Life Cycle Greenhouse Gas Emissions and Water Consumption From Existing and Emerging Hydrogen Pathways

Solutions for Today | Options for Tomorrow

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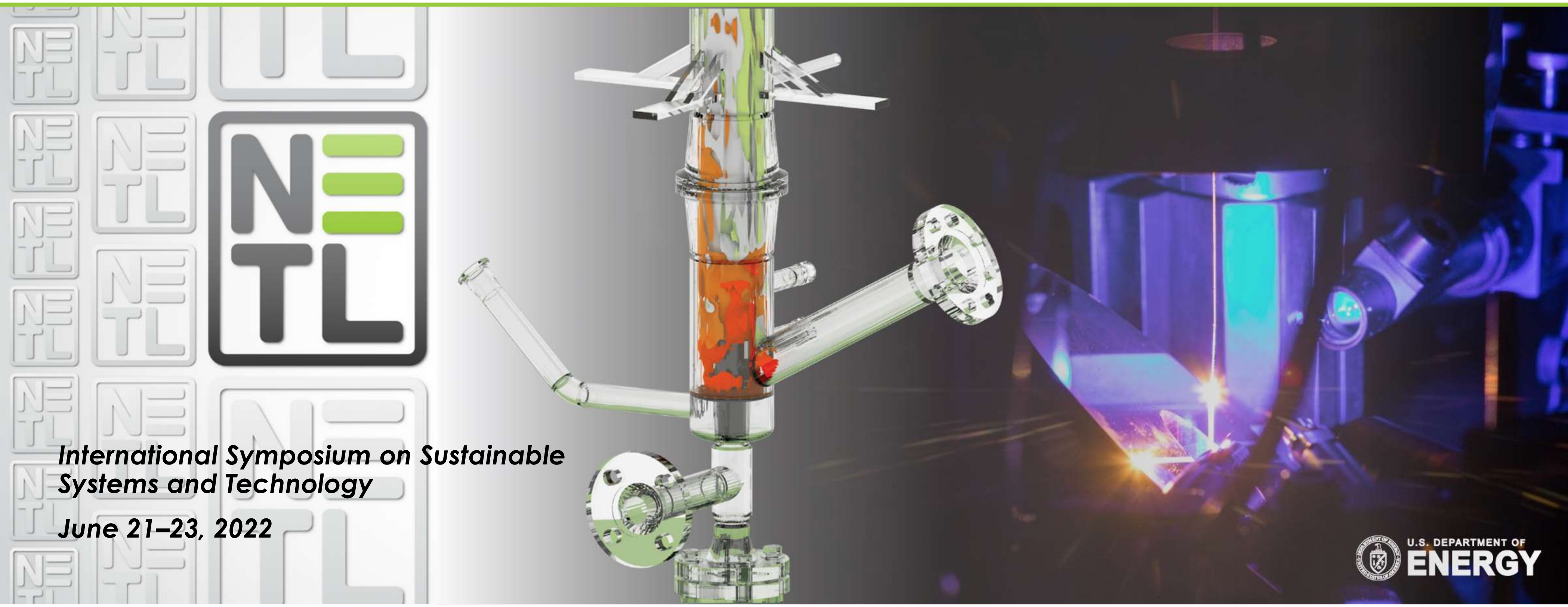

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Project Overview

- Prospective analysis in support of the hydrogen (H_2) economy with a special emphasis on water-related effects.
- Consideration of 11 H_2 pathways with existing and advanced technologies.
- Consideration of water quality and quantity impacts from H_2 production.
- Full life cycle inventories performed (only GHG and water results shown).

Overview of H_2 Production Technologies

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Descriptions of 11 Pathways Considered

Baseline

- Steam Methane Reforming
- Steam Methane Reforming w/ CCS*
- Autothermal Reforming w/ CCS
- Coal Gasification
- Coal Gasification w/ CCS
- Coal + Biomass Gasification w/ CCS

Advanced

- Biomass Gasification
- Biomass Gasification w/ CCS
- Methane Pyrolysis
- Proton Exchange Membrane
- Solid Oxide Electrolysis

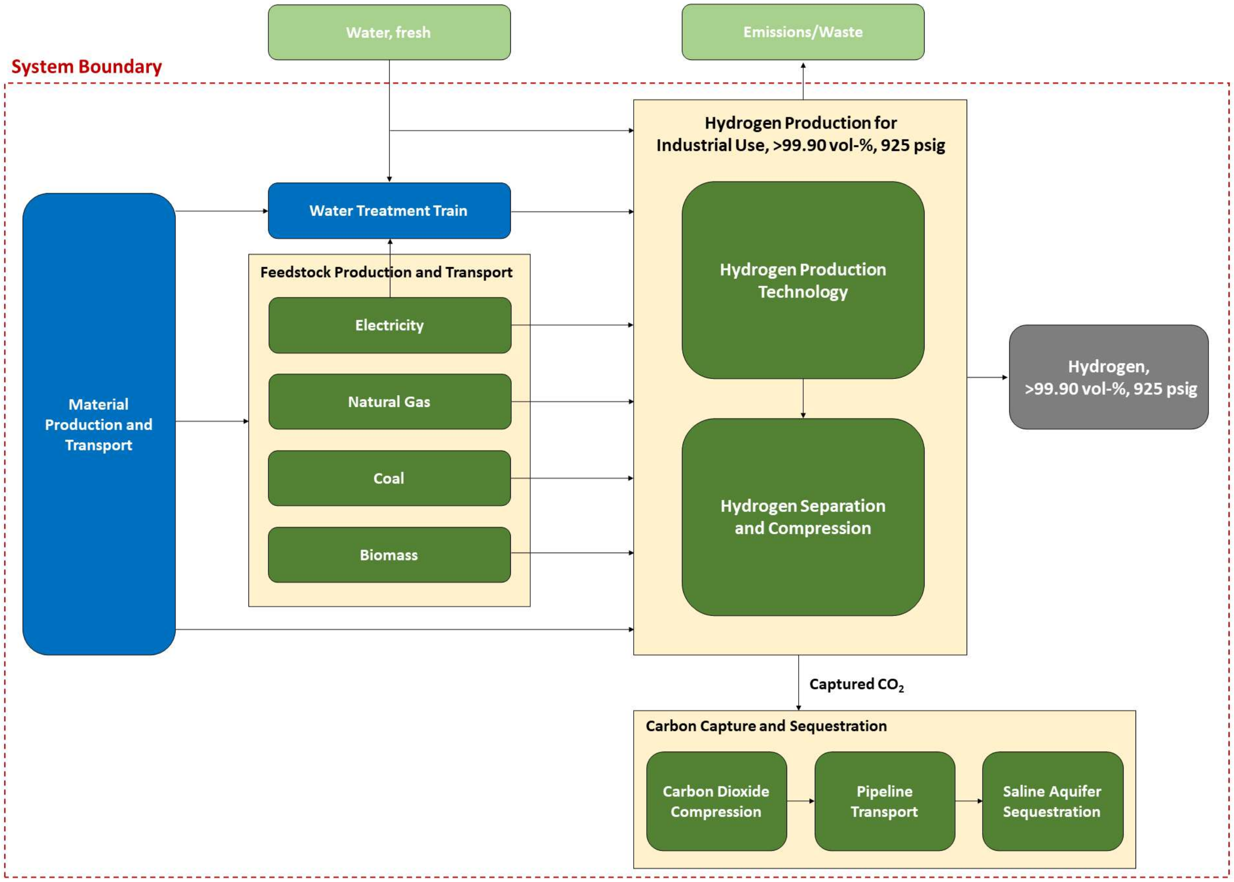
*CCS – Carbon Capture and Storage

Study Design and Methodology

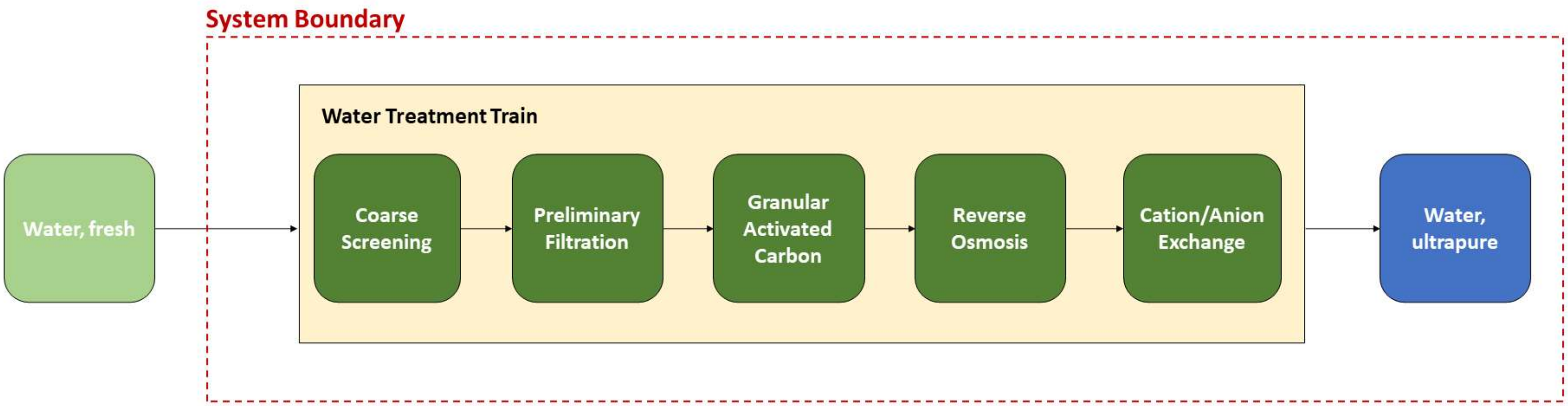
- Functional unit: 1 kg of hydrogen, >99.90 vol. %.
- System boundary is cradle-to-gate.
  - Includes upstream feedstocks, materials.
  - Excludes facility construction.
- Primary data source: NETL LCA data.

Impact Assessment

- Global warming potential (GWP) is assessed using the Intergovernmental Panel on Climate Change AR5, 100-yr time horizon, with climate carbon feedback.
- Water consumption is calculated as water withdrawn minus water discharged.
- Only blue water (from ground or surface) was considered.



A Focus on Water Treatment



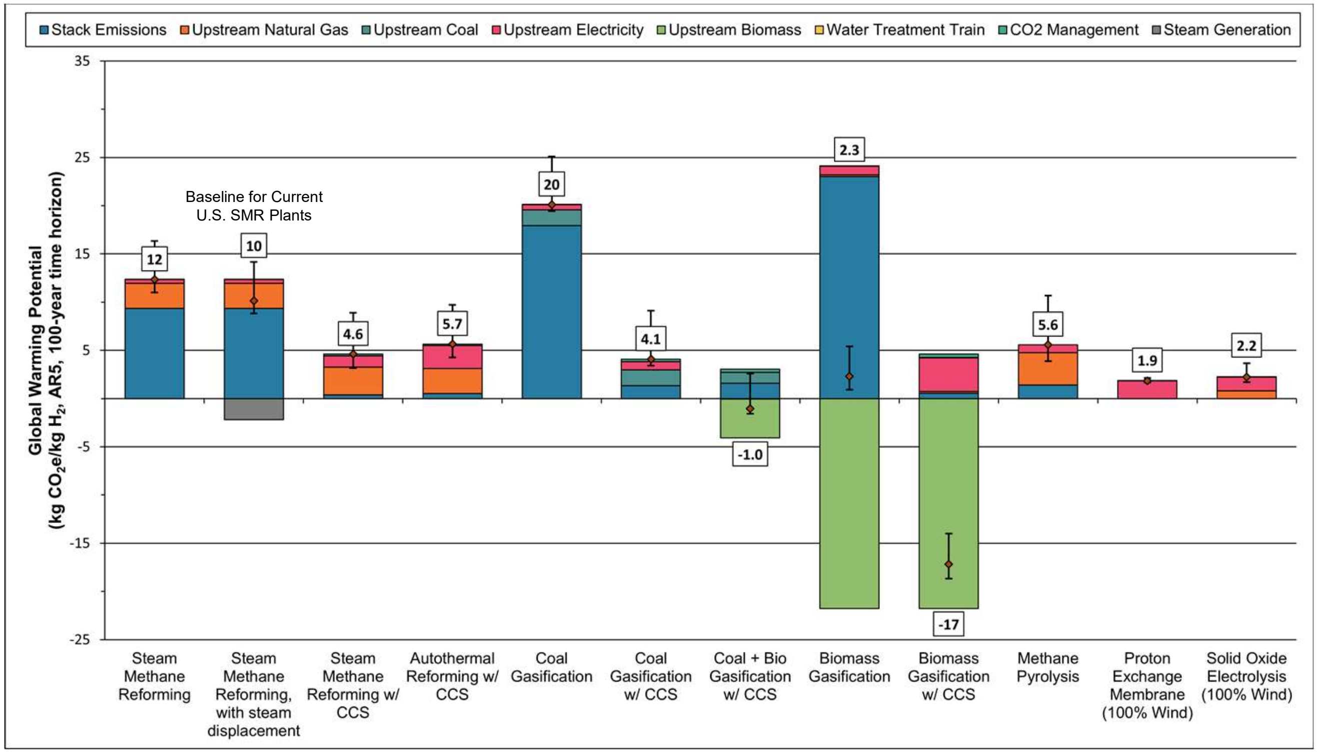
- Most hydrogen production technologies require ultrapure and deionized water as a process input.
- A water treatment train was modeled for purification of fresh water to an ASTM Type II quality standard[1] (TOC* ≤ 50 μg/L, chloride ≤ 5 μg/L).
- Unit process data were sourced from EPA technology models[2].
- Although purification requirements differ by technology, water was treated to the same standard for all processes as the impact on results was deemed negligible.

*TOC – Total Organic Carbon

[1] ASTM D1193-06 | Standard Specification for Reagent Water

[2] Drinking Water Treatment Technology Unit Cost Models | US EPA

Life Cycle GWP Results for H_2 Production



Technology results largely depend on feedstock.

- For fossil-based technologies, GWP ranges from 4 to 20 kg CO_2e/kg H_2.
- For biomass-based technologies, GWP ranges from -17 to 1.4 kg CO_2e/kg H_2.
- For electrolysis technologies, GWP ranges from 1.9 to 2.2 kg CO_2e/kg H_2 when using 100% renewable electricity from wind.

Contribution from water treatment train is negligible for GWP results.

Life Cycle GWP Results for H_2 Production

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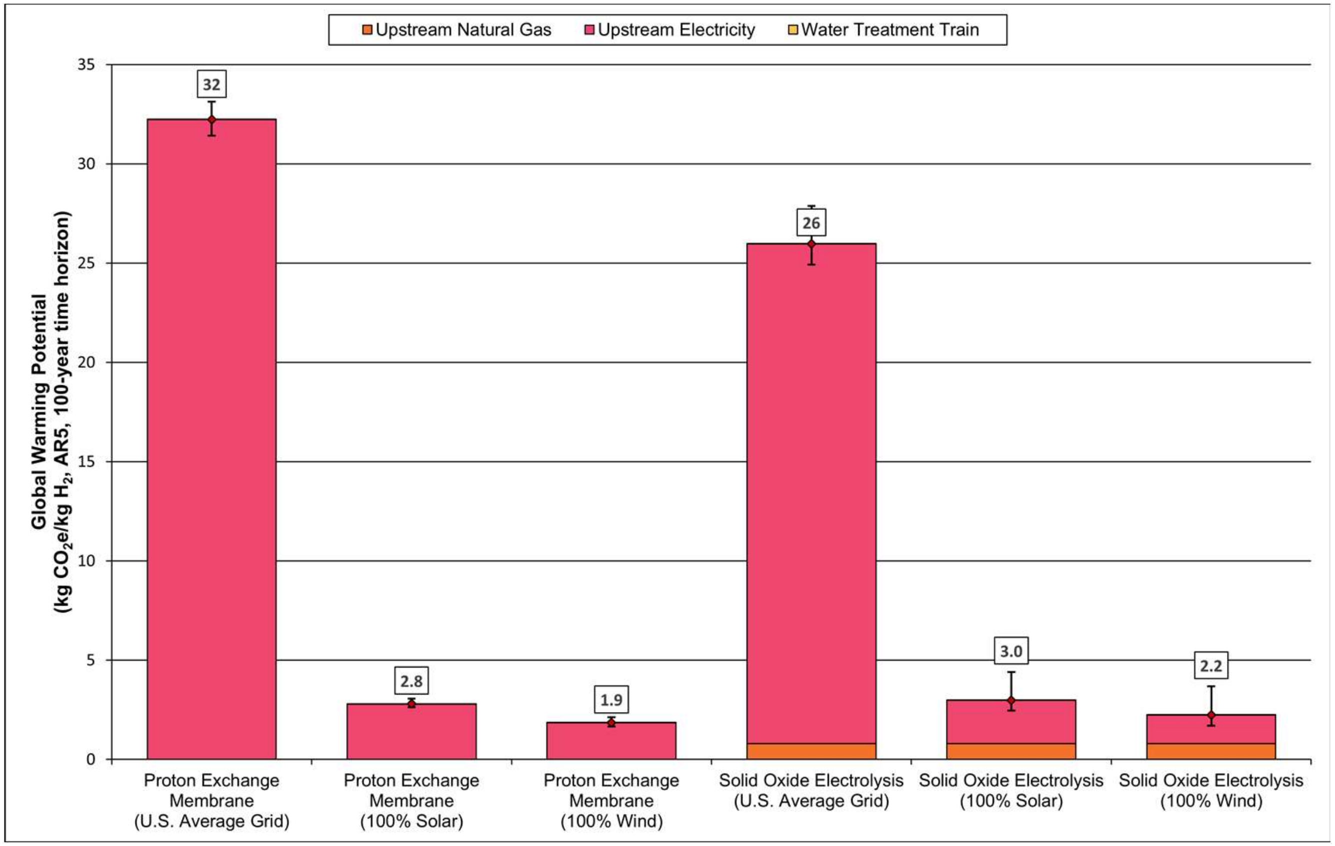
Electrolysis Technologies With Renewable Cases

GWP results for PEM* and SOEC primarily rely on upstream electricity source.**

- Wind electricity slightly outperforms solar electricity.
- GWP results using U.S. average grid electricity are an order of magnitude higher than 100% renewable cases.

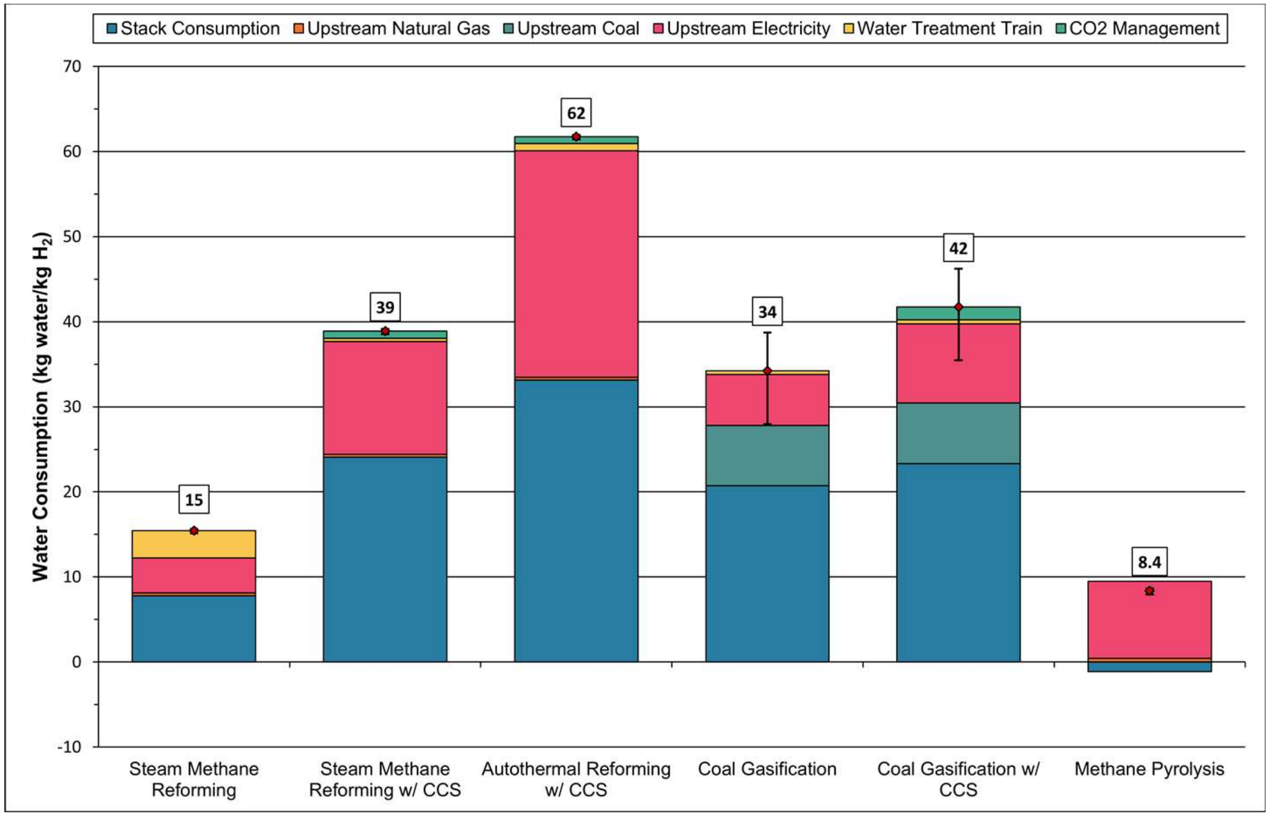


*PEM – Proton Exchange Membrane

**SOEC – Solid Oxide Electrolysis Cell

Life Cycle Water Consumption Results for H_2 Production

Non-Biomass Technologies



For fossil-based technologies, the use of CCS results in higher water consumption.

- Includes slightly higher stack consumption due to MDEA scrubber.
- Greater electricity requirement indirectly increases water consumption, as well.

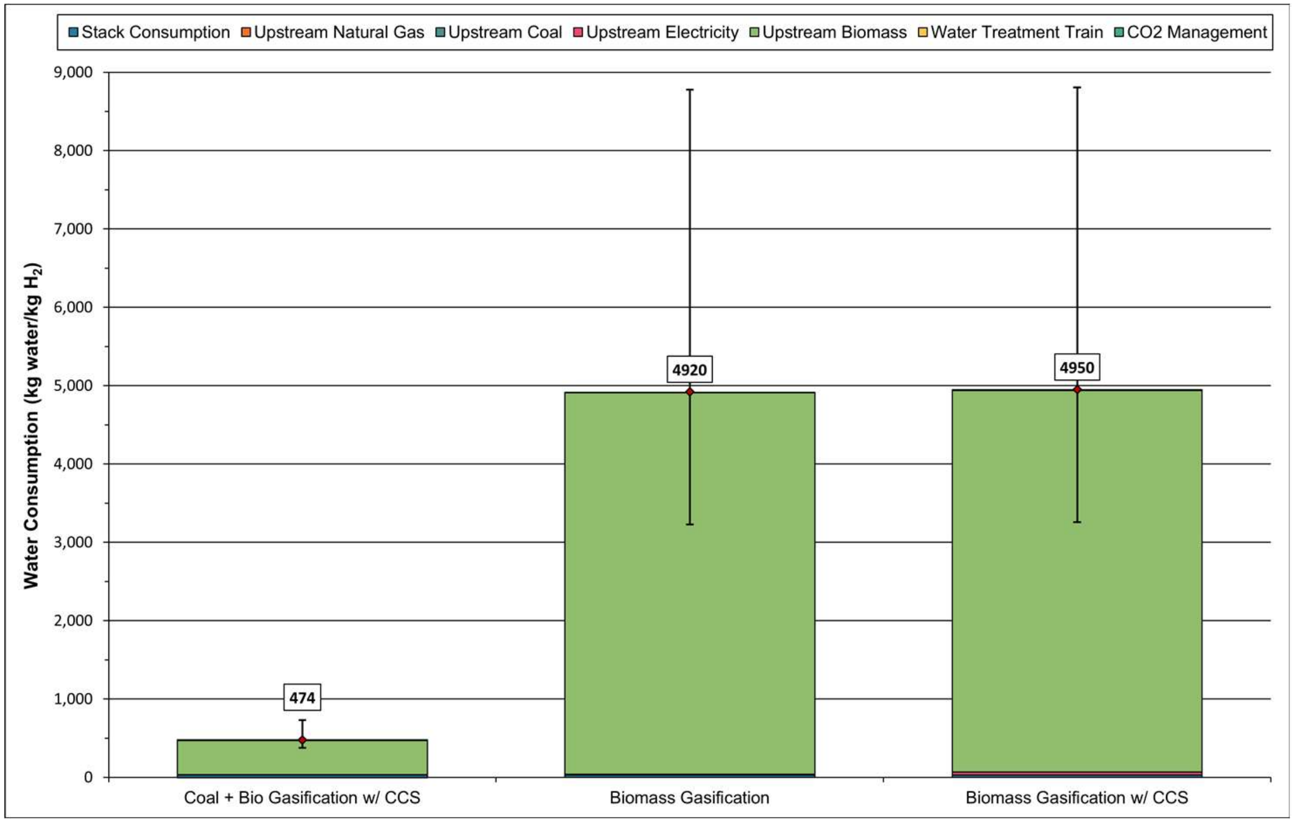
Life Cycle Water Consumption Results for H_2 Production

Biomass Technologies

Water consumption results are 100–1,000 times higher than fossil-based pathways and 10–100 times higher than electrolysis pathways.

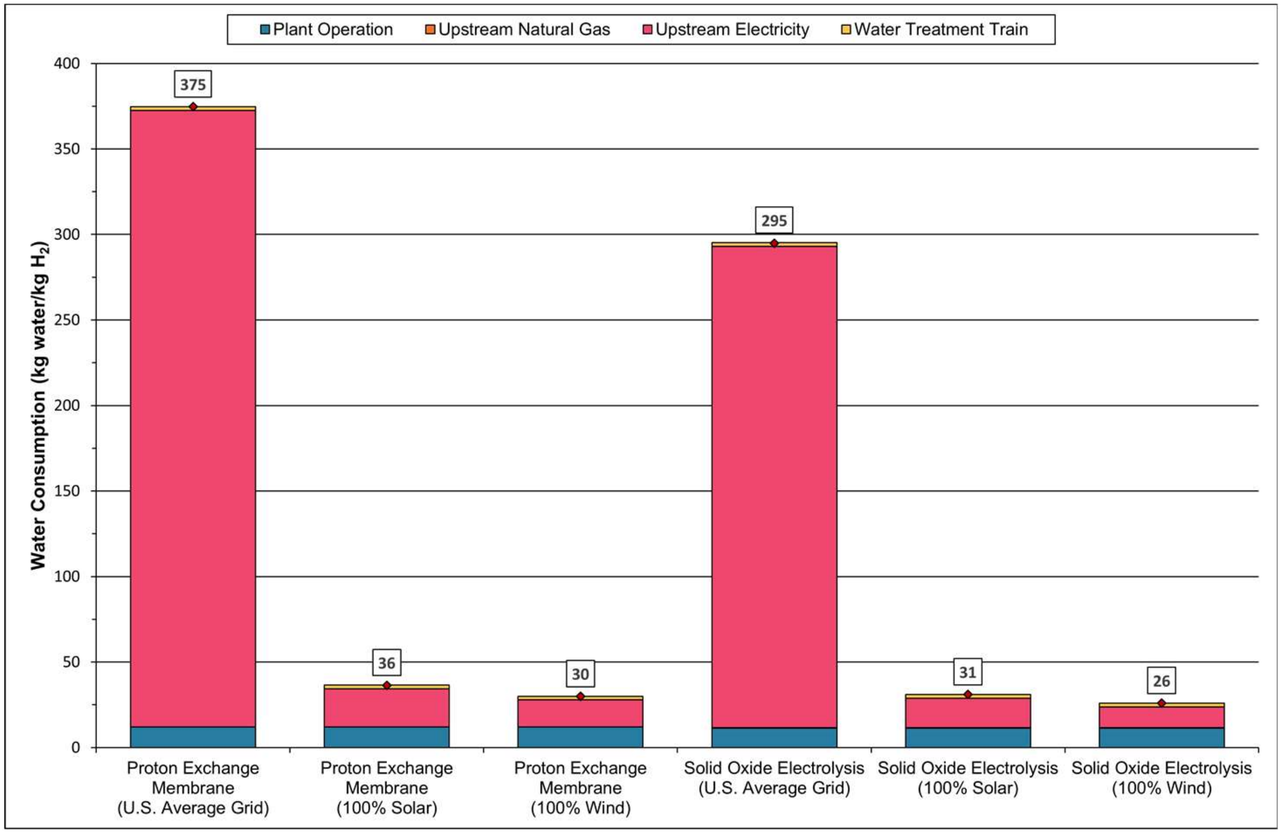
- Results are an order of magnitude higher for biomass-only cases due to greater biomass input.
- If rainwater is added to an impact assessment, total water consumption results would be nearly five times higher.

Water consumption varies widely by agricultural region.



Life Cycle Water Consumption Results for H_2 Production

Electrolysis Technologies With Renewable Cases



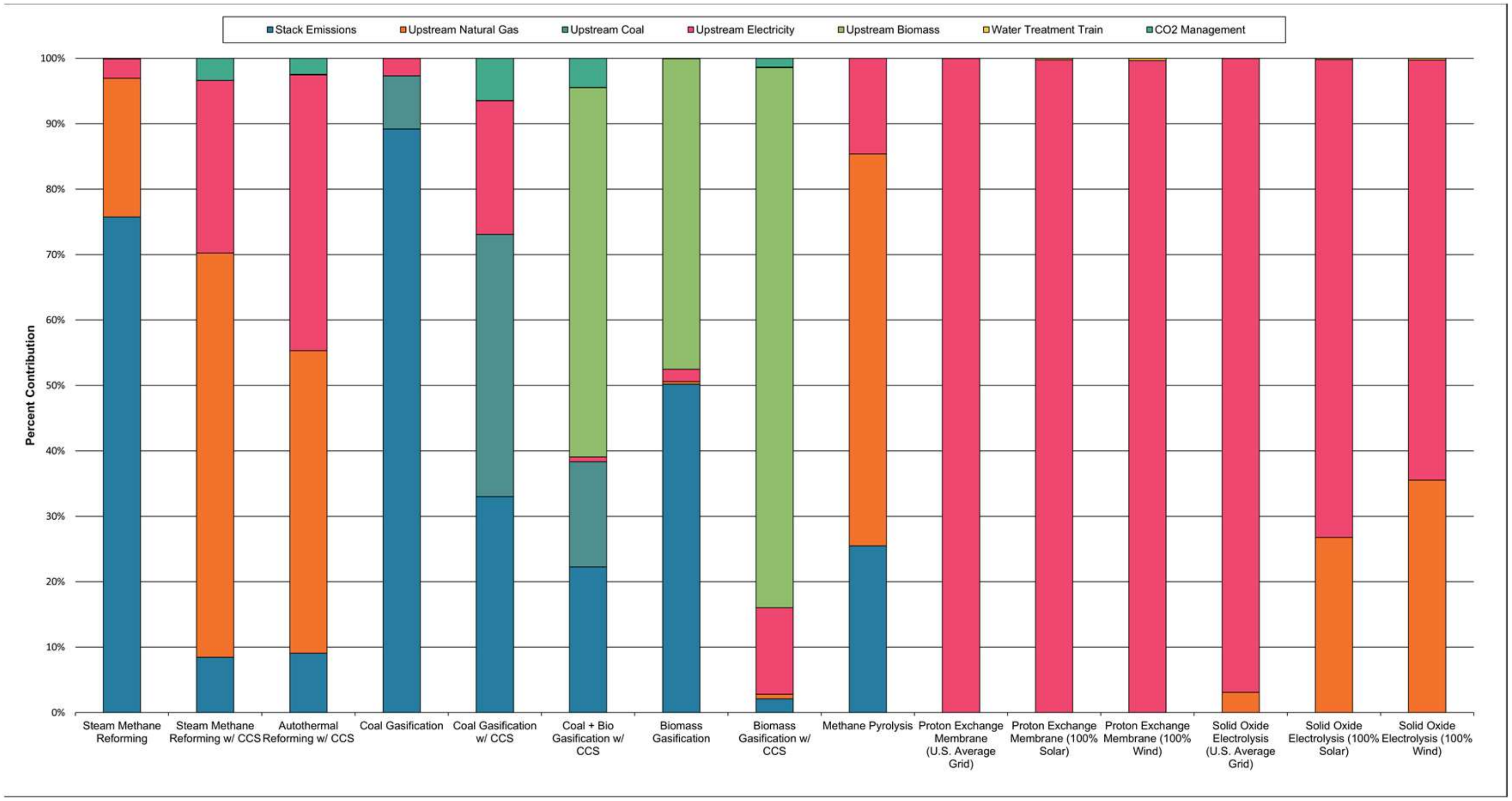
Water consumption is an order of magnitude lower for 100% renewable cases.

- Variability data are not available for renewable electricity cases.

Like GWP results, wind electricity slightly outperforms solar electricity for both electrolysis technologies.

Assessing Contribution Results

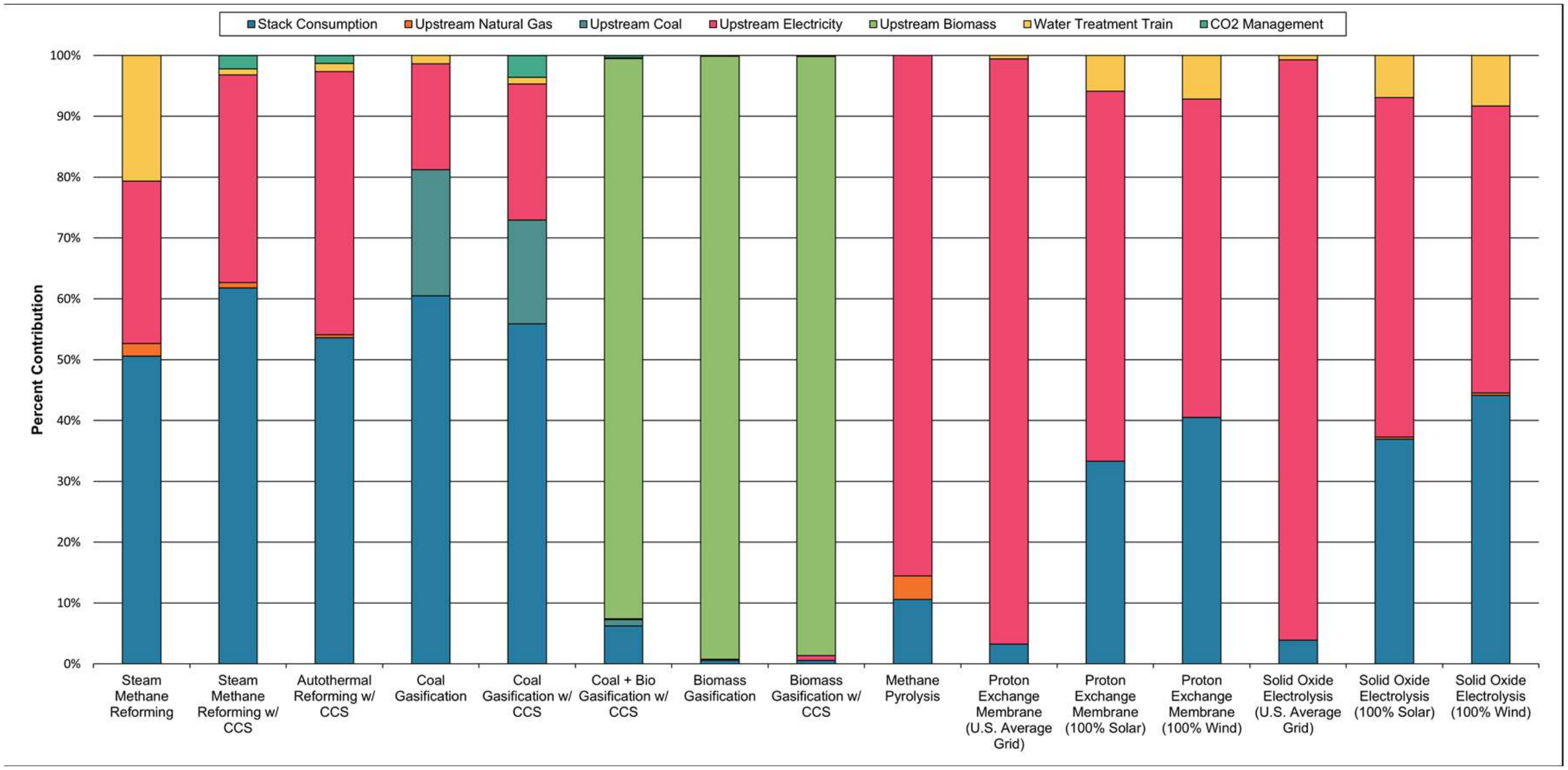
Global Warming Potential



A technology's feedstock and stack emissions are the primary contributors to total GWP.

Assessing Contribution Results

Water Consumption



Contributions are still dominated by the primary feedstock and process consumption, but the water treatment train contributes meaningfully (up to 20%) for some technologies.

Conclusions and Future Work

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Key Takeaways

- CCS can significantly reduce GWP for fossil-based technologies, but it comes at a higher water consumption cost.
- Biomass-based technologies see the lowest GWP results, but they require significantly more water than other technologies.
- Low GWP for PEM and SOEC can only be achieved when using low-carbon electricity.
- Water purification contributes little to total GWP results, but it meaningfully impacts water consumption results for some technologies.

Future Work

- Incorporate regionalization to assess water scarcity impacts.
- Add water consumption sensitivity data to upstream renewable electricity cases.

Disclaimer

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