

# Converting waste to hydrogen and sustainable fuels and chemicals

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IFAT Hydrogen Stage

5<sup>th</sup> May 2026, 9:30 to 10:20

# Converting waste to hydrogen and sustainable fuels and chemicals

1. Liquid and solid wastes can be converted to hydrogen, chemicals and fuels
  - a) Waste feedstocks
  - b) Conversion technologies
  - c) Products
2. The level of risk, scale and technical complexity
3. Value chains most likely to have an impact on circularity in the next 10 years.



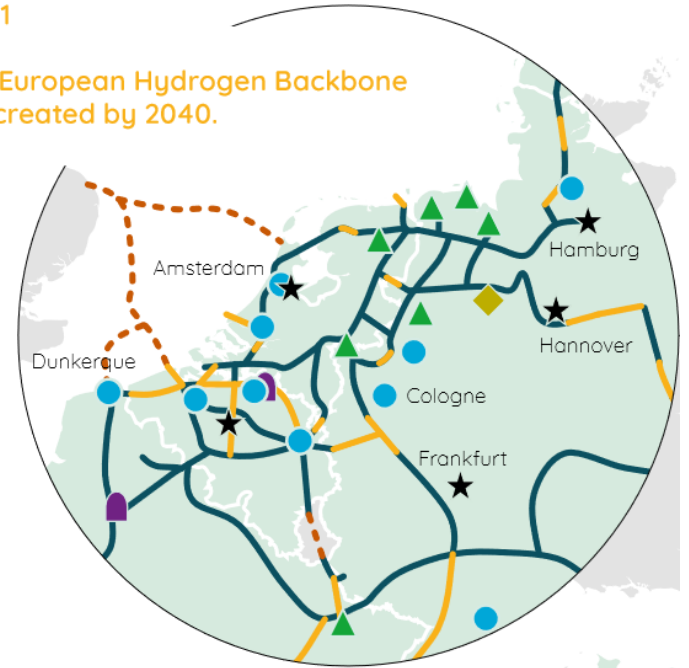
Decentralised waste to hydrogen creates circularity within communities and can bridge the decades between now and centralised hydrogen production and pipeline transmission.

HRS size	Very small ≤ 80 kg/day	Small ~ 200 kg/day	Medium ~ 400 kg/day	Large ~1000 kg/day	Very large ≥ 1000 kg/day
Distribution option					
On-site electrolysis	On-site power requirement may become an issue: 400 kg/day ≈ 1 MW				
On-site reforming	Difficult to capture CO <sub>2</sub>		Required footprint for production facility is an issue		
CGH2 truck	Delivery of 300 kg up to potential maximum of 1000 kg per truck				
LH2 truck	Relatively large boil-off for demand levels in early markets				
CGH2 pipeline	Due to high investments pipelines are not likely in early markets unless already available				
Color coding: <span style="color: green;">■</span> Very likely <span style="color: orange;">■</span> Possible <span style="color: red;">■</span> Less likely					

Figure 12.1 Overview of delivery options for a hydrogen infrastructure for road transport IEA, 2013. Hydrogen refuelling stations and role of utilization rates: key messages and issues.

FIGURE 1

Mature European Hydrogen Backbone can be created by 2040.



# 1) Biogas from liquid and solid wastes to hydrogen

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# Upgrading biogas to biomethane from liquid wastes to make biomethane and biogenic CO<sub>2</sub>. Biomethane can be purified and then reformed to make syngas, which can be purified to yield hydrogen.



Biogas is generated from biomass through anaerobic digestion

- Biogas consists predominantly of CH<sub>4</sub> and CO<sub>2</sub> with potential traces of H<sub>2</sub>S, H<sub>2</sub>O and other gases

Biomethane is produced from biogas through purification or 'upgrading' of biogas

- CO<sub>2</sub> removal
- H<sub>2</sub>S removal
- Drying

# Steam methane reforming of purified biomethane produces hydrogen.



- |                            |                                    |                         |                               |
|----------------------------|------------------------------------|-------------------------|-------------------------------|
| 1. Ventilation fan         | 5. Hydrogen storage                | 9. Reformate cooler     | 13. Low temperature shift     |
| 2. Desulphurisation vessel | 6. Water separator for vacuum pump | 10. Electronics cabinet | 14. Coolant expansion vessel  |
| 3. PSA-vessels             | 7. Vacuum pump                     | 11. Steam generator     | 15. Burner air blower         |
| 4. Off-gas storage         | 8. Coolant heater                  | 12. Reformer unit       | 16. Water purification system |

- Land fill gas or biomethane is stripped of sulphur prior to entering the reformer.
  - Catalyst longevity, reduced maintenance issues, increased reaction conversion efficiencies
- Pressure swing adsorption for hydrogen purification, eg to fuel cell grade, if required.
- PSA off-gases used as reformer burner fuel.
- Heat from the burner is utilised to generate steam for the reforming reaction.
- Performance (3 Sizes)
  - Output: 47 Nm<sup>3</sup>/hr H<sub>2</sub> (3.8kg/hr) – 141 Nm<sup>3</sup>/hr (11.5 kg/hr) H<sub>2</sub>
  - Feedstocks
    - Landfill gas or biomethane 23 Nm<sup>3</sup>/hr (~16 kg/hr) – 69 Nm<sup>3</sup>/hr (~48 kg/hr)
  - Electricity: 14.5 – 29.5 kW
  - Water: 100 – 300 litres/hr

# Biomethane is a feedstock for methane pyrolysis for turquoise hydrogen and high-value carbon.

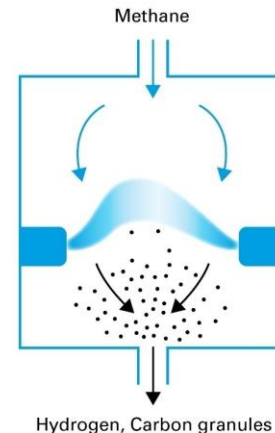
- Turquoise hydrogen from landfill gas or biogas can be carbon negative due to the carbon being locked into solid carbon and not released as CO<sub>2</sub>.
- If renewable power is used for the DC, AC or microwave plasma (instead of a fired burner for reforming), the CO<sub>2</sub> intensity of the hydrogen can be reduced.
- Levidian working with United Utilities in Manchester.



<https://hydrogen-central.com/sewage-biogas-produced-manchester-become-sustainable-feed-source-graphene-and-hydrogen-production-thanks-to-a-pioneering-partnership-between-levidian-and-united-utilities/>

**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
- Renewable electricity can be used to generate the plasma
- Methane can be from natural gas or biogas



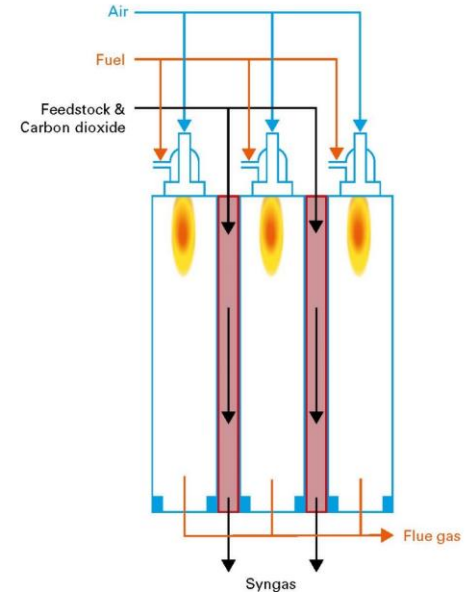
	Plasma Pyrolysis
Process shown	Monolith Materials
Hydrogen content at reactor outlet	~95%
Carbon production	Carbon black as powder or granules
Catalyst required	No
Heating mechanism	Direct heating with plasma
Reactor temperature	2000 °C
Reactor pressure	Close to atmospheric pressure

# Raw biogas can be used for combined methane reforming.

- Biogas contains about 50% CO<sub>2</sub> and 50% CH<sub>4</sub>. This is an ideal feedstock for dry methane reforming (DMR).
- Catalyst coking is a common problem in DMR and can be avoided if steam is added, so the process operates as DMR and SMR, or Combined Methane Reforming (CMR).
- Electrification of the energy input for the endothermic reforming (instead of a using a fired burner) can support low-carbon hydrogen production, if renewable power is used.

## DMR for syngas production

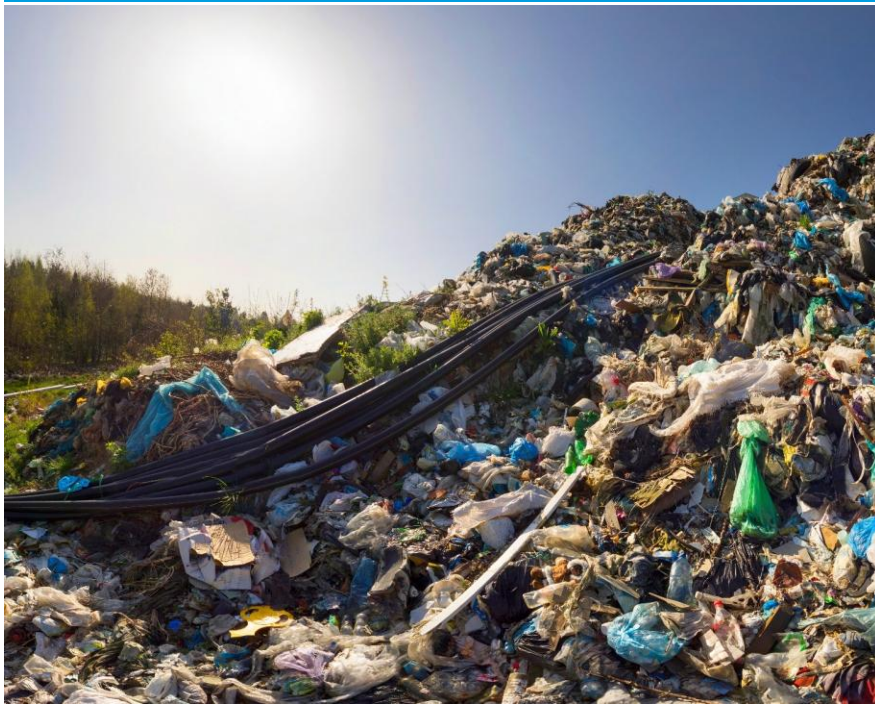
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	Dry Methane Reforming – DMR (Carbon Dioxide Reforming)
Carbon feedstock	Natural gas plus carbon dioxide, or biogas
Oxygen feedstock	Air for fuel combustion to heat the process (not used for hydrogen generation in the SMR reactor tubes)
Steam feedstock	No
Catalyst required	Yes, Nickel, Nickel-Molybdenum, Cobalt and others
Target chemical reactions	$\text{CO}_2 + \text{CH}_4 \rightarrow 2\text{CO} + 2\text{H}_2$
Additional side reactions	$\text{CO}_2 + \text{H}_2 \rightarrow \text{CO} + \text{H}_2\text{O}$ (Reverse water gas shift) $\text{CO}_2 + 4\text{H}_2 \rightarrow \text{CH}_4 + 2\text{H}_2\text{O}$ (Methanation) $\text{CH}_4 \rightarrow \text{C} + 2\text{H}_2$ (Methane Pyrolysis / Cracking) $2\text{CO} \rightarrow \text{C} + \text{CO}_2$ (Boudouard Equilibrium)
Energy required/released	Endothermic, 15% more heat input than SMR
Hydrogen content in syngas	~50%
Syngas pressure	1 to 20 bar
Syngas temperature	~700 to 1100 °C

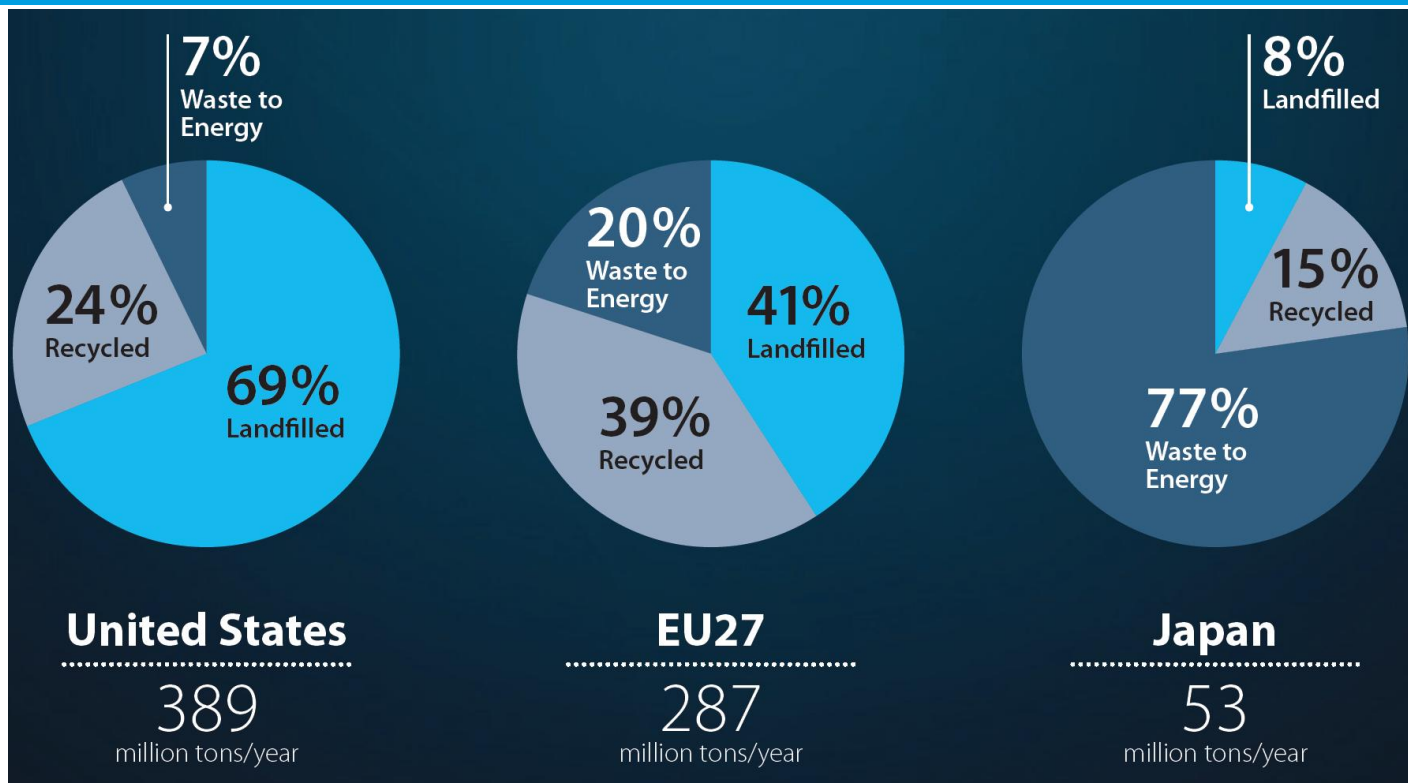
Landfill gas is like biogas. Conversion to hydrogen is possible using similar techniques.



## 2) MSW as a feedstock for hydrogen production

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In US and Europe, more than 380 million of tonnes of MSW could be diverted from landfill to yield circa 13 million tonnes of hydrogen each year, circa 18% of current global H<sub>2</sub> demand.



# EU Taxonomy of sustainable investment refers to minimising incineration of waste and avoidance of landfill, for example through “energy recovery”, ie conversion of MSW to hydrogen.

## Substantial contribution to the transition to a circular economy

1. An economic activity shall qualify as contributing substantially to the transition to a circular economy, including waste prevention, re-use and recycling, where that activity:
  - (a) uses natural resources, including sustainably sourced bio-based and other raw materials, in production more efficiently, including by:
    - (i) reducing the use of primary raw materials or increasing the use of by-products and secondary raw materials; or
    - (ii) resource and energy efficiency measures;
  - (j) minimises the incineration of waste and avoids the disposal of waste, including landfilling, in accordance with the principles of the waste hierarchy;

REGULATION (EU) 2020/852 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL  
of 18 June 2020  
on the establishment of a framework to facilitate sustainable investment, and amending Regulation (EU) 2019/2088

DIRECTIVE 2008/98/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL  
of 19 November 2008  
on waste and repealing certain Directives

Article 4

### Waste hierarchy

1. The following waste hierarchy shall apply as a priority order in waste prevention and management legislation and policy:
  - (a) prevention;
  - (b) preparing for re-use;
  - (c) recycling;
  - (d) other recovery, e.g. energy recovery; and
  - (e) disposal.

Plastic wastes are mostly made up of Carbon and Hydrogen. SRF / RDF from non-recyclable plastics is an ideal feedstock for hydrogen generation.



Waste plastic	Ultimate analysis, wt.%				
	C	H	O	N	S
HDPE	78.18	12.84	3.61	0.06	0.08
PP	83.74	13.71	0.98	0.02	0.08
PS	90.40	8.56	0.18	0.07	0.08



# ISO 21640 Standard defines the SRF source and quality (EN 15359 is an alternative)

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INTERNATIONAL  
STANDARD

ISO  
21640

First edition  
2021-05

## Solid recovered fuels — Specifications and classes

*Combustibles solides de récupération — Spécifications et classes*



Reference number  
ISO 21640:2021(E)

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Table 2 — Classification for solid recovered fuels

Classification characteristic	Statistical measure	Unit	Classes				
			1	2	3	4	5
Net calorific value (NCV)	Mean	MJ/kg (ar)	≥ 25	≥ 20	≥ 15	≥ 10	≥ 3
Chlorine (Cl)	Mean	% in mass (d)	≤ 0,2	≤ 0,6	≤ 1,0	≤ 1,5	≤ 3
Mercury (Hg)	Median 80 <sup>th</sup> percentile	mg/MJ (ar)	≤ 0,02	≤ 0,03	≤ 0,05	≤ 0,10	≤ 0,15
		mg/MJ (ar)	≤ 0,04	≤ 0,06	≤ 0,10	≤ 0,20	≤ 0,30

Table 3 (continued)

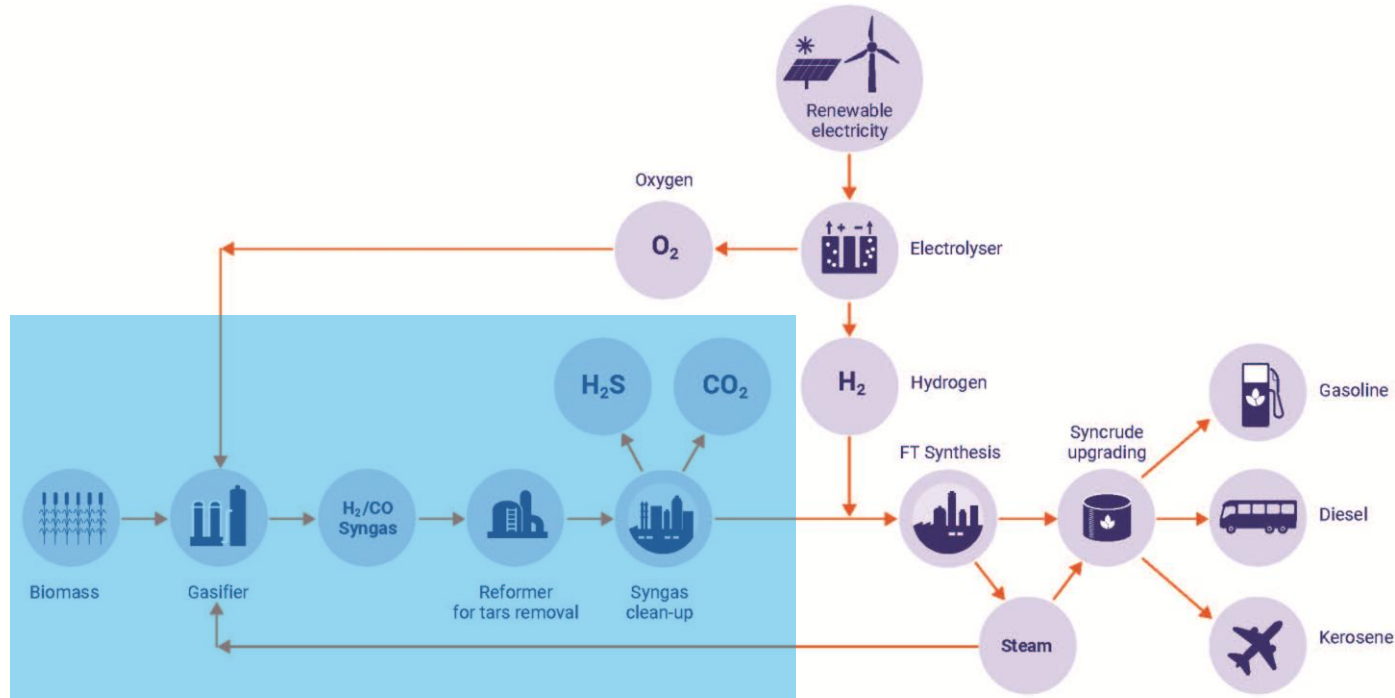
3. Non-hazardous waste from waste management facilities	3.4 wastes from the mechanical treatment of waste (for example sorting, crushing, compacting, pelletising)	3.4.1 paper and cardboard waste
		3.4.2 textile waste
		3.4.3 wood waste
		3.4.4 plastic and rubber waste
		3.4.5 other non-hazardous wastes (including mixtures of materials) from mechanical treatment of wastes
	3.5 end-of-life vehicles from different means of transport (including off-road machinery) and wastes from dismantling of end-of-life vehicles and vehicle maintenance	3.5.1 end of life tyres
		3.5.2 plastic waste (except packaging)
		3.5.3 other non-hazardous waste from end-of-life vehicles
4 Non-hazardous waste from material recycling facilities	4.1 reject fractions from material recycling facilities, not otherwise mentioned	4.1.1 paper and cardboard waste
		4.1.2 textile waste
		4.1.3 wood waste
		4.1.4 plastic waste
		4.1.5 other non-hazardous waste from material recycling facilities

MSW preparation with pelletising can assist with downstream materials handling and chemical processing. Torrefaction of the pellets may also be required.



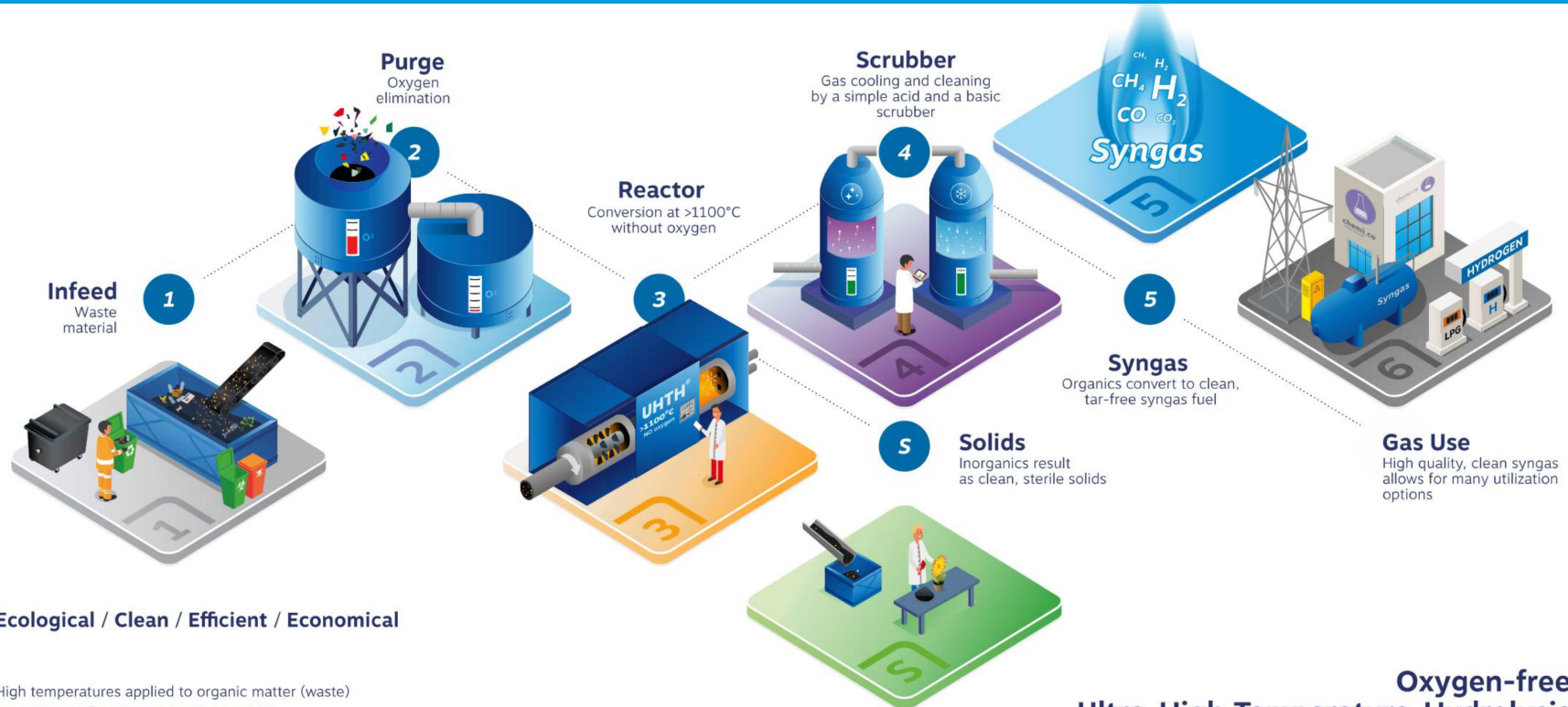
## 3) Technologies and projects for MSW to hydrogen and liquid fuels

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- Gasification takes place with a precise amount of oxygen.
- Reforming combines steam and a hydrocarbon.
- Water can be used to convert CO from the syngas to additional hydrogen and CO<sub>2</sub> in the water-gas-shift stage.
- Or, the syngas can be upgraded to produce liquid fuels.

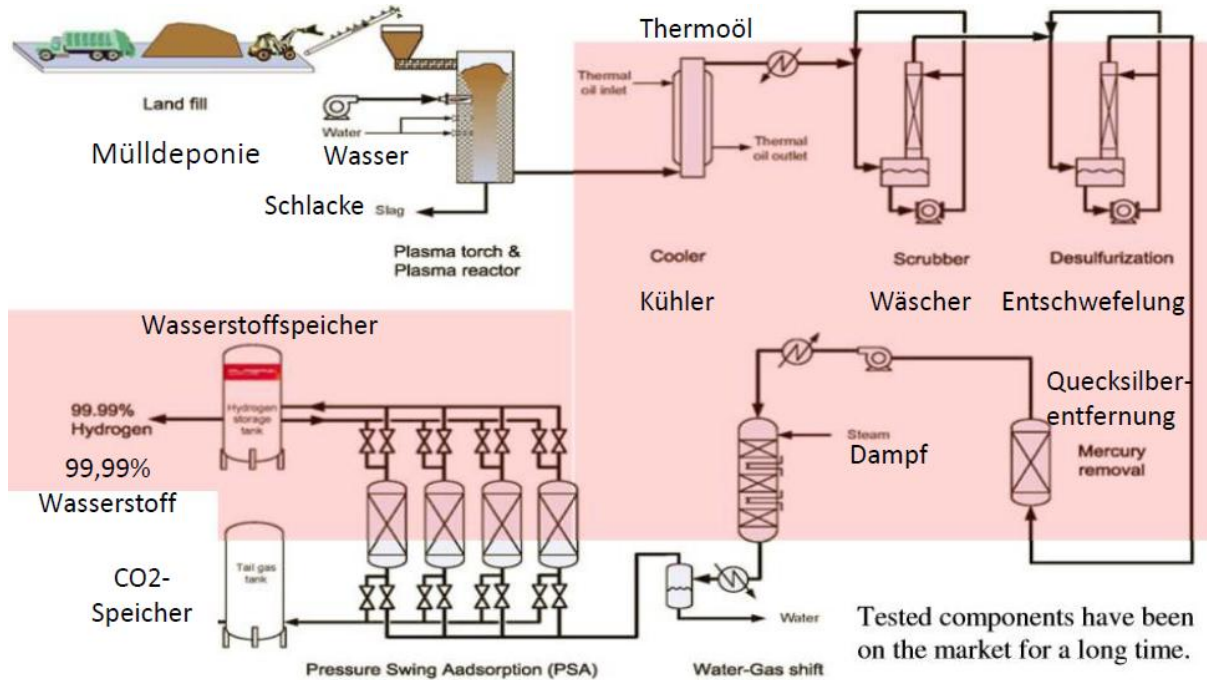
# Ultra-High-Temperature-Hydrolysis at 1,100 °C with Carbon is released as a solid char.



Ecological / Clean / Efficient / Economical

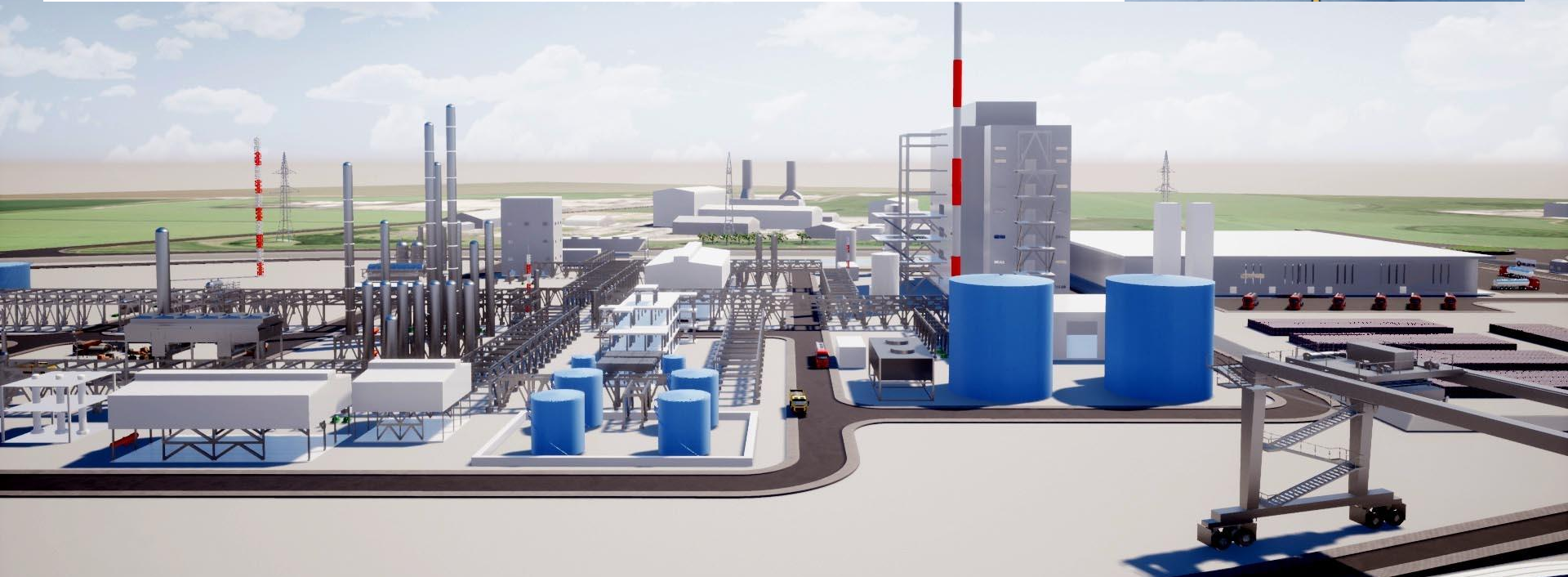
High temperatures applied to organic matter (waste) in an oxygen-free environment converts:

# Plagazi MSW plasma gasification concept. Much of the process is syngas treatment. Carbon is released as CO<sub>2</sub>, which is purified.

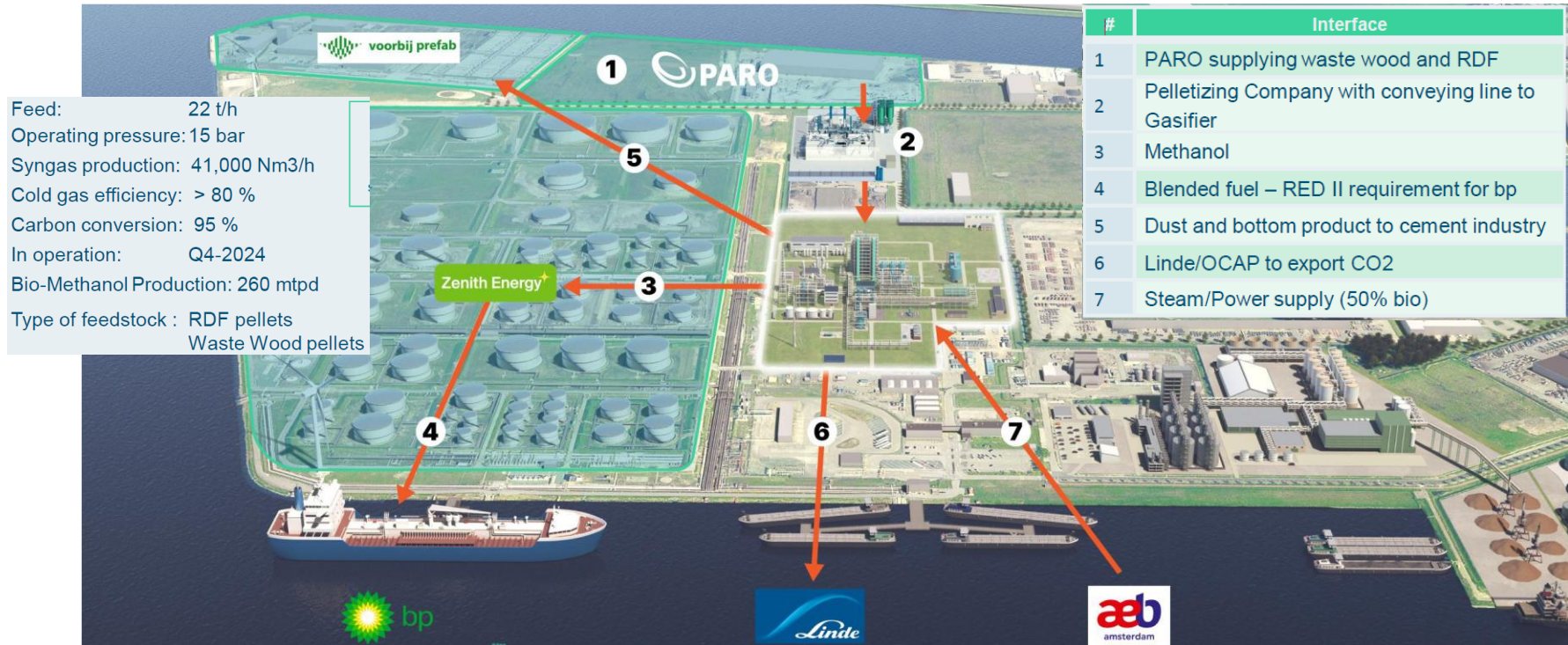


- Gasification takes place with a precise amount of oxygen.
- Plagazi injects water/steam into the plasma gasification reactor.
- Reforming combines steam and a hydrocarbon.
- Water is also used to convert CO from the syngas to additional hydrogen and CO<sub>2</sub> in the water-gas-shift stage.
- Heat from the gasification can be used to make high pressure steam for power generation.
- Waste heat can be used for district heating.
- H<sub>2</sub> and CO<sub>2</sub> clean up and purification follow the reaction stages.

- ALTALTO Immingham - Velocys waste to fuels plant proposal for UK
- In partnership with British Airways to make SAF
- 500,000 tonnes of MSW per year
- 60,000 tonnes of liquid fuels (kerosene, diesel and gasoline fractions)
- Engineering study awarded to NEXTCHEM (updraft fixed bed gasifier)
- COD planned for 2030



# GIDARA Energy' Advanced Methanol Amsterdam: pelletised waste wood and RDF gasification for methanol, with CO2 offtake. High Temperature Winkler(HTW) Gasifier. Methanol can be processed to yield fuels or chemicals. The project location is currently under review.



## 4) Lessons from the past

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TV1 and TV2.  
350,000 tonnes  
per annum RDF  
gasification,  
50MWe  
Billingham, UK  
2015 to 2016.  
Westinghouse  
plasma gasifiers  
– not tested  
previously at this  
scale.



# Fulcrum Bioenergy, Sierra Nevada: gasifier technology selection was risky; construction was fragmented; and operational problems led to failure.



- Circa 150,000 MTPA of MSW per year
- 11 million gallons per year of clean fuels
- TRI gasifier
  - Proven on pulp mill liquors, not MSW
  - Pulsed combustion caused stresses
  - Secondary 'Carbon Trim Cell' operation was complex
- Downstream POx burner (Linde HOT technology)
- Arvos (Schidtsche Schack) heat exchange technology for syngas cooling and steam generation
- Wet gas scrubbing and CO enrichment of syngas
- FTS conversion to syncrude onsite
- Syncrude refined to fuels offsite by Marathon Petroleum

5) Waste to energy is the low-risk  
option for hydrogen generation

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Waste thermolysis is not suitable for all waste types. Waste incineration (waste to energy) can be an option for more complex wastes.



- Waste is not a precisely controlled feedstock
- Mixing for even heat and mass transfer is difficult
- Tar accumulation can lead to clogging
- Slagging must be considered, or avoided
- Eutectic / ash bridging in the gasifier is a risk
- Refractory lining replacement leads to downtime and may need redundant equipment
- Risk of air ingress to the pyrolysis zone of the reactor and explosion
- Some waste types yield poisonous for the downstream WGS catalyst or PSA bed – these must be carefully removed
  - Chlorine from PVC (5% max PVC is generally OK)
  - Oxygen from PET (10% max PET is generally OK)
  - Sulphur from tyres

# MSW for Waste to Energy, then hydrogen from electrolysis. Pilot in Wuppertal, Germany 2020.



- 1) Incineration of sorted residual municipal solid waste (MSW) "Restmüll" (biogenic fraction close to 50%)
- 2) Power generation on 427,000 tonnes per year MSW to energy plant (2x 20MW electrical power turbines)
- 3) Excess power generation (during low electricity demand periods) to a 1.25MW Hydrogenics hydrogen electrolyser
- 4) Maximator integrated hydrogen storage of 425kg hydrogen capacity and Hydrogen Refuelling Station (HRS)
- 5) Certified "green" hydrogen for local Van Hool A330 Fuel Cell Electric Bus fleet

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# Introduction to Stephen B. Harrison and sbh4 consulting

**Stephen B. Harrison** is the founder and managing director at sbh4 GmbH in Germany. His work at sbh4 over the past 8 years has focused on hydrogen, industrial decarbonisation, CCU/S, biofuels, e-fuels and clean fertilizers.

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

Stephen supports the IFC to track down and evaluate the most attractive green hydrogen, biofuels and decarbonisation projects worldwide. He has also supported EIB and ADB on several hydrogen and CCS initiatives.

Stephen has extensive due diligence and investment advisory experience in the clean-tech sector. Private Equity firms, investment fund managers and green-tech start-ups are regular clients.

Industrial corporations often seek his guidance on their industrial decarbonisation plans and growth strategies to offer products and services to the emerging hydrogen economy and energy transition.

Startups are increasingly turning to Stephen to guide their technology development roadmaps from a solid techno-economic basis. He also advises and supports their tech-to-market strategies.

