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Environmental Performance of Hydrogen Production from Industrial Waste: Towards Circular Economy

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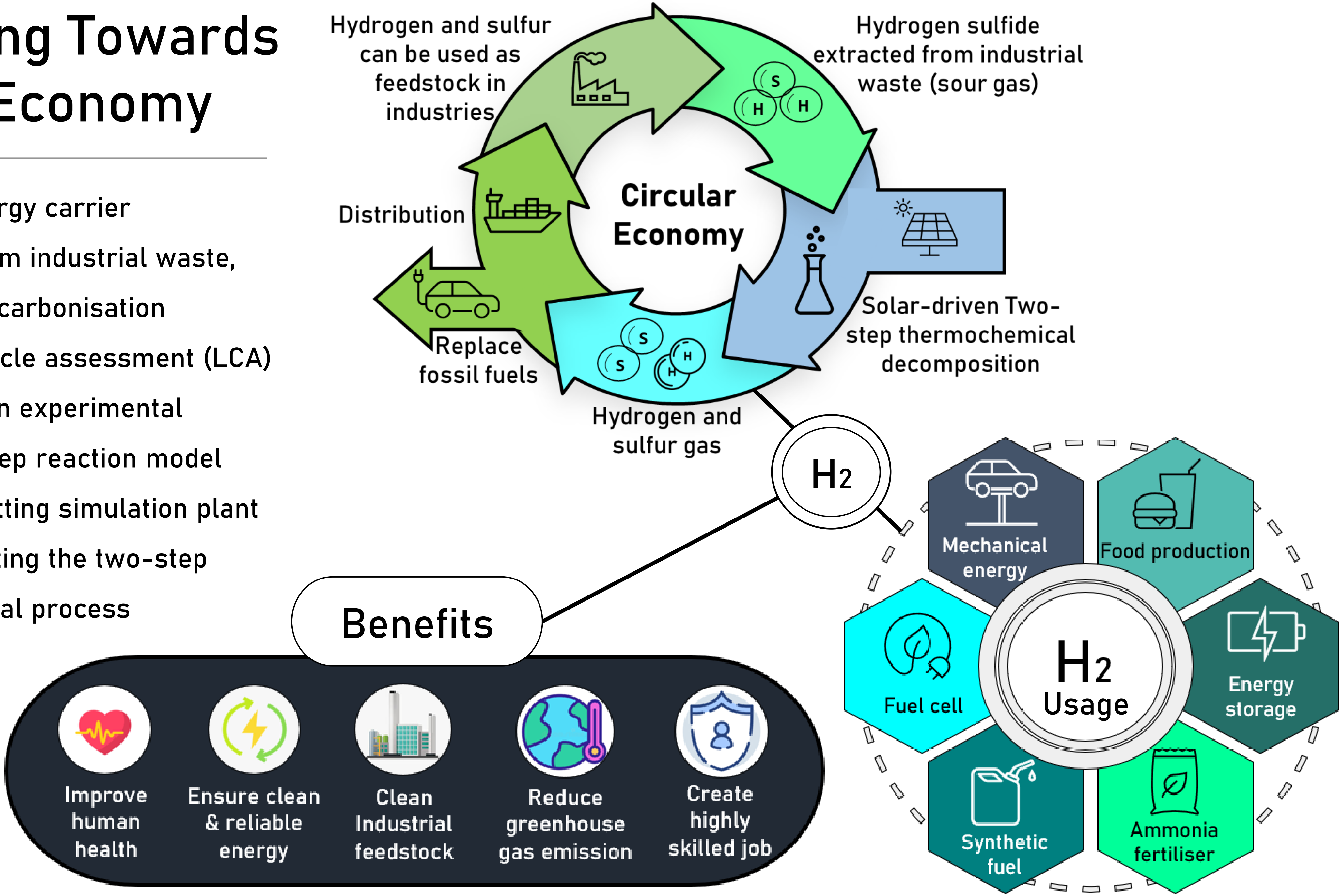
Transitioning Towards Hydrogen Economy

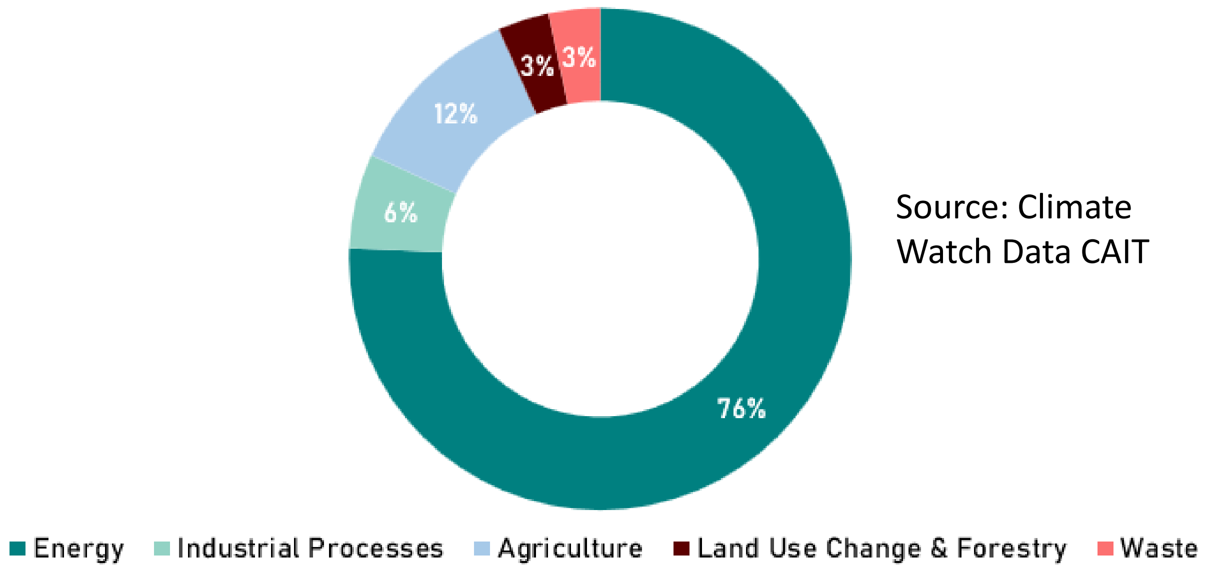
- Hydrogen as an energy carrier
- Energy recovery from industrial waste, H_2S is crucial for decarbonisation
- Gate-to-gate Life cycle assessment (LCA) was conducted on an experimental microkinetic multistep reaction model
- Pilot-scale H2S splitting simulation plant was built by integrating the two-step solar thermochemical process



Driving Force of this Research

- Almost 47% of the world's hydrogen generation as of the end of 2021 comes from natural gas, 27% from coal, 22% from oil (as a by-product), and just around 4% from electrolysis (*Hydrogen*, n.d.)
- Emitting H_2S, a dangerous and poisonous gas, into the atmosphere without treatment would lead to detrimental environmental impacts
- The hydrogen element is usually wasted due to the high cost of tail gas treatment (Huang and T-Raissi, 2008)

Global Sources of GHG Emissions



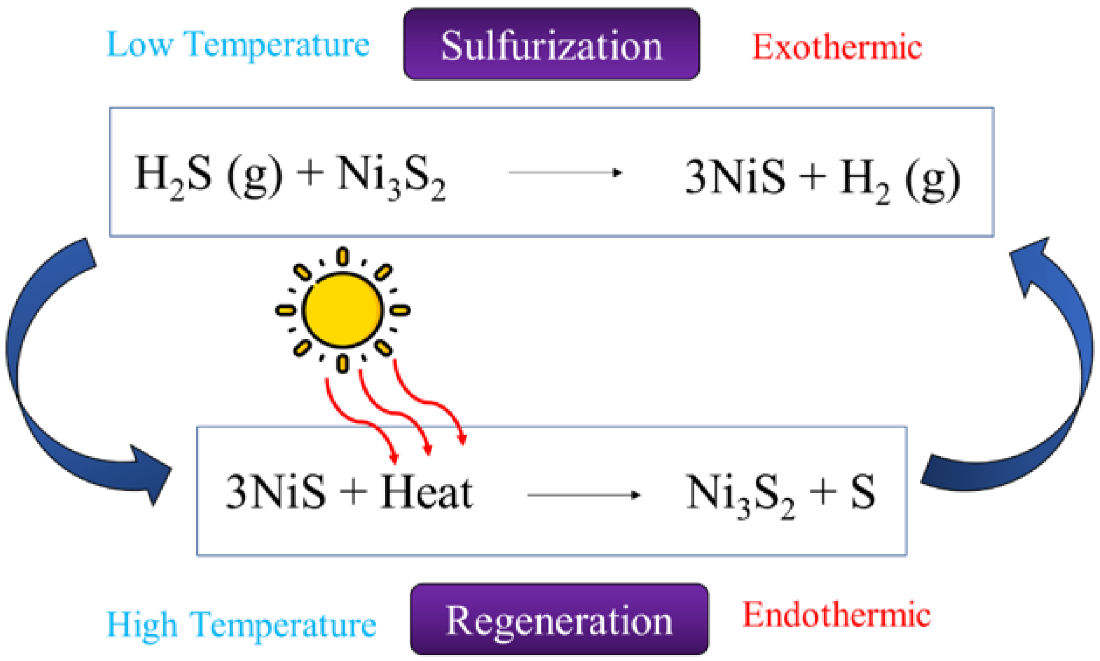
Source: Climate Watch Data CAIT

Key Findings Based on Previous Literature

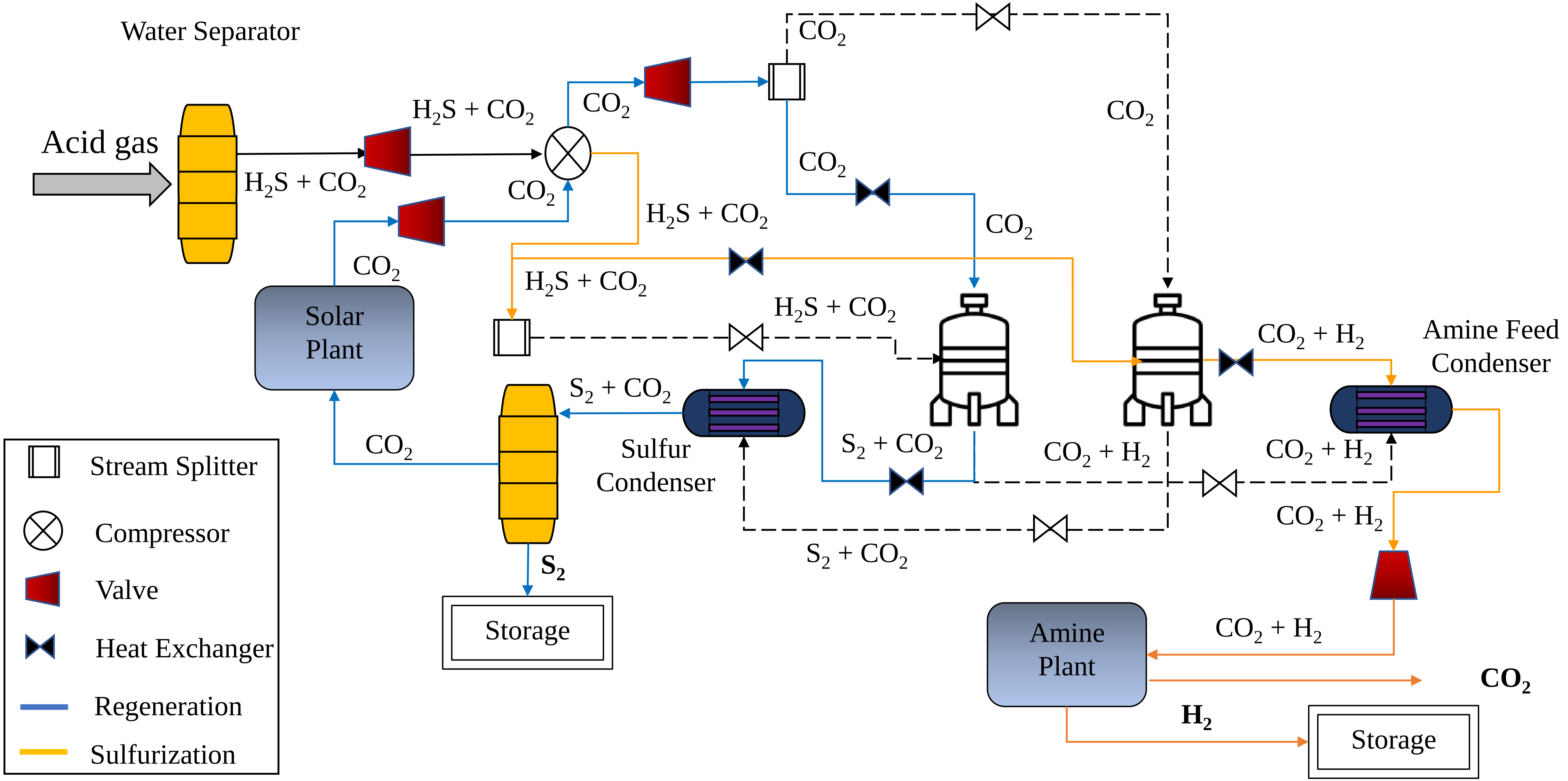
Findings	Reference
Cu-Cl cycle's thermochemical water-splitting approach was better than other technologies in terms of carbon dioxide equivalent emissions, followed by wind and solar electrolysis to produce hydrogen	Cetinkaya et al. (2012)
Renewable energy which includes solar, and wind are the only scenarios that produce hydrogen with minimal environmental damage	Gerloff (2021)
One of the most promising methods for creating green hydrogen at scale effectively and using thermal energy is thermochemical water splitting	Ozcan et al. (2023)
LCA could be a useful evaluation approach to assess various hydrogen-generating processes	Zhang et al. (2022)

Key Parameters of the H_2S Simulation Plant

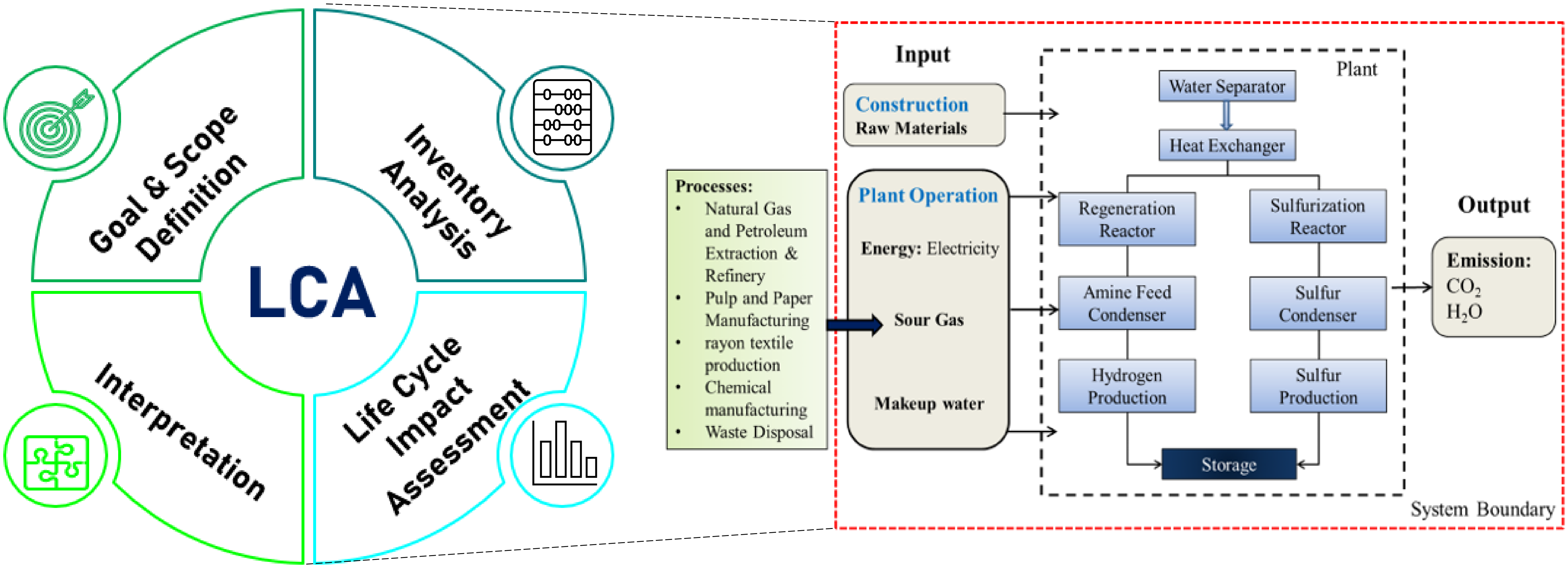
Parameter	Value	Unit
Plant Reactors		
Specific Surface	0.45	m^2/g
Active Metal Dispersion	20	%
Size of Cell	1.0 × 1.0	Mm
Wall Thickness	0.2	Mm
Total effective internal surface area per unit volume	0.28×10^6	m^{-1}
Sulfurization Step		
Feed Volumetric Flowrate	80	MMSFD
Hydrogen Sulfide, H_2S	0.5	Mol
Nitrogen, N_2	0.5	Mol
Temperature	500	°C
Pressure	1.8	Bar
Regeneration Step		
Feed Volumetric Flowrate	40	MMSFD
Carbon Dioxide (CO_2)	1.0	
Temperature (°C)	700	°C
Pressure	1.8	Bar



H_2S Splitting Simulation Plant

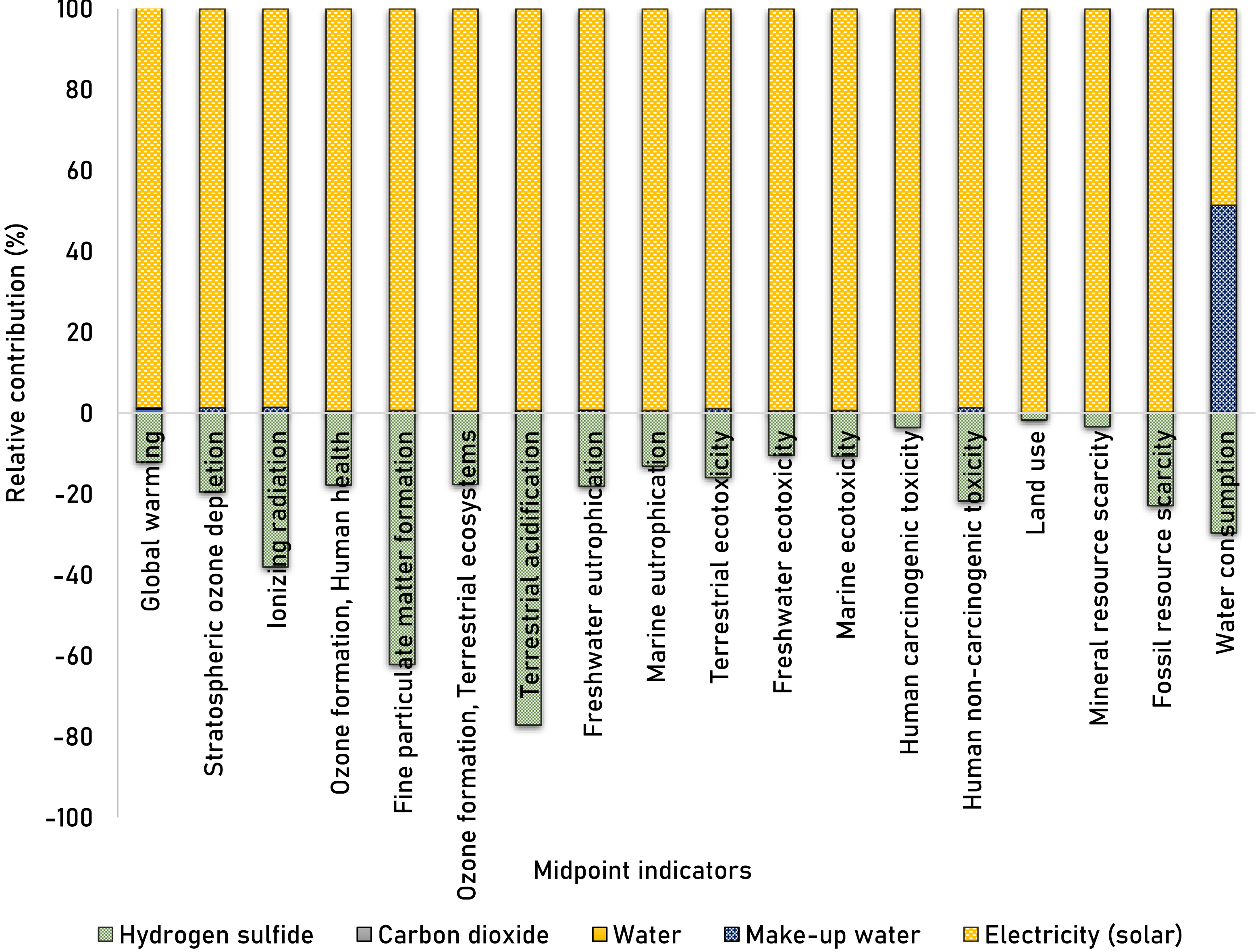


LCA of Pilot-Scale Two-Step Thermochemical H_2S Splitting Powered by Solar Energy

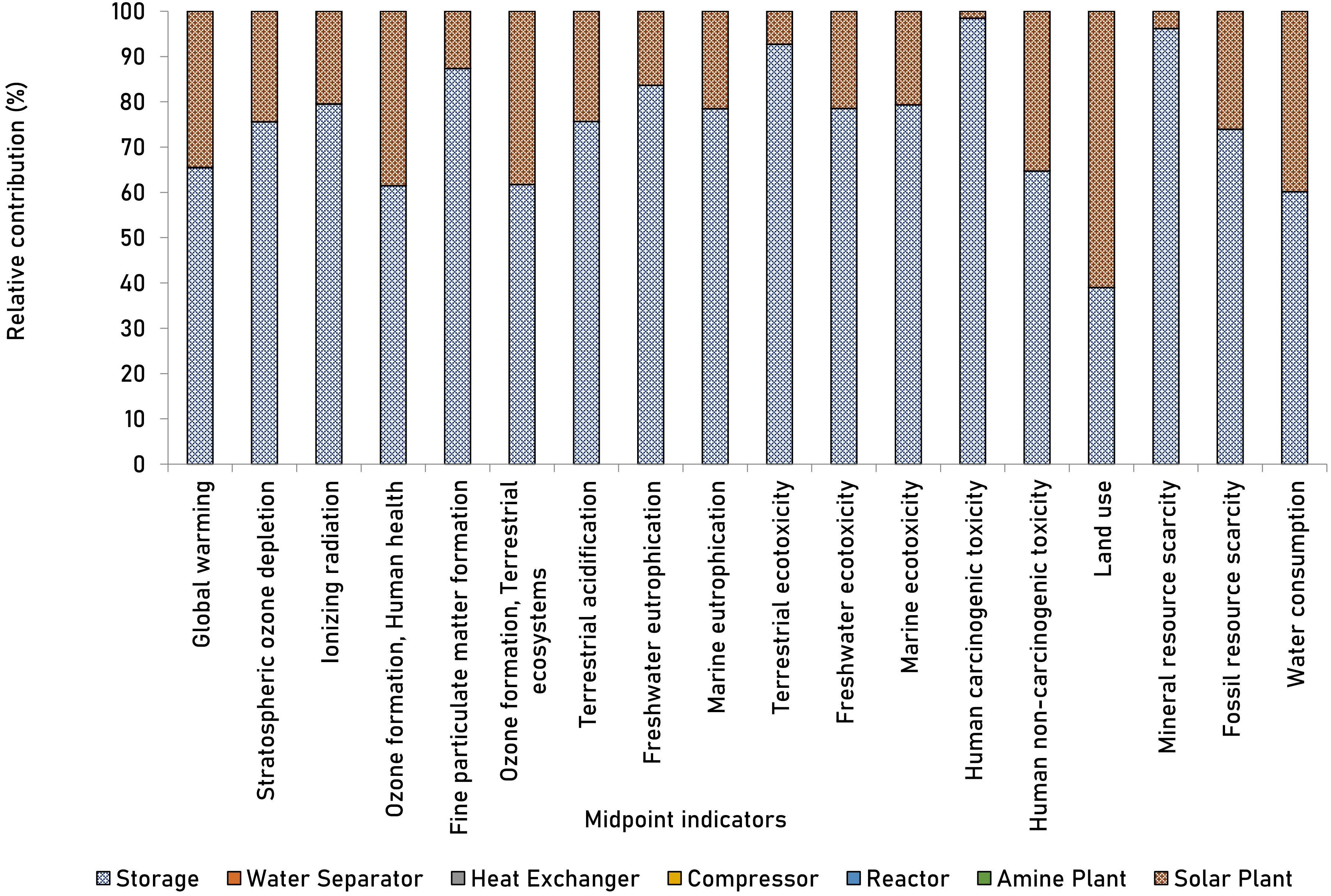


System Boundary to produce 1kg of Hydrogen

Environmental Performance of H_2S Splitting Plant



Midpoint level impact assessment for the operational phase of the H_2S splitting process model to produce 1 kg of H_2



Midpoint level impact assessment for the constructional phase of 1 unit of H_2S splitting plant

Significant Findings

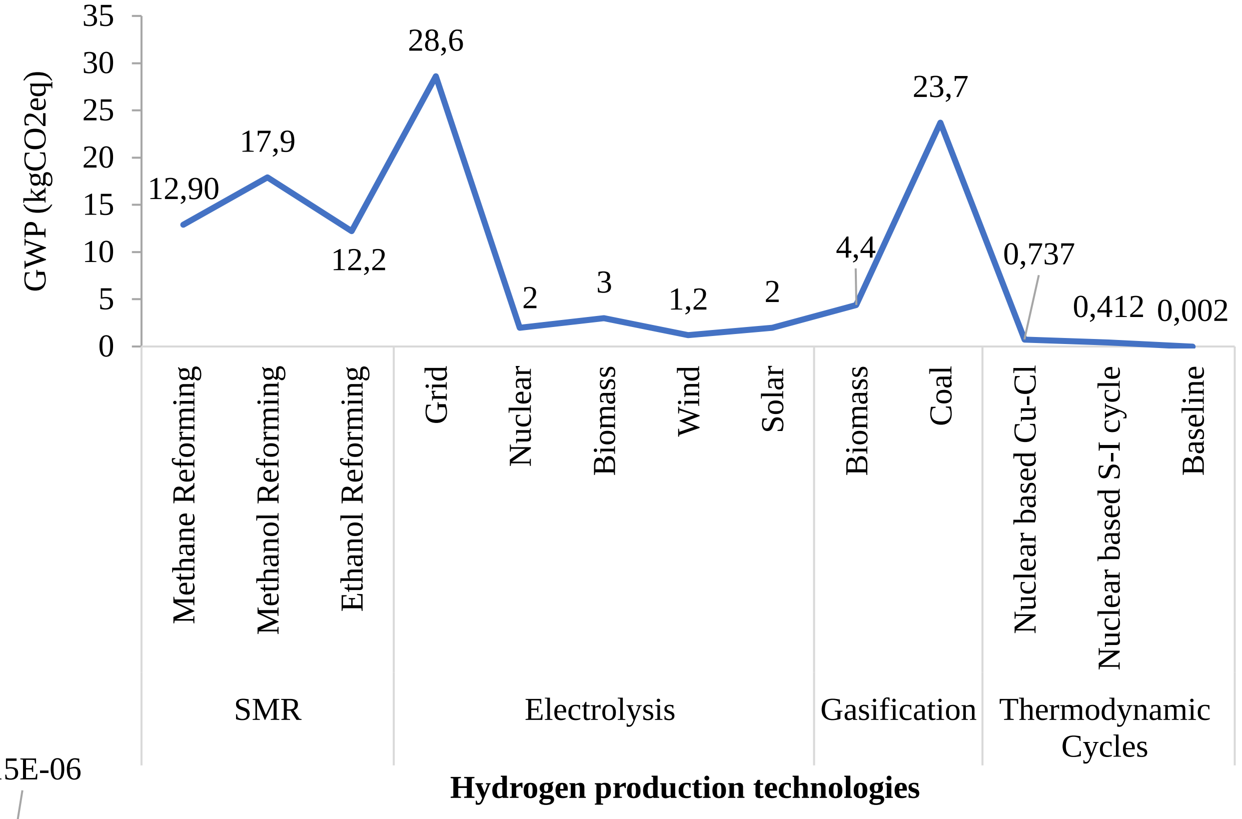
Table: Endpoint level impact assessment for the operational phase of the H_2S simulation plant to produce 1 kg of H_2

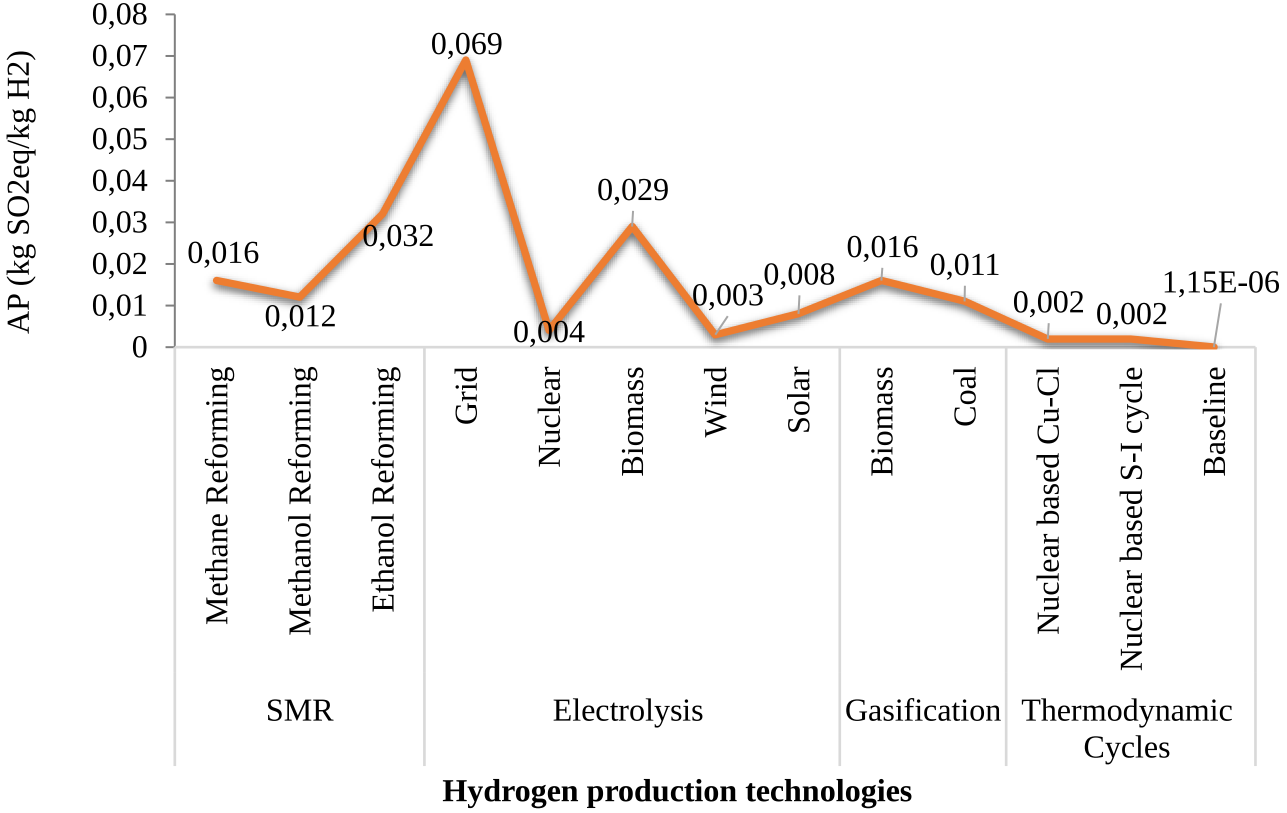
Damage category	Human health (DALY)	Ecosystems (species.yr)	Resources (USD2013)
Hydrogen sulfide	-1.10×10^{-9}	-1.67×10^{-12}	-4.41×10^{-5}
Water	9.93×10^{-14}	5.35×10^{-16}	2.68×10^{-10}
Make-up water	4.52×10^{-11}	1.86×10^{-13}	3.68×10^{-7}
Electricity (solar)	4.42×10^{-9}	9.30×10^{-12}	1.92×10^{-4}
Total	3.36×10^{-9}	7.81×10^{-12}	1.48×10^{-4}

Table: Endpoint level impact assessment for constructing 1 unit of H_2S splitting simulation plant

Damage category	Human health (DALY)	Ecosystems (species.yr)	Resources (USD2013)
Storage	4.37×10^{5}	2.43×10^{2}	3.39×10^{9}
Water Separator	4.62×10^{-2}	2.57×10^{-5}	3.59×10^{2}
Heat Exchanger	1.51	8.42×10^{-4}	1.17×10^{4}
Compressor	3.78×10^{-1}	2.10×10^{-4}	2.93×10^{3}
Reactor	7.43	4.95×10^{-3}	7.66×10^{4}
Amine Plant	1.50×10^{1}	8.10×10^{-3}	1.40×10^{5}
Solar Plant	5.21×10^{4}	1.19×10^{2}	1.28×10^{9}
Total	4.89×10^{5}	3.62×10^{2}	4.67×10^{9}

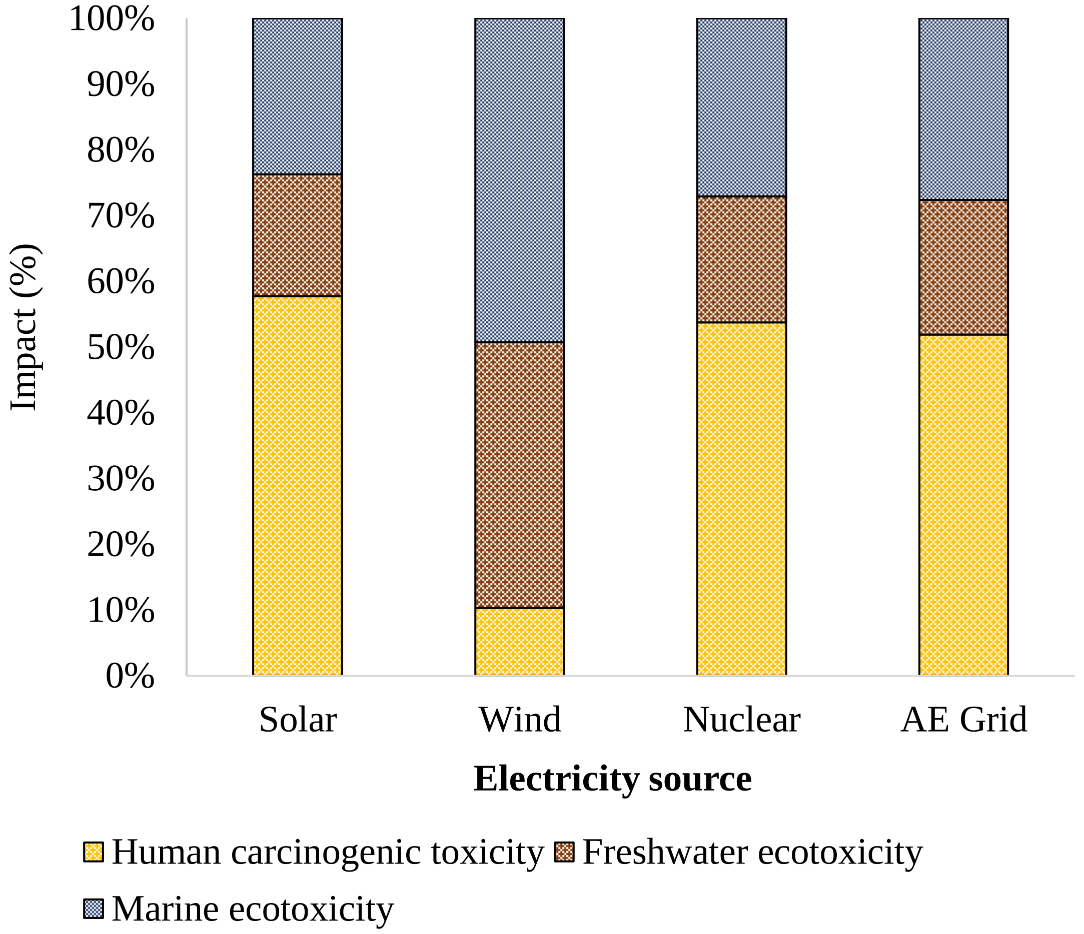
Comparison of the Environmental Performance of Producing Hydrogen via H_2S Splitting and Various Other Technologies





Sensitivity Analysis

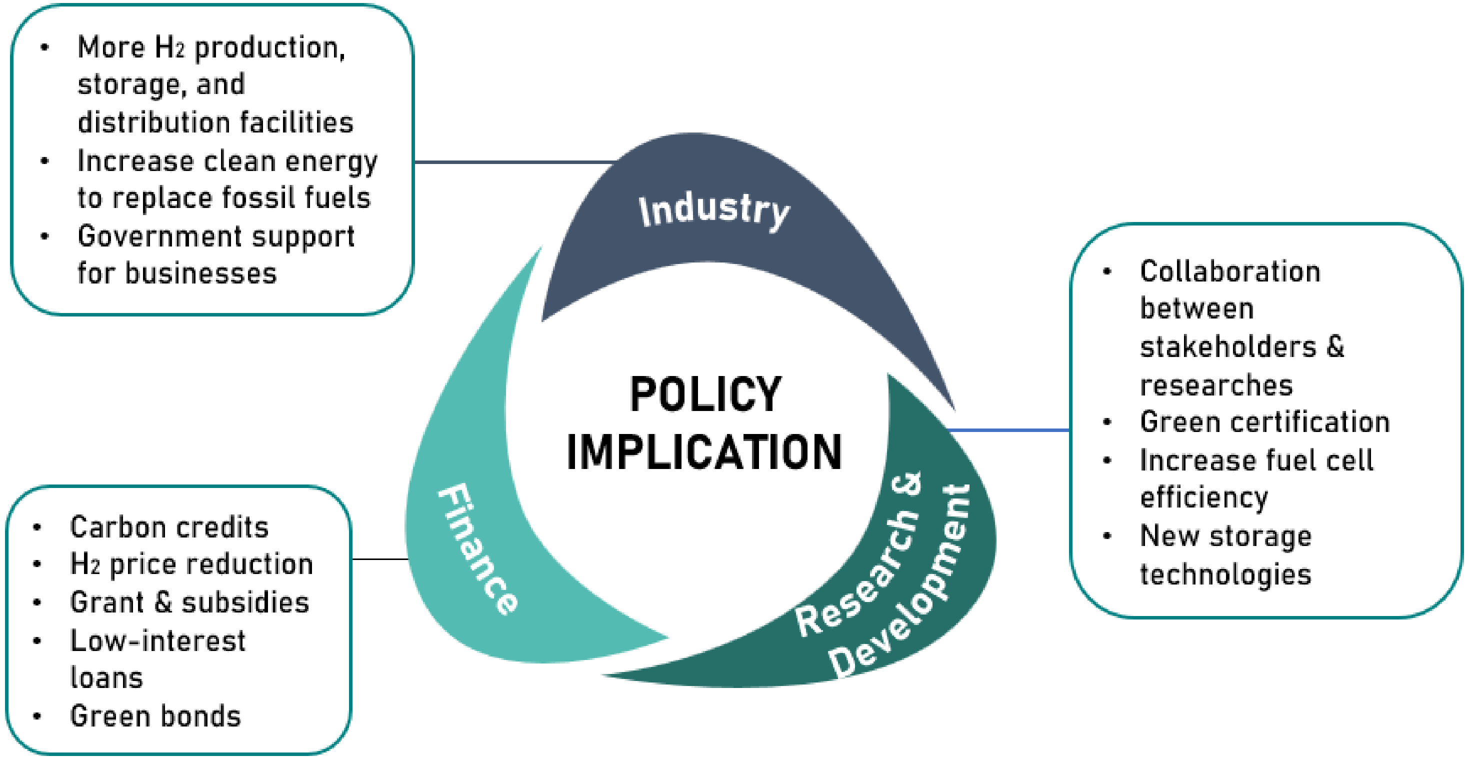
Scenario	Source of Electricity	Description
Baseline	Solar	Generation of electricity with a 20MW solar tower.
Scenario 1	Wind	Production of high voltage electricity at grid-connected wind power plants with a capacity of more than 3MW
Scenario 2	Nuclear	Production of high voltage electricity at a grid-connected nuclear pressure water reactor (PWR)
Scenario 3	UAE grid	Electricity available on the high voltage level in United Arab Emirates



Midpoint level impact assessment of producing 1 kg of H_2 using different sources of electricity

CONCLUSION & POLICY IMPLICATION

- This manufacturing phase of this technology has the highest impact towards human health because of the raw material consumption that mainly consists of steel.
- Treating H_2S instead of directly releasing it to the atmosphere has significantly improved the environmental performance of this process.
- Storage has the highest contribution, followed by the solar plant in impacting all 18 midpoint categories.
- H2S splitting technology has the least impact towards both midpoint categories when compared with other hydrogen production methods followed by electrolysis powered by renewable resources.
- Electricity powered by renewable sources needs to reduce adverse effects towards human health to be more feasible.



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