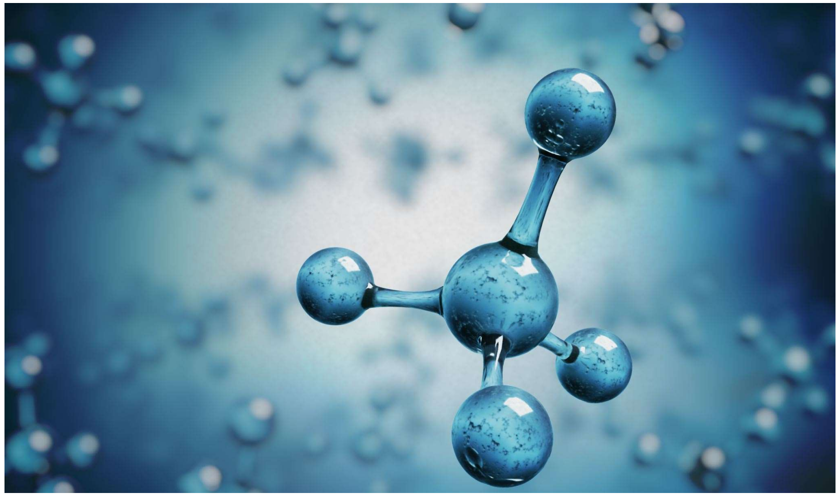
IEA Bioenergy
Technology Collaboration Programme



Task project

Biomass gasification for hydrogen production

State-of-the art technology

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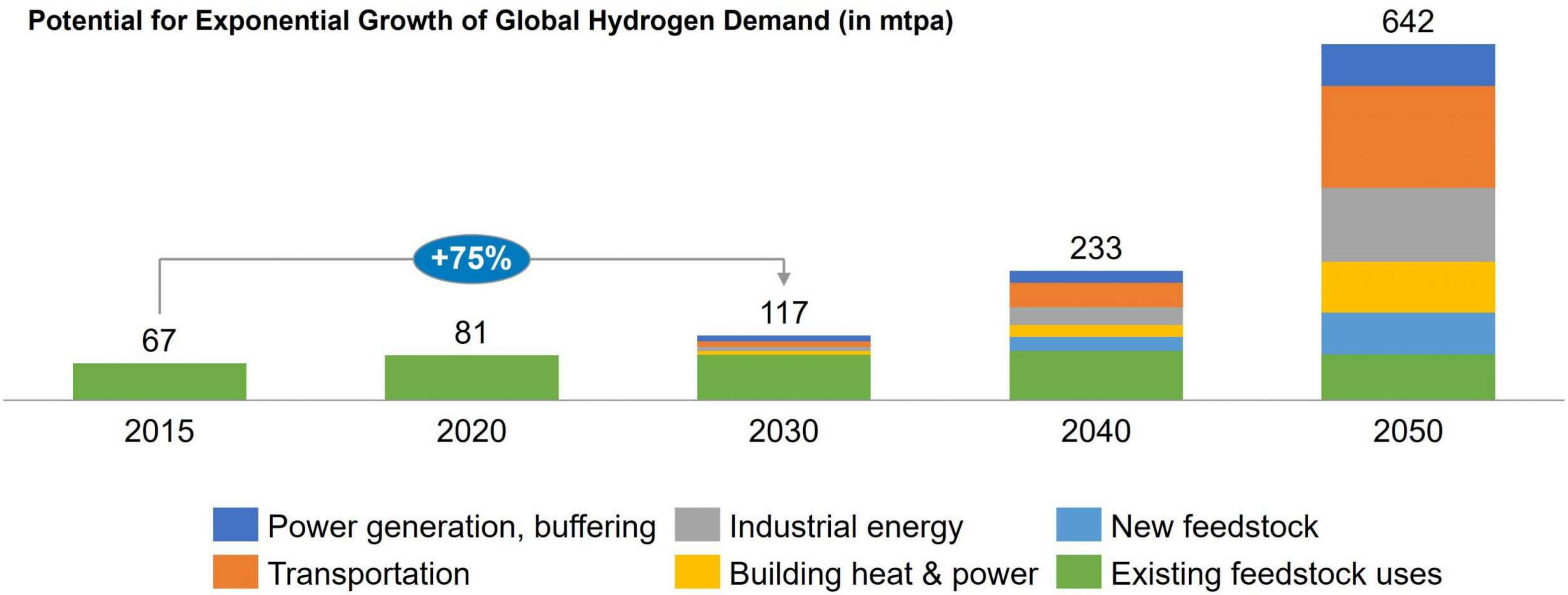
Aim and objectives

- Provide a comprehensive description and review of different gasification technologies suitable for bio-hydrogen production.
- Describe on-going commercial initiatives in the field.
- Assess techno-economic opportunities and challenges and identify potential knowledge gaps to better understand the need of further research and development.

The demand for green hydrogen is expected to skyrocket



Source: Hydrogen Council

Hydrogen demand directly converted to power demand

- Other production pathways than electrolysis seems overlooked
- Hydrogen via biomass gasification deserves more attention
  - Non-weather dependent, fossil-free, large-scale hydrogen production
  - Mitigate the power demand
  - Process integration opportunities
  - Negative CO_2-emissions

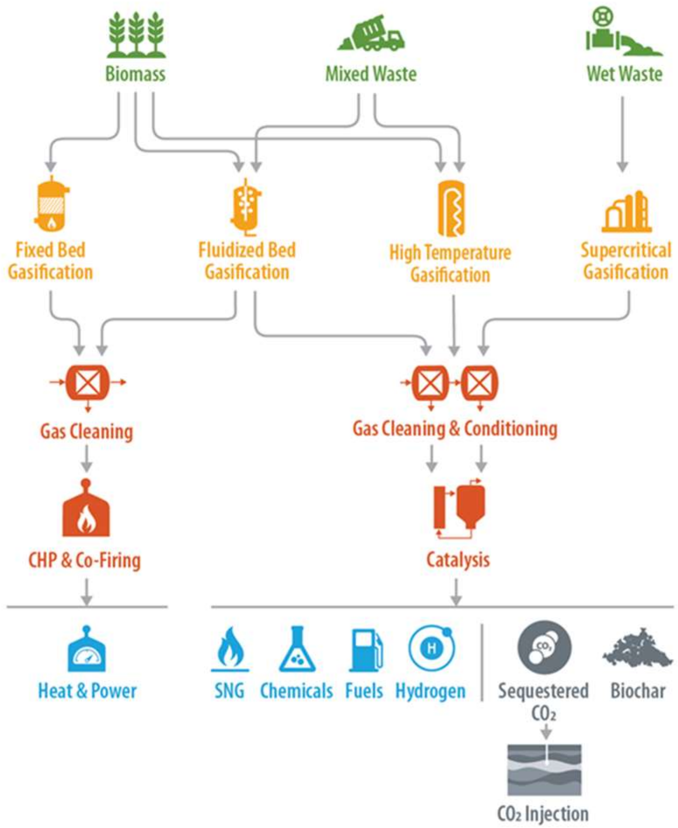
Figure 4. An Illustrative Hydrogen Colour Spectrum

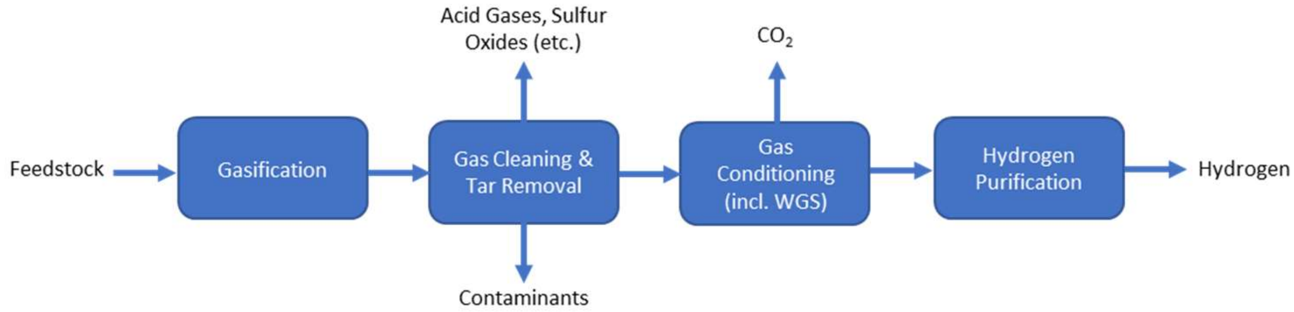
	Terminology	Technology	Feedstock/ Electricity source
PRODUCTION VIA ELECTRICITY	Green Hydrogen	Electrolysis	Wind, Solar, Hydro, Geothermal, Tidal
	Purple/Pink Hydrogen		Nuclear
	Yellow Hydrogen		Mixed-origin grid ener
PRODUCTION VIA FOSSIL FUELS	Blue Hydrogen	Natural gas reforming + CCUS gasification + CCUS	Natural gas, coal
	Turquoise Hydrogen	Pyrolysis	Natural gas
	Grey Hydrogen	Natural gas reforming	
	Brown Hydrogen	Gasification	Brown coal (lignite)
	Black Hydrogen		Black coal

**GCG footprint given as a general guide but it is accepted that each category can be higher in son*

Source: Global Energy Infrastructure (GEI), 2021

Gasification – flexible in feedstock & broad product portfolio





- For every ton of dry biomass gasified, about 0.1 ton of H_2 can be produced together with 1.5-2 ton of CO_2, i.e., 15-20 kg CO_2 per kg H_2

Reported experimental results on H2-purity

- Indian Oil demonstrated production of fuel-cell quality bio-H2 in a small-scale woody-biomass gasifier
  - Average yield was 100-105 g H2 per dry kg biomass
  - Hydrogen recovery in vPSA: 70-72 %
  - A small fuel-cell system tested using the produced bio- H2 (>250 hours of operation)
- TU Vienna produced hydrogen in lab-scale from a synthetically pre-mixed producer gas and a real producer gas from a downdraft fixed-bed gasifier.
  - The concentrations of impurities were lower than the thresholds of the standard ISO 14687:2019

Operational parameters influencing the hydrogen yield (Berend)

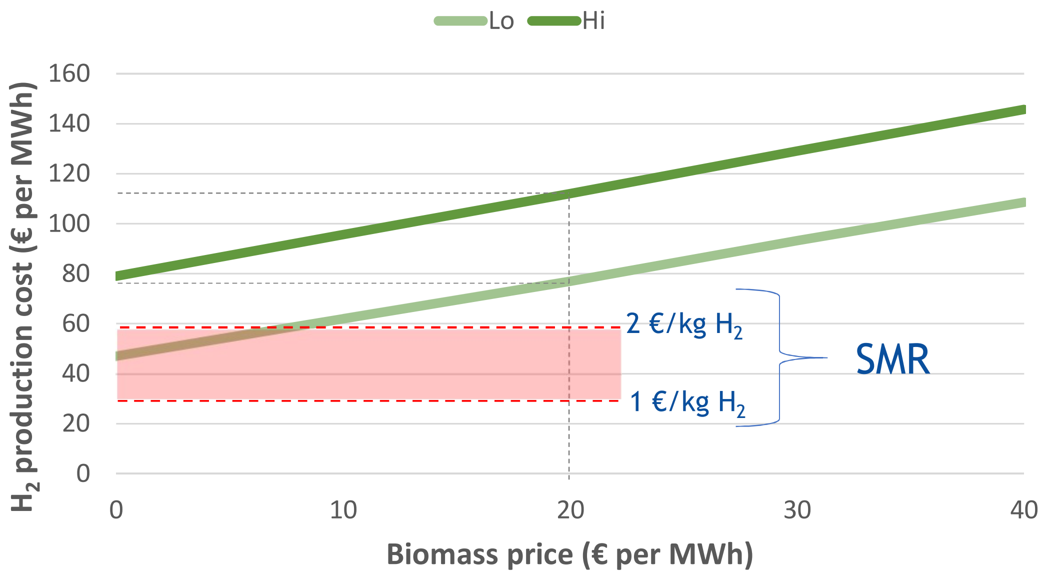
- Fuel characteristics
- Oxidants-fluidization media
- Temperatures
- Bed material
- Pressure
- Low-Temperature Catalytic Gasification of Biomass
- High-Temperature Catalytic Gasification of Biomass

Techno-economic and environmental assessments

Technology readiness level

Process steps	TRL	Weight [%]	Comments
Feedstock handling system	9	10	Covers the conveyance of the prepared feedstock to the gasifier. Most gasifiers use conventional off-the shelf technology
Gasification reactor with heat supply	7-8	30	Gasification systems for more advanced applications can be considered proven on demonstration scale (GobiGas etc). Higher TRL for CHP and fuel gas applications.
Product gas conditioning, cleaning, and purification	8	20	This concerns off-the shelf technology and is commercial for coal gasification. Not tested in large commercial scale with bio-based producer gases.
Integrated operation	5	40	Tests in pilot scale are reported
Overall “Weighted Average”	6.6-6.9		
Overall “Weakest Link”	5		Integrated operation to be proven

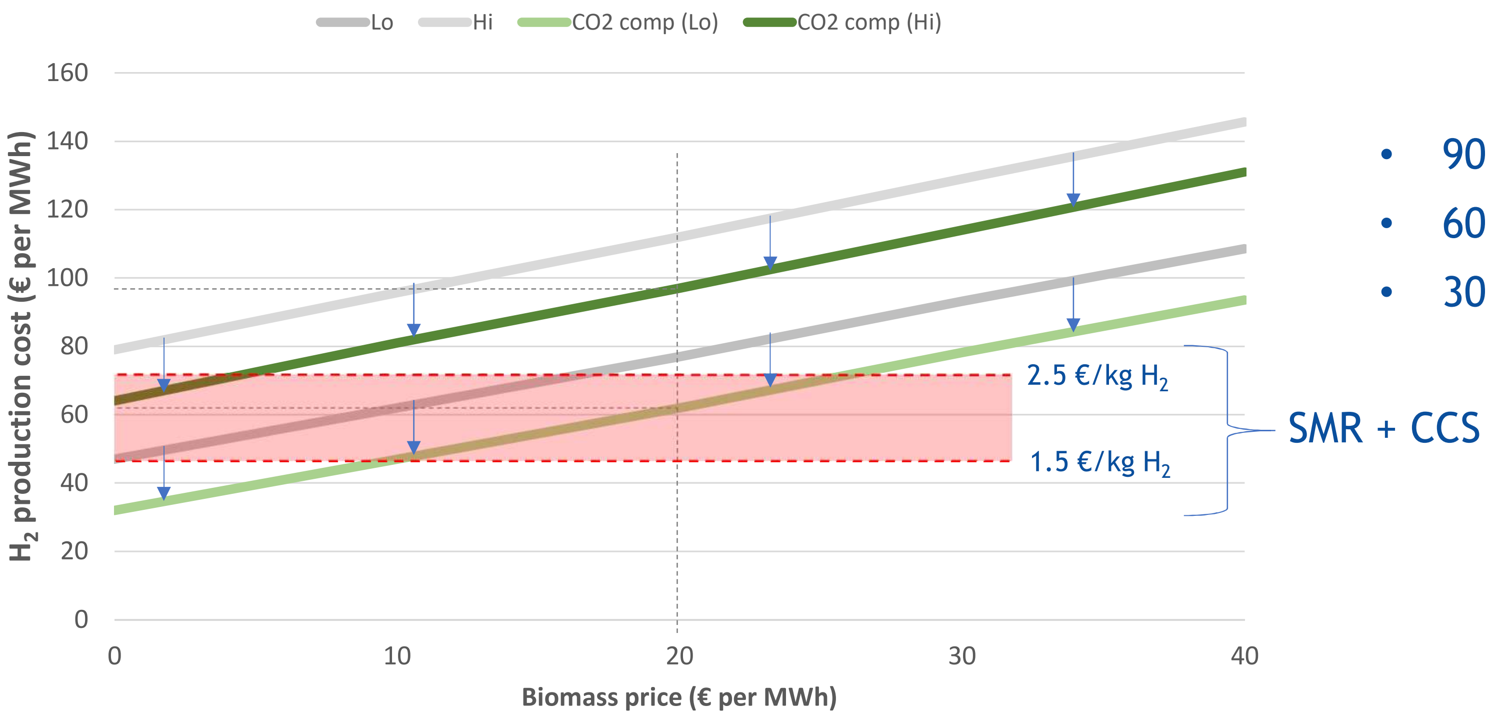
Cost for producing bio-hydrogen via gasification



- Production costs methanol/methane ≈ hydrogen – Added 10% on CAPEX
- CO_2 captured and stored = Negative emissions
- Price negative emissions = 100 € per ton CO_2
- Cost for CO_2 transport and storage = 50 € per ton CO_2
- Net credit = 50 € per ton CO_2

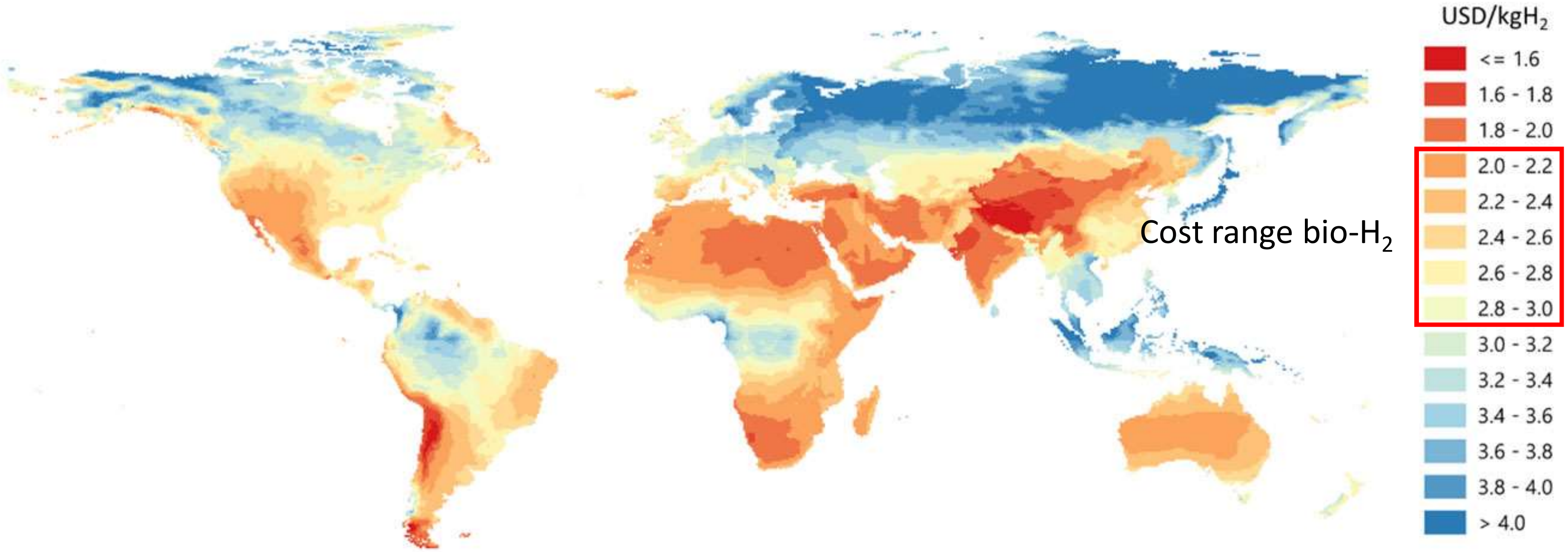
Ref: Advanced Biofuels – Potential for Cost Reduction, IEA Bioenergy, 2020

Cost for producing bio-hydrogen via gasification



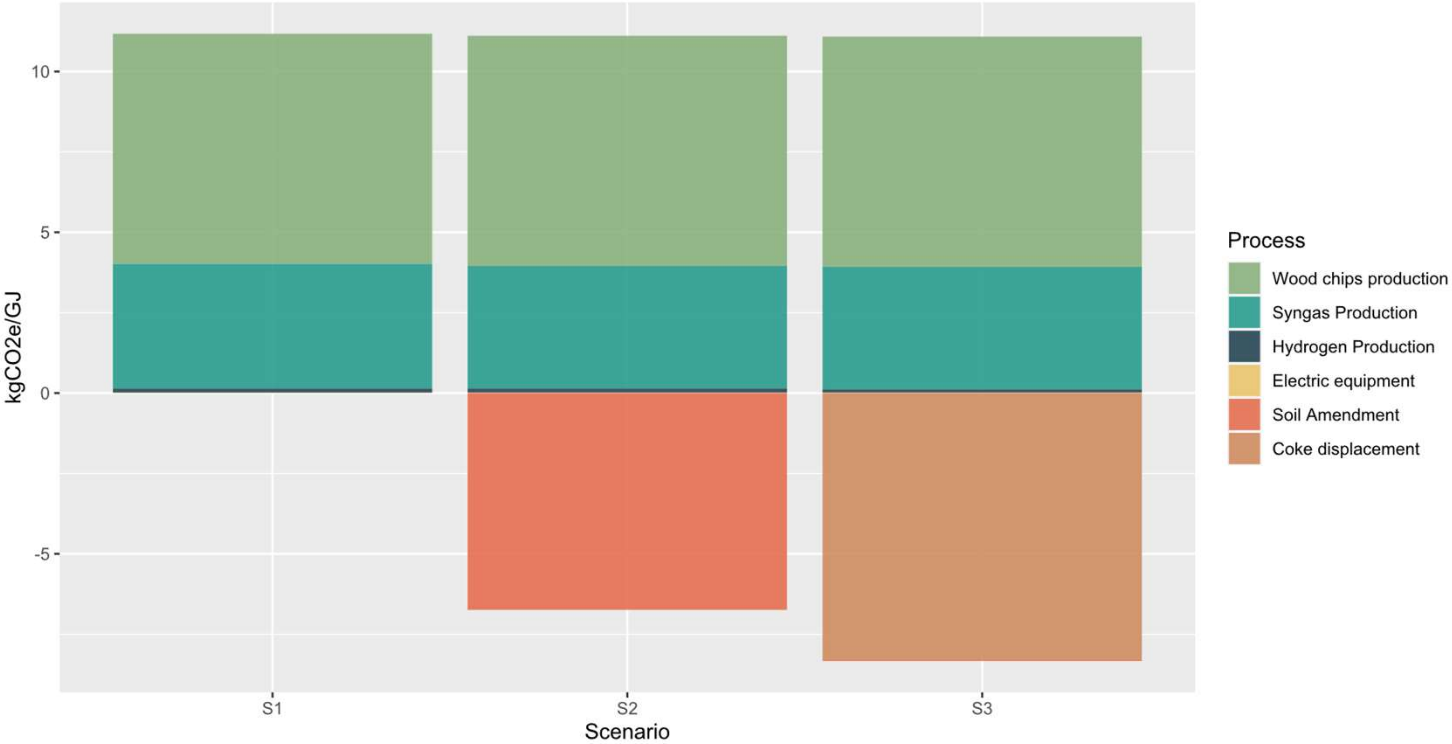
- 90 €/MWh H_2 = 3 €/kg H_2
- 60 €/MWh H_2 = 2 €/kg H_2
- 30 €/MWh H_2 = 1 €/kg H_2

Estimated cost of hydrogen based on solar cells and onshore wind power beyond 2040-2050



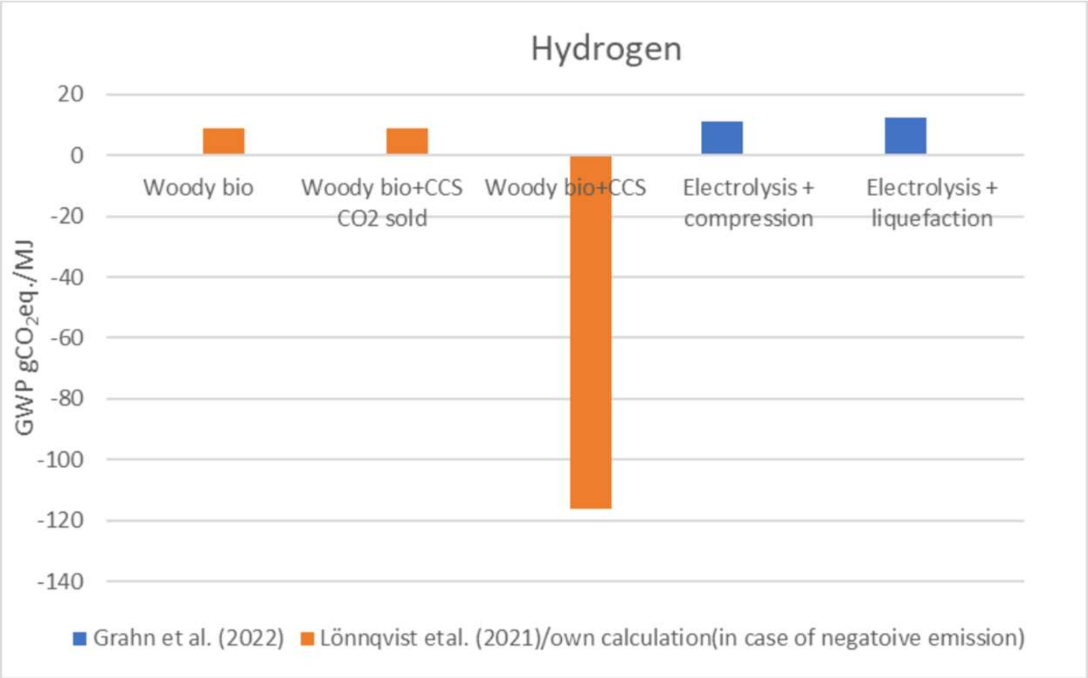
Ref: IEA Hydrogen Outlook, 2020

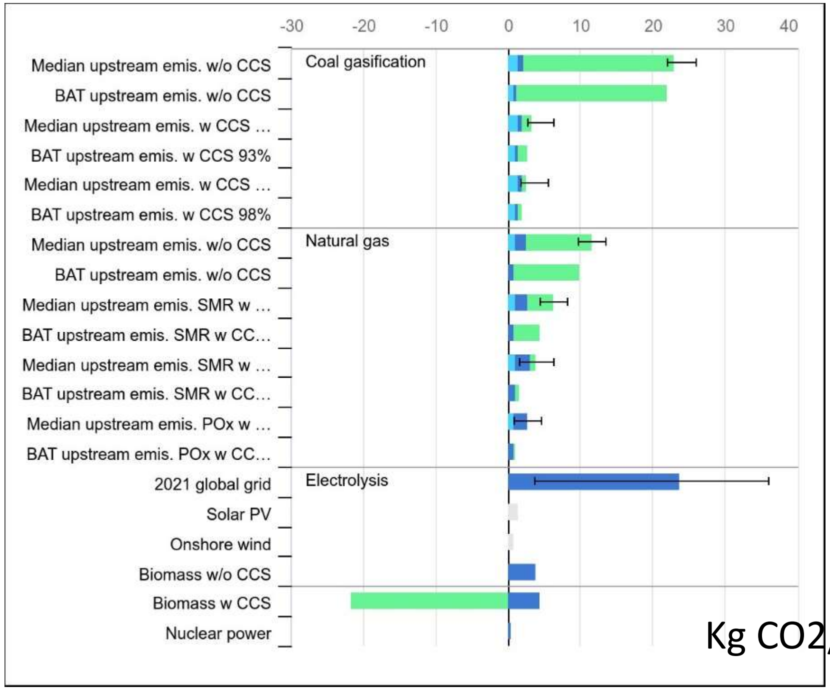
GHG-performance - LCA on Cortus WoodRoll (prel. results)



Scenario	Total GWP ($kgCO_{2-eq}$)
S1	11.17
S2	4.37
S3	2.75

GHG-performance

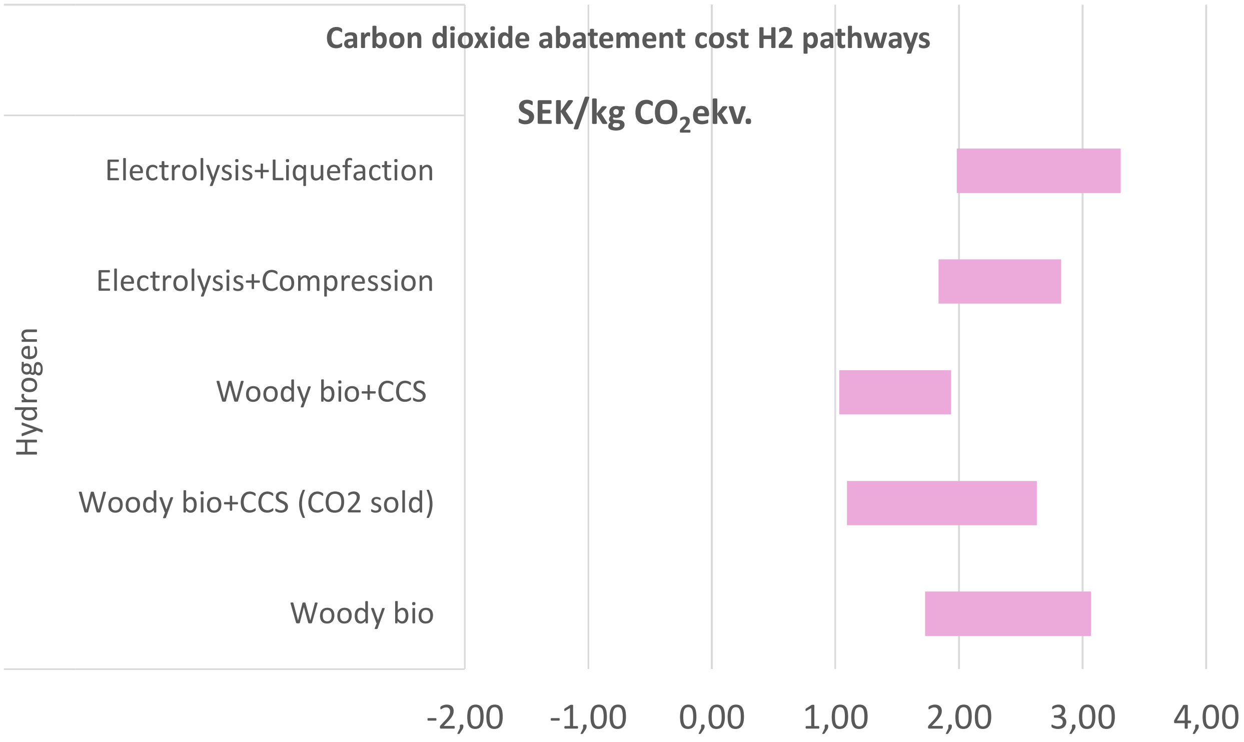




Kg CO2/kg H2

Ref: Hansson et.al, 2023. Costs for reducing GHG emissions from road and air transport with biofuels and electrofuels
IEA, 2021

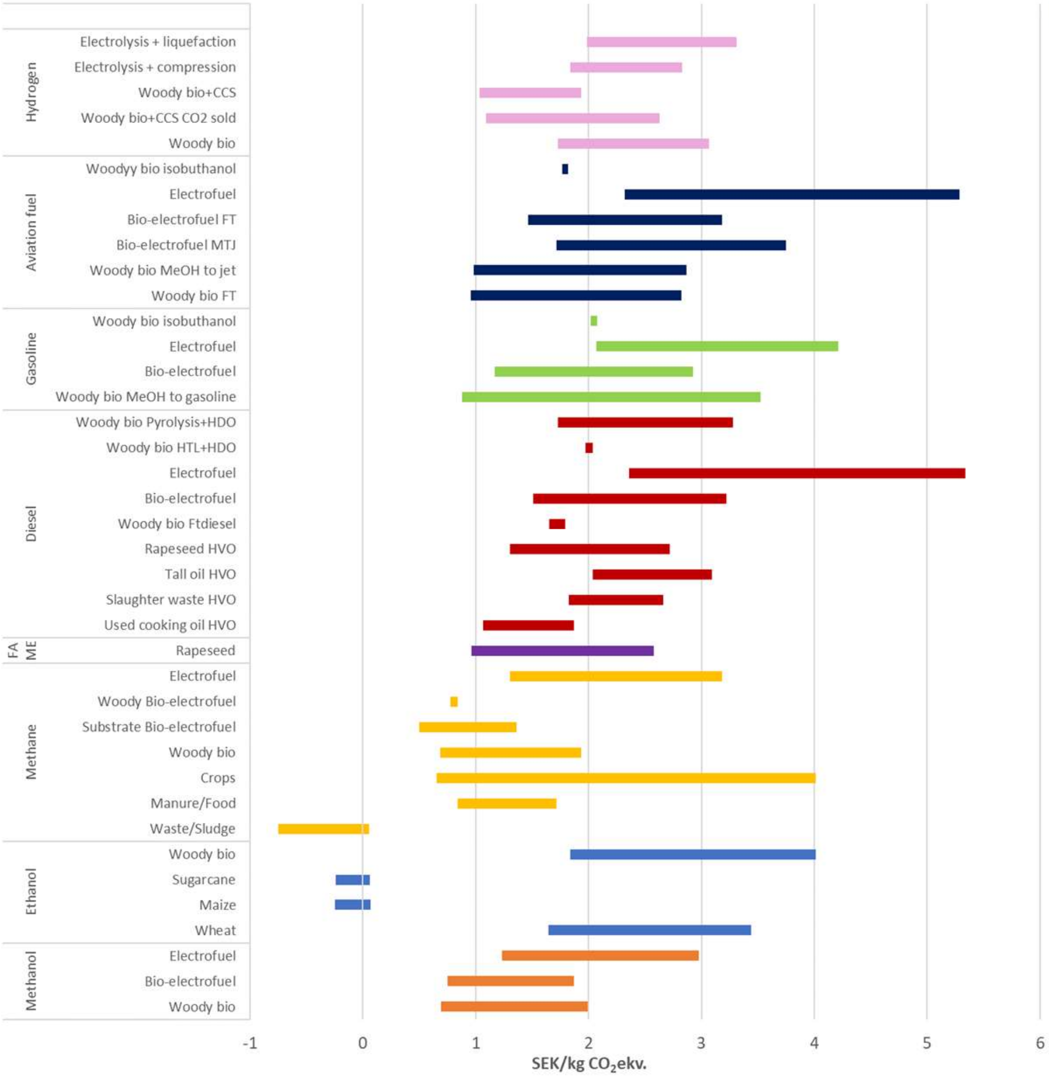
CO_2-abatement cost



- Assumptions:
  - Bio-H_2 replaces H_2 from natural gas
  - CO_2-emssion factor of EU electricity mix
  - Electricity price: 50 € per MWh

Ref: Hansson et.al (2023). Costs for reducing GHG emissions from road and air transport with biofuels and electrofuels, Report to Swedish Energy Agency

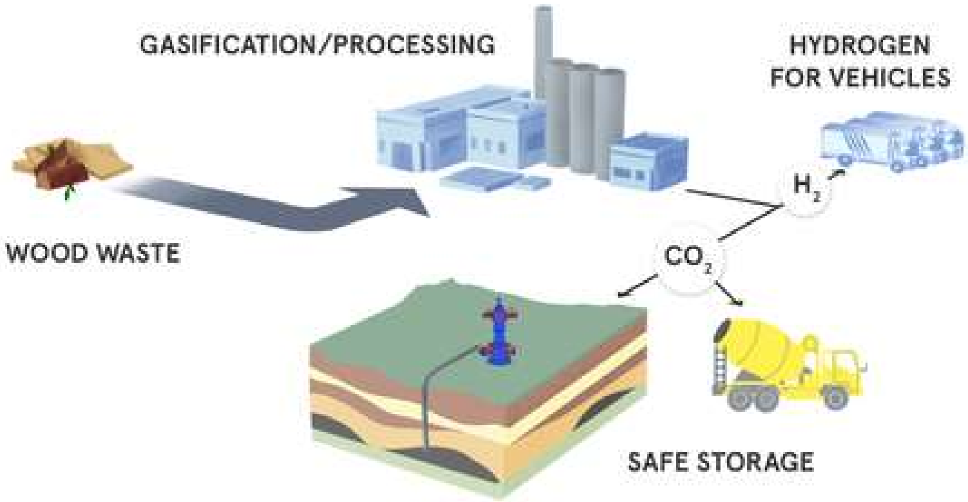
CO_2-abatement cost



Ref: Hansson et.al (2023). Costs for reducing GHG emissions from road and air transport with biofuels and electrofuels, Report to Swedish Energy Agency

Ongoing commercial initiatives

Initiatives in North America



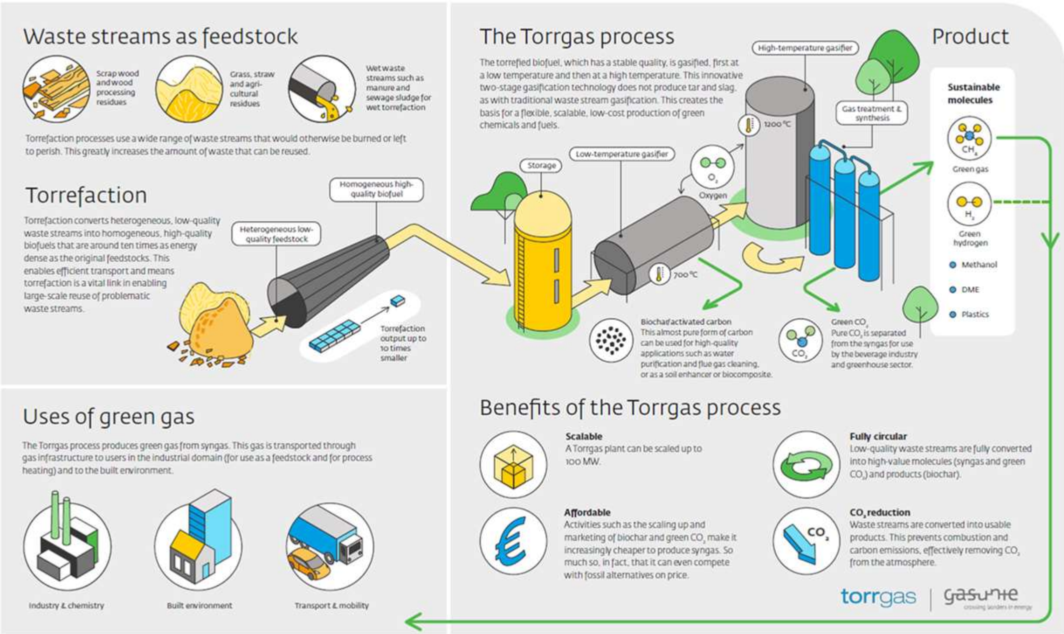
- US company Mote plans a facility to convert wood waste into hydrogen while capturing, utilizing, and sequestering the CO2.
- SunGas Renwables technology – based on GTI's U-Gas® technology
- Canadian company H2Naturally has three plant locations for gasification- based bio-hydrogen with CCS planned for British Columbia.

Initiatives in North America

SG H2 ENERGY
FUELING A CLEAN ENERGY FUTURE, TODAY

- SGH2 uses a plasma-enhanced thermal catalytic conversion process optimized with oxygen- enriched gas.
- Plasma torches in the gasification island's catalyst-bed chamber - high temperatures (3500º-4000º C)
- Very high-quality hydrogen-rich bio-syngas free of tar, soot and heavy metals.
- After PSA, the hydrogen purity is greater than 99.97% (fulfilling SAE-J2719 standard for use in Proton Exchange Membrane fuel cell vehicles)

Initatives in Europe - Torrgas



- Torrgas develops a 50 MW demonstration unit to produce hydrogen by gasifying torrefied biomass.
- Biochar is produced, sold as a soil improver.
- The technology is scalable to 100 MW (1,4 PJ green gas) per gasifier unit.
- Seems to abandon H2-production due to NL-policy issues?

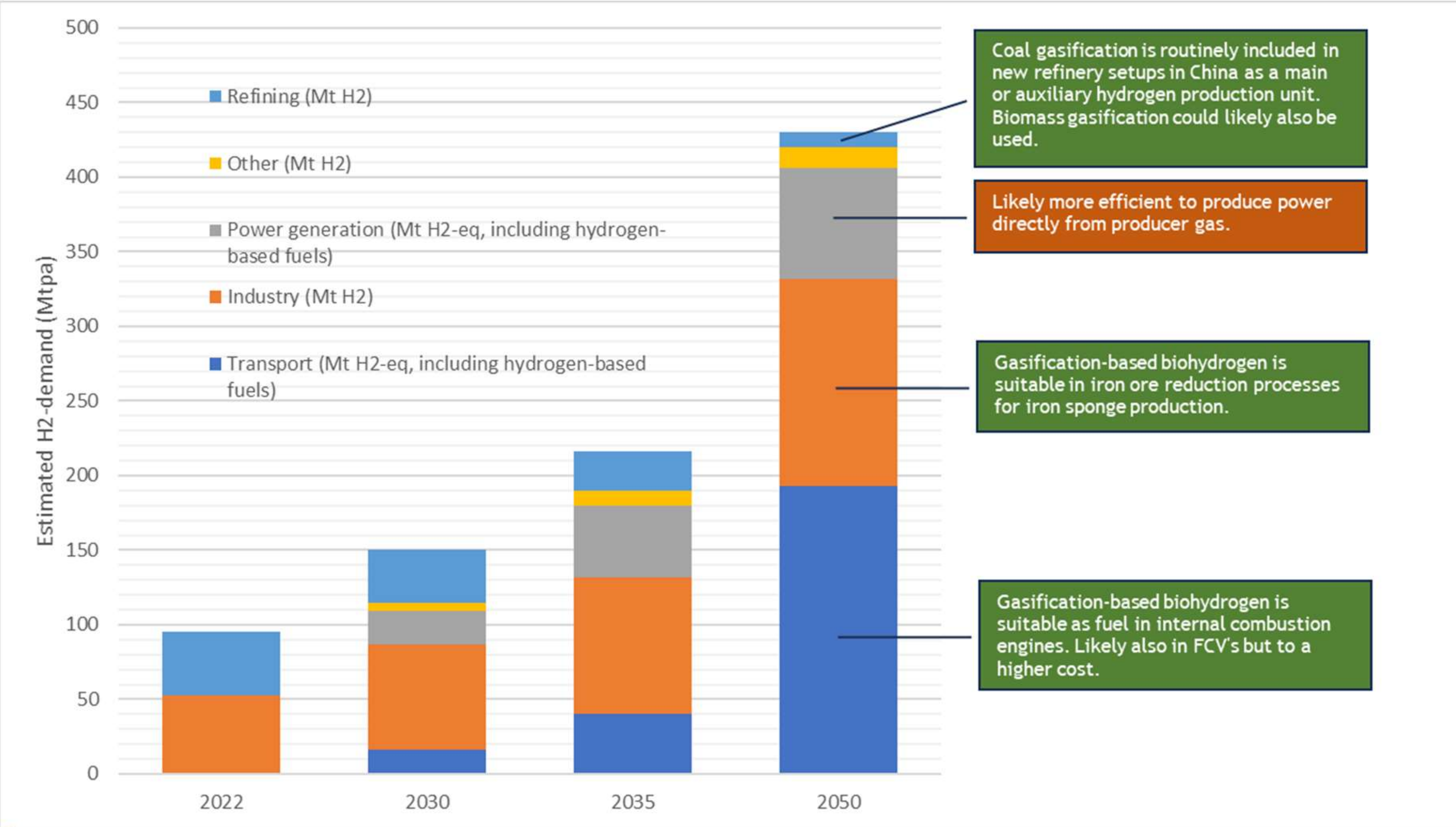
Initatives in Europe - Advanced Biofuel Solution Ltd (ABSL)

- The ABSL plant in Swindon convert household waste into bio-substitute natural gas (BioSNG) that is injected into the local gas grid.
- Slipstream of syngas taken after the WGS and purified (Xebec PSA) to meet the specification for proton electron membrane fuel cells.
- The hydrogen is compressed and transferred to tube trailers that will take it to hydrogen refueling stations for use in buses and other hydrogen vehicles.

Other initiatives

- Cortus (S) using wood-pellets to produce syngas with high H2-conc.
- Plagazi (S) using waste plastic to produce hydrogen
- NettEnergy (NL) using roadside grass to produce hydrogen and biochar
- China Datang Co. Ltd (China) using biomass pellets to produce hydrogen
- Jin Tong Ling Technology Group (China) using straw to produce hydrogen
- Dok-Ing (Croatia) developing a gasification process on waste to hydrogen

Potential contribution from gasification



Summary

- Assessed ”weighted average” TRL 6-7, ”weakest link” TRL 5
  - High technology maturity of individual sub-process.
  - Actual hydrogen production reported in pilot-scale/slip-streams.
  - Integrated production in demonstration scale remains.

- Several commercial initatives in EU and US – but still only plans.

- Today, difficult to compete economically with fossil-based hydrogen, but…
  - The current developments of CCUS in other applications will lead to lower capital costs.
  - Every progress made within CCUS thus means more competitive gasification systems.

Summary

- Very good GHG-performance – GWP -115 up to 15 kg CO2eq/GJ
- Production cost and CO_2-abatement cost likely to be lower than the costs of power based H_2 in many world regions.
- Great potential for gasification-based H2 in several sectors – not necessary to aim for fuel-cell purity.

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