

Hydrogen



THINK GREEN

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ENTEC Research Area to Support Low Carbon Energy Research

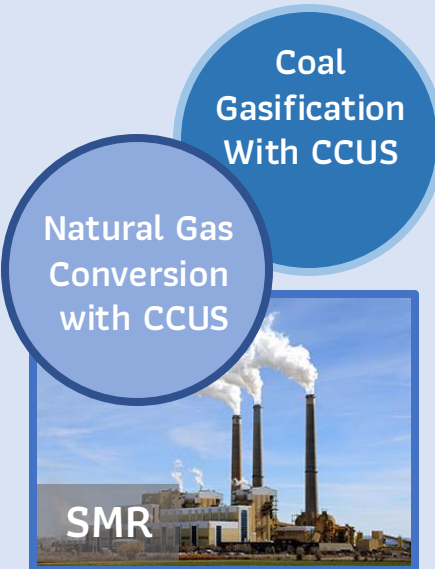
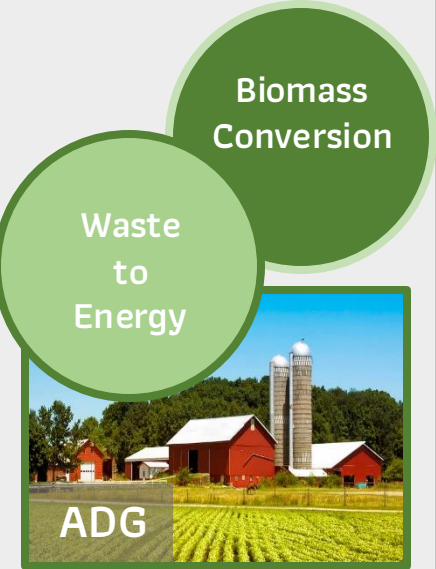
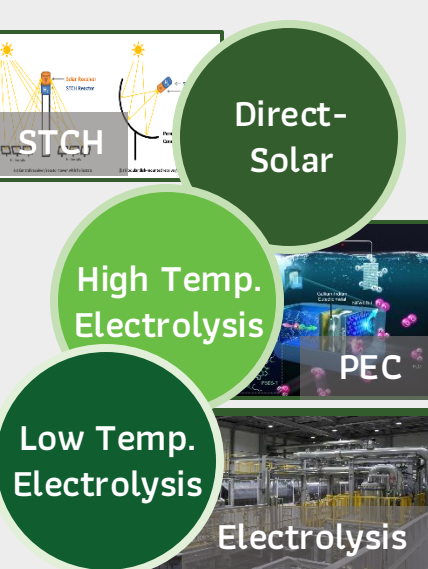


Resilience: Maintain conventional risk of RE and change to fast recovery based on our energy resilience concept (address SDG and enhance climate adaptability)

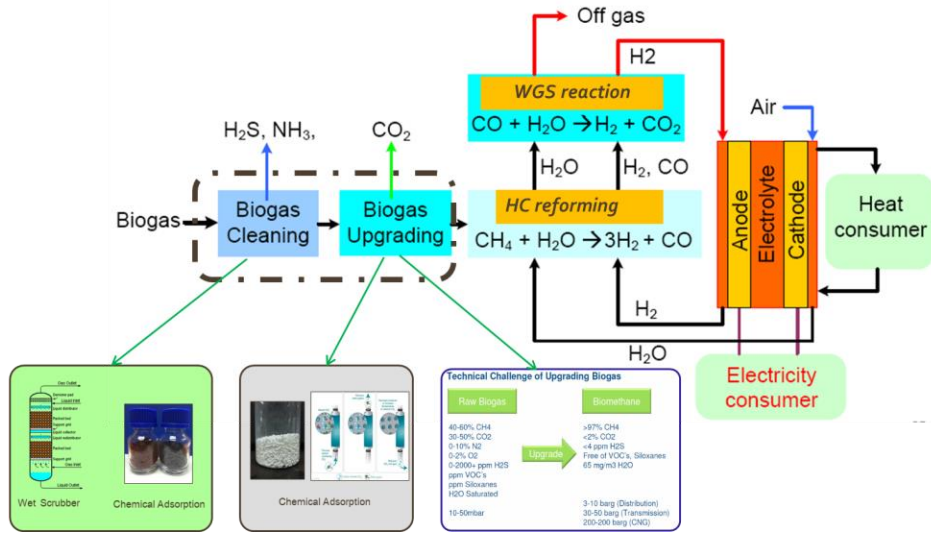


Hydrogen Production

Terminology	Technology	Feedstock	GHG footprint
White	Natural	Natural	N/A
Green	Electrolysis	Renewable energy	Minimal
Pink	Electrolysis	Nuclear	Minimal
Yellow	Electrolysis	Mixed grid energy	Medium
Blue	Gasification + CCUS	Natural gas	Low
Turquoise	Pyrolysis	Natural gas	Solid carbon
Grey	thermochemical	Natural gas	Medium-high
Brown	thermochemical	Brown coal (lignite)	High
Black	thermochemical	Black coal	High

FOSSIL RESOURCES	BIOMASS/WASTE	H ₂ O SPLITTING
<ul style="list-style-type: none"> Low-cost, large-scale hydrogen production with CCUS New options include byproduct production, such as solid carbon 	<ul style="list-style-type: none"> Options include biogas reforming and fermentation of waste streams Byproduct benefits include clean water, electricity, and chemicals 	<ul style="list-style-type: none"> Electrolyzers can be grid-tied, or directly coupled with renewables New direct water-splitting technologies offer longer-term options 

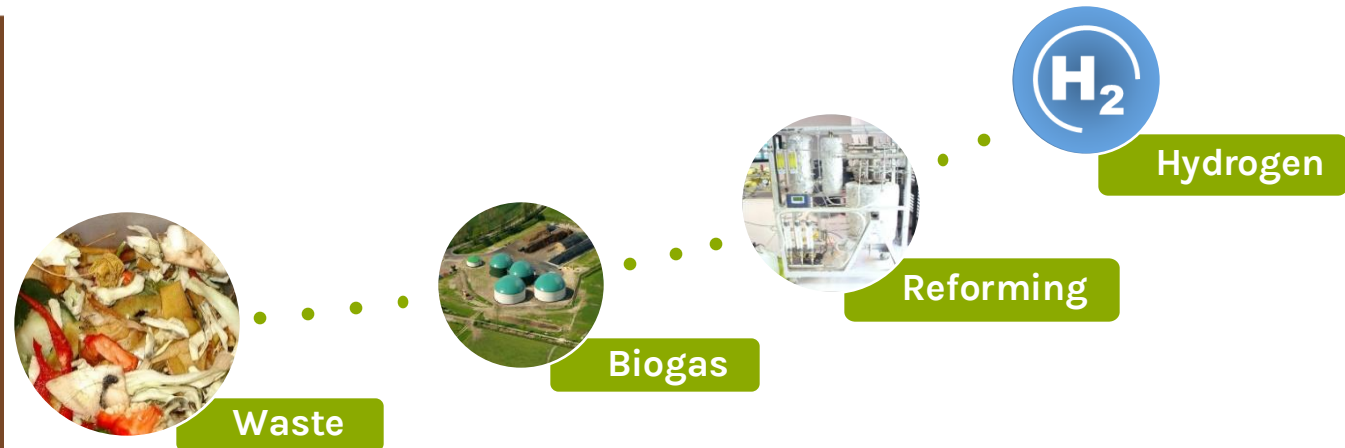
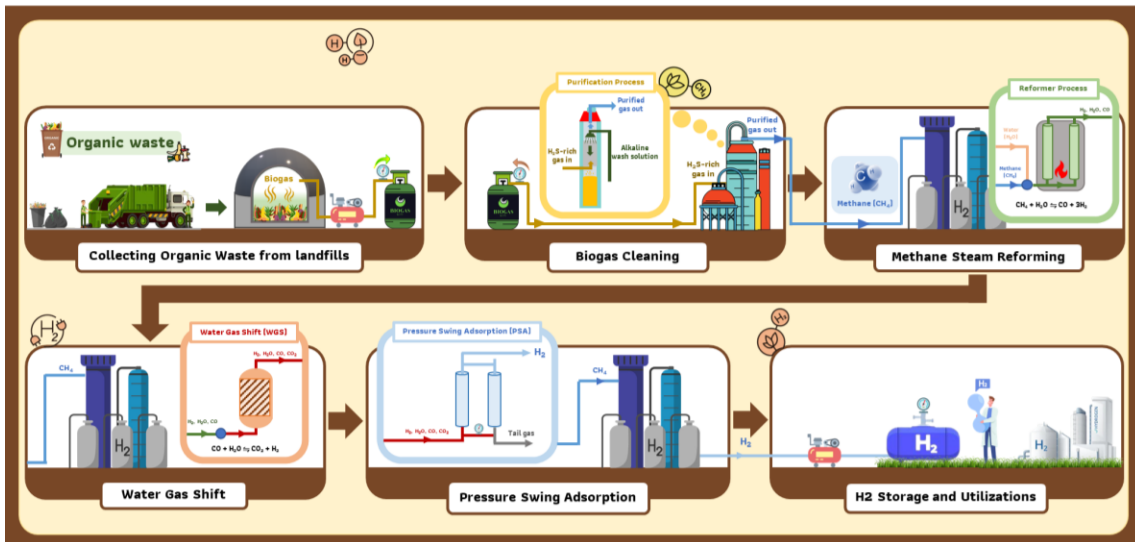
H2 from Biomass/Biogas



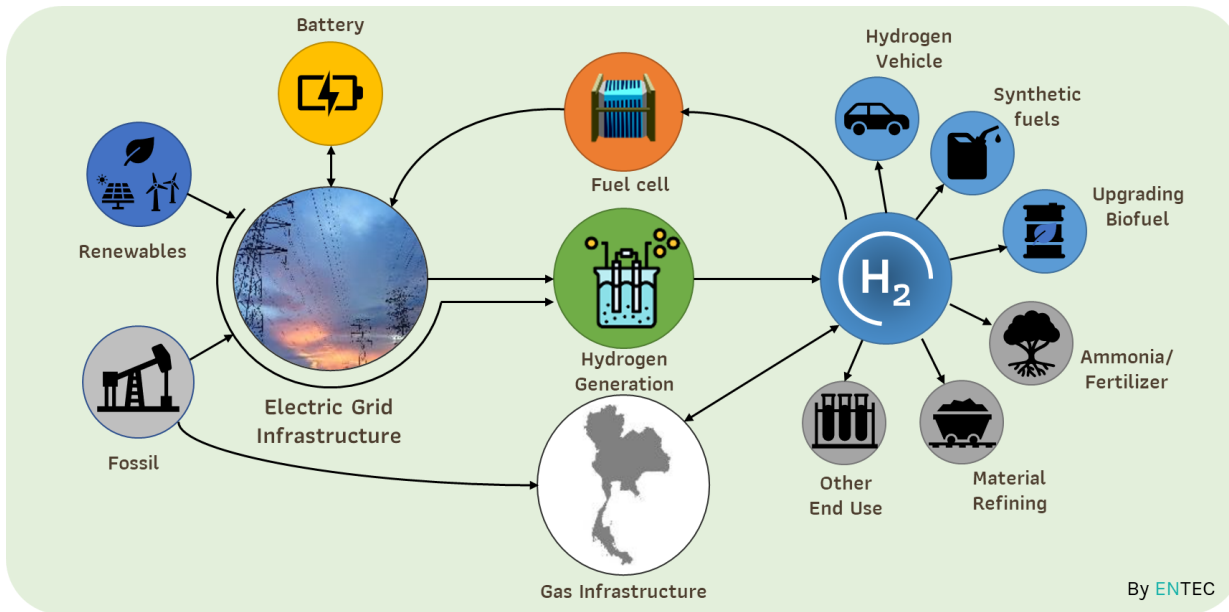
Technical Challenge of Upgrading Biogas

Raw Biogas	Biomethane
40-60% CH ₄	>97% CH ₄
30-50% CO ₂	<2% CO ₂
0-10% H ₂	<4 ppm H ₂
0-2% O ₂	Free of VOC's, Siloxanes
0-2000 ppm H ₂ S	65 mg/m ³ H ₂ O
ppm VOC's	
ppm Siloxanes	
H ₂ O Saturated	
10-50bar	3-10 barg (Distribution) 30-50 barg (Transmission) 200-300 barg (CNG)

- Biomass is an abundant domestic resource
- Biomass/Biogas "recycles" carbon dioxide
- Waste to energy
- CH₄ is 28 times Global warming potential than CO₂

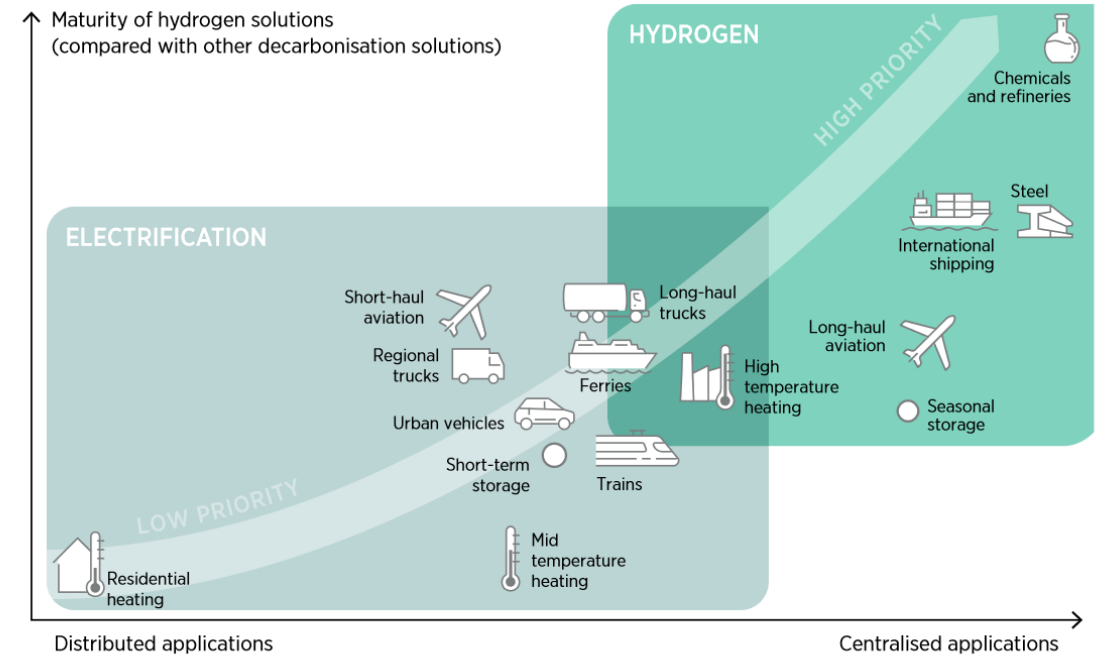


Hydrogen for decarbonization



The benefits of using **Hydrogen** for decarbonization

- Decarbonizing Heavy Industries
- Flexibility in Energy Systems
- Potential for Large-Scale Decarbonization
- Versatility in Applications
- Potential for Carbon Capture and Utilization
- Support for Net-Zero Goals



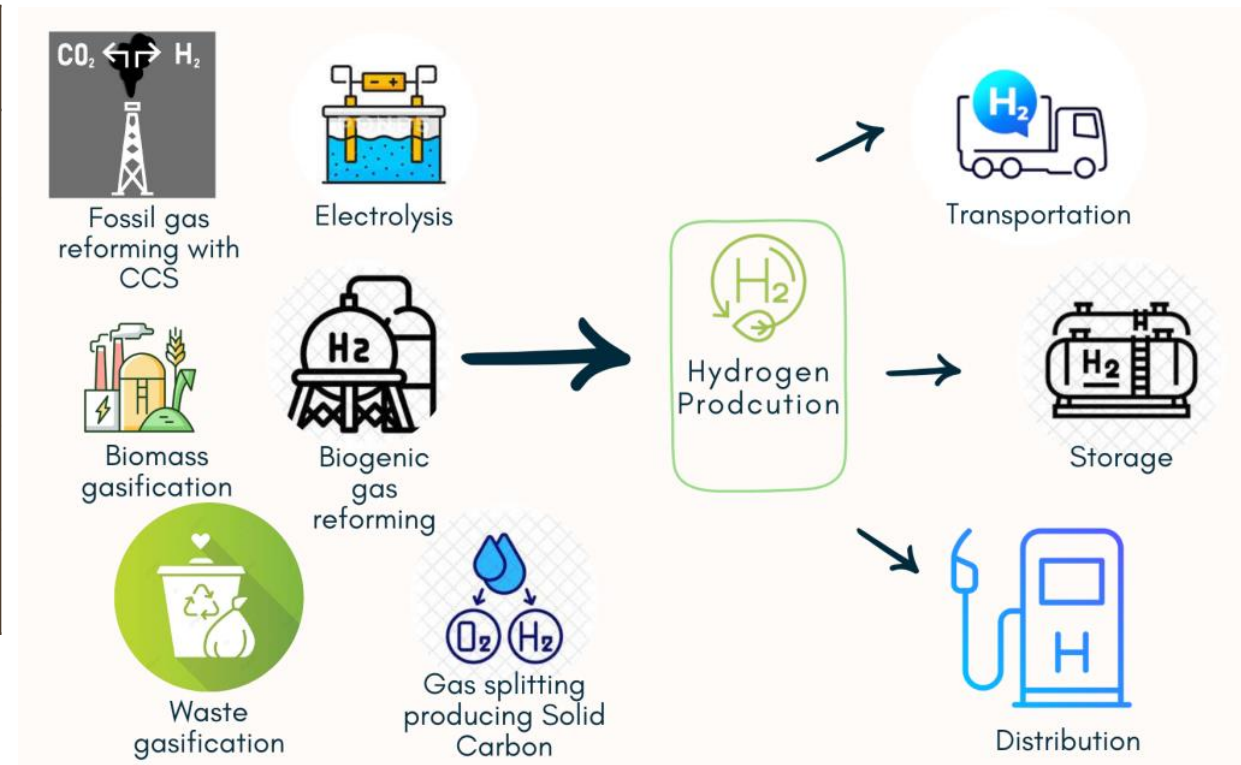
Source: IRENA (2022e).

Low Carbon H2 production



Technology and Informatics Institute for Sustainability (TIIS)

Terminology	Feedstock	Energy	Technology	Product	C Footprint [kgCO ₂ /kgH ₂]
White	Natural/ By-product	Mixed	PSA	H ₂	0.7-1.0
Green	Water	Renewable energy	Electrolysis	H ₂ +O ₂	0.5-2.5
Green	Biomass /Biogas	Biomass /Biogas energy	thermochemical	H ₂ +CO ₂	-26.5-10
Blue	Natural gas	Natural gas	SMR + CCUS	H ₂ +CO ₂ [capture]	1.5-5
Grey	Natural gas	Natural gas	SMR	H ₂ +CO ₂	10-20



Source: Decarbonising Europe's hydrogen production with biohydrogen, European Biogas Association (2023)
 Bareiß, K., et al., Applied Energy (2019)
 Towards hydrogen definitions based on their emissions intensity, IEA (2023)
<https://re24.energy/blog-low-carbon-hydrogen-standards-a-comprehensive-lookout/>