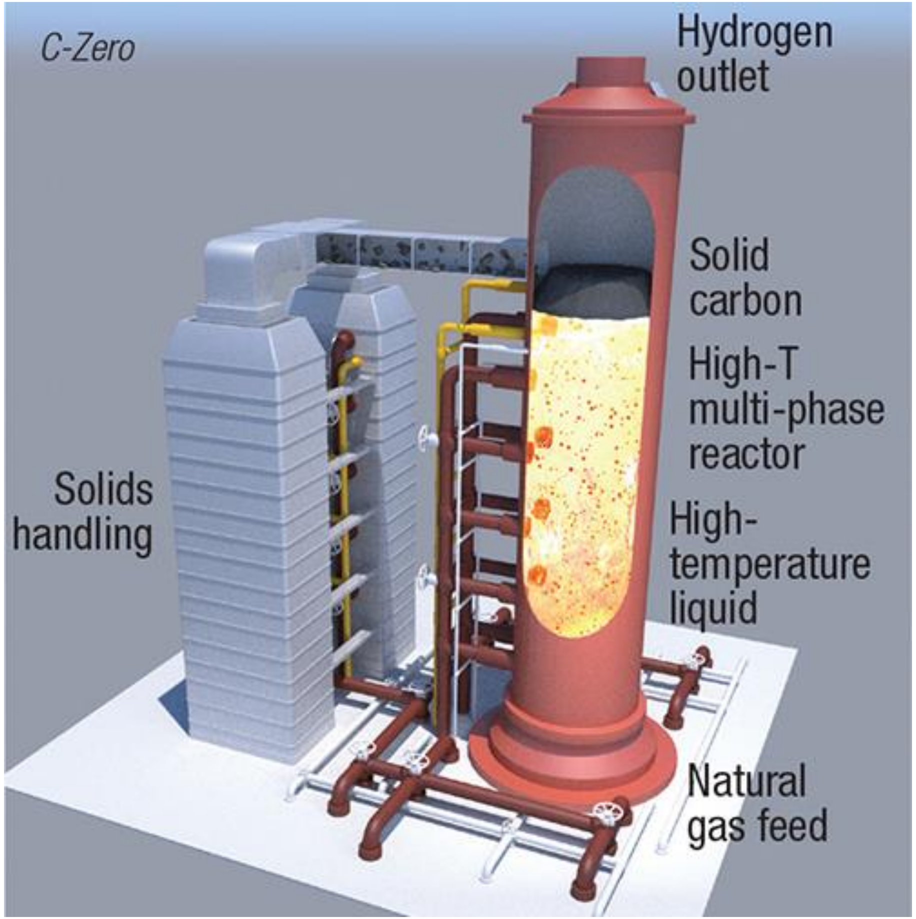
Image copyright Hazer Group Pty

Molten metal methane pyrolysis, with molten salt for carbon separation



PSA purification | Molten metal reactor with heating furnace | Carbon – salt filter | Carbon – water filter | Dryers

Molten salt methane pyrolysis



Turquoise hydrogen production economics can be enhanced if the carbon has value

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The largest application for functional grades of carbon black is tyre production

Solid carbon can be used to substitute coke for iron processing

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Solid carbon has the potential to be used as a soil enhancer

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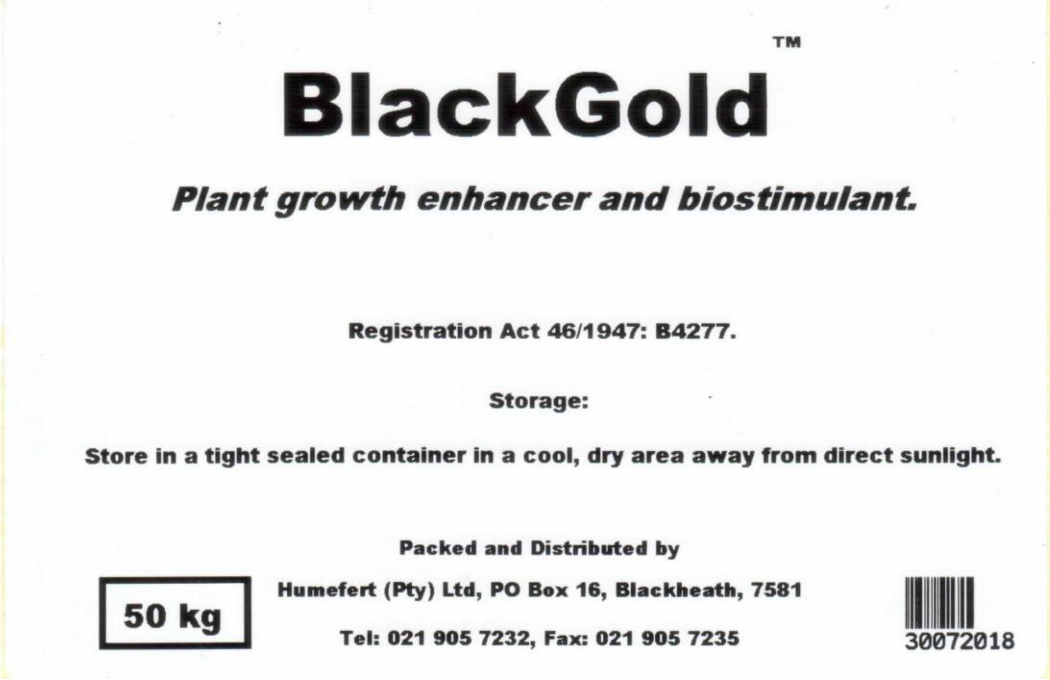

Which colour of low-carbon hydrogen is right for you?

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Turquoise – methane pyrolysis with solid carbon

Purple – coal (or petcoke) gasification with CCS

Blue – natural gas reforming with CCS

Green – renewable power or biomethane

Pink – nuclear power

Colour? - waste to hydrogen

Local conditions drive the choices. Compare and contrast...

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Example location →	UK	Japan
Market for carbon black for tyres and rubber	Medium, European market is 2 million Tonnes per annum	High, Asian market is 8 million Tonnes per annum
Market for carbon as substitute for coke in iron & steel making	Low, UK annual steel production 7 million Tonnes	High, Japanese annual steel production 99 million Tonnes
Underground CO_2 storage potential, eg in depleted gas wells	High, local in the North Sea	Low, some local testing but likely to export CO_2, (eg to Indonesia or Australia)
Potential to repurpose CO_2 transmission infrastructure for CCS	High, eg Acorn project and St Fergus gas terminal	Low, purpose built ships would be required to export CO_2
Summary →	**Fits blue well**	**Fits turquoise well**

Biomass to biogas to biomethane, then methane pyrolysis: carbon-negative

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Curious to know more? Join the World Hydrogen Leaders training on 6th July.

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Technologies for Turquoise Hydrogen Production

2:00 PM – 5:00 PM

Google Calendar · ICS

This course will introduce the main technologies for producing turquoise hydrogen and identify the companies leading their development and commercialisation. The course will also explore current and emerging high scale applications for the solid carbon and graphite that are produced through these processes.

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