

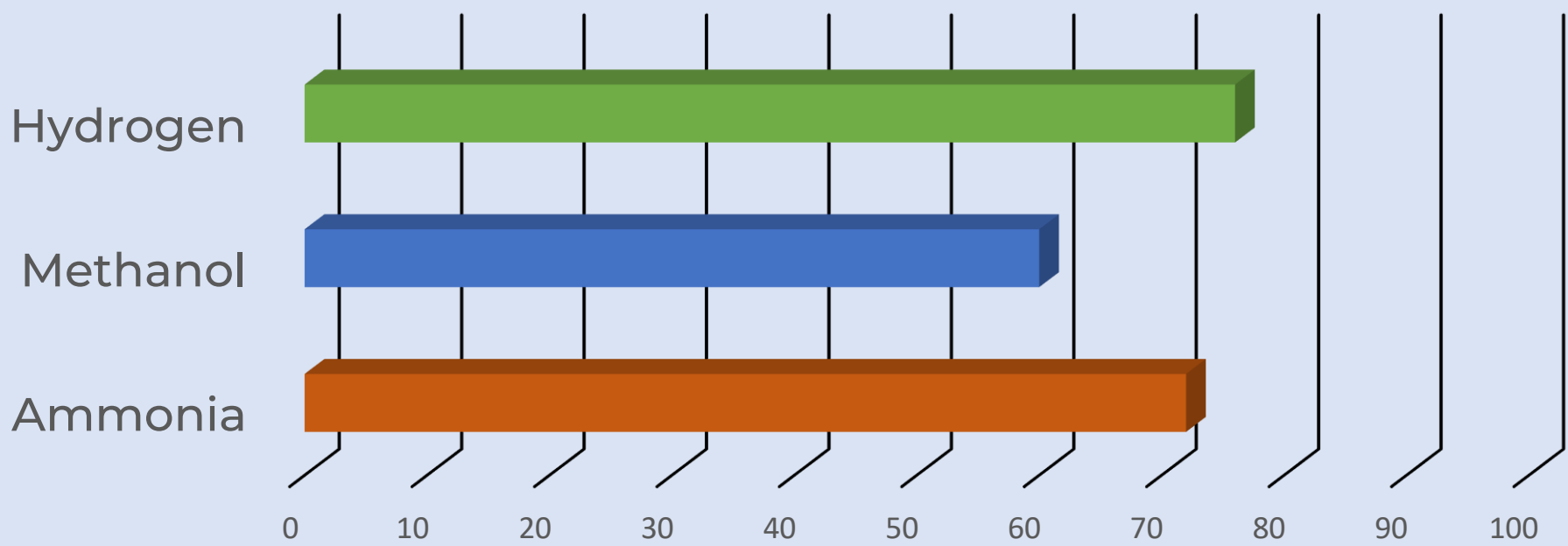
On-Site Hydrogen Generation Using Methanol and Comparison to H₂ (l) and Ammonia

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Current H₂ Generation and H₂ Carrier Production Practices

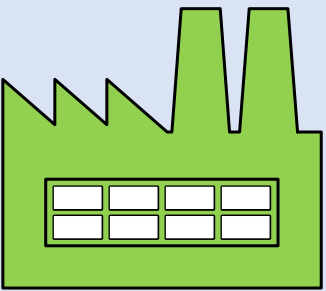
- Natural gas is currently the predominant feedstock used to meet global demand for hydrogen production and liquid hydrogen carriers.
- While trends toward renewable feedstock for hydrogen and hydrogen carriers continues, it will likely be decades until natural gas is even a minority constituent in global methanol, ammonia, or liquid hydrogen production.
- Given this current supply relationship, optimizing the efficiencies and GHG emissions in production, transportation, and consumption of these options will make the most efficient and cost-effective use of global natural gas reserves.

Percent of Global Production from Natural Gas



Levelized Cost of Manufacturing, Average Manufacturing Process Efficiency^{1,2}, and Lifecycle GHG Emissions^{3,4}

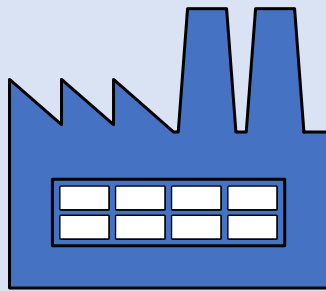
SMR, PSA, and
liquification:
54% Efficiency



Liquid H₂
\$0.51/MJ

Life Cycle
GHG: 16.2 kg
CO₂(eq)/kg
H₂

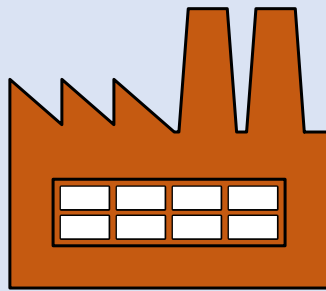
SMR and
Fischer-Tropsch:
63% Efficiency



Methanol
\$0.15/MJ

Life Cycle
GHG: 15.8 kg
CO₂(eq)/kg
H₂

SMR, ASU, and
Haber-Bosch:
58% Efficiency

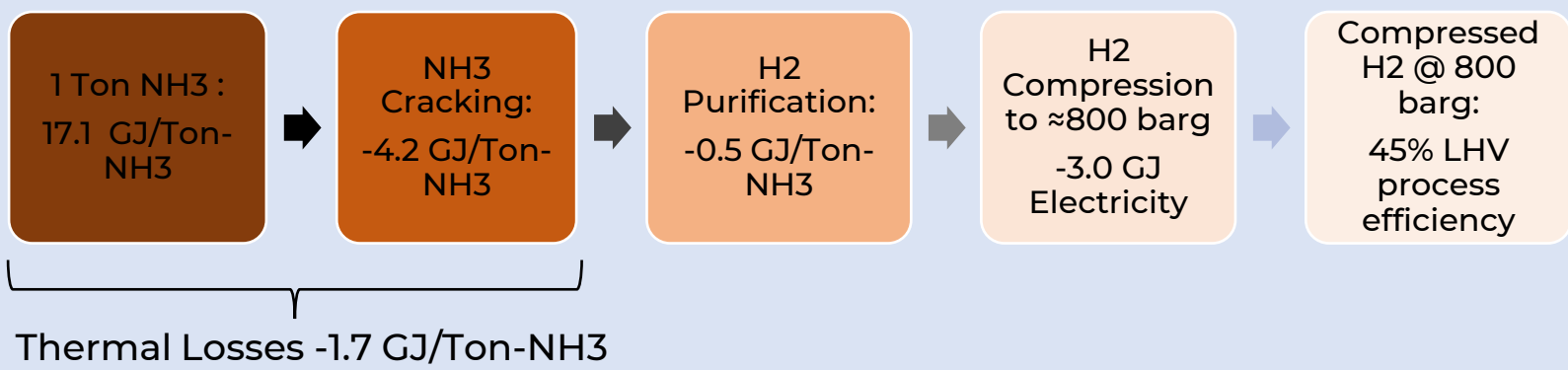


Ammonia
\$0.23/MJ

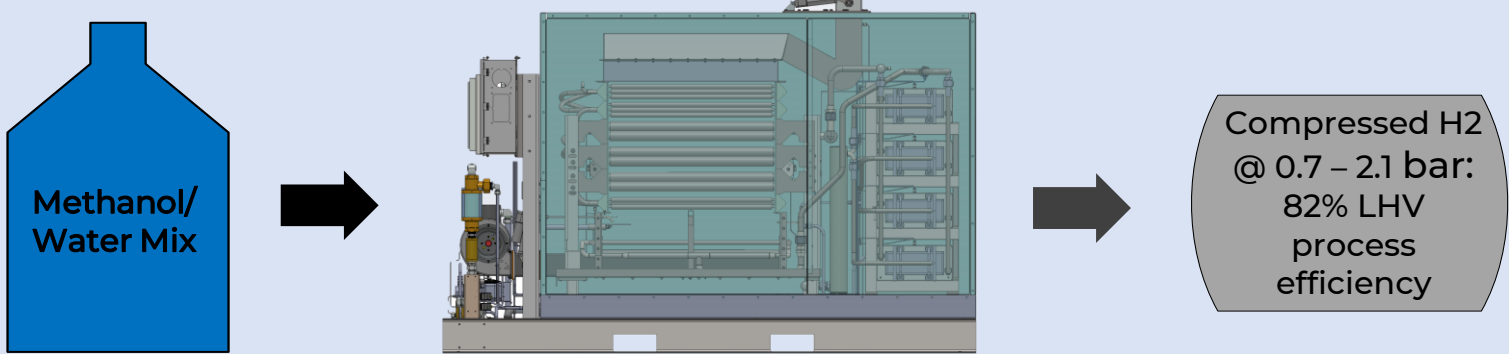
Life Cycle
GHG: 22.6 kg
CO₂(eq)/kg
H₂

Efficiency and Transportation of H₂ Carriers

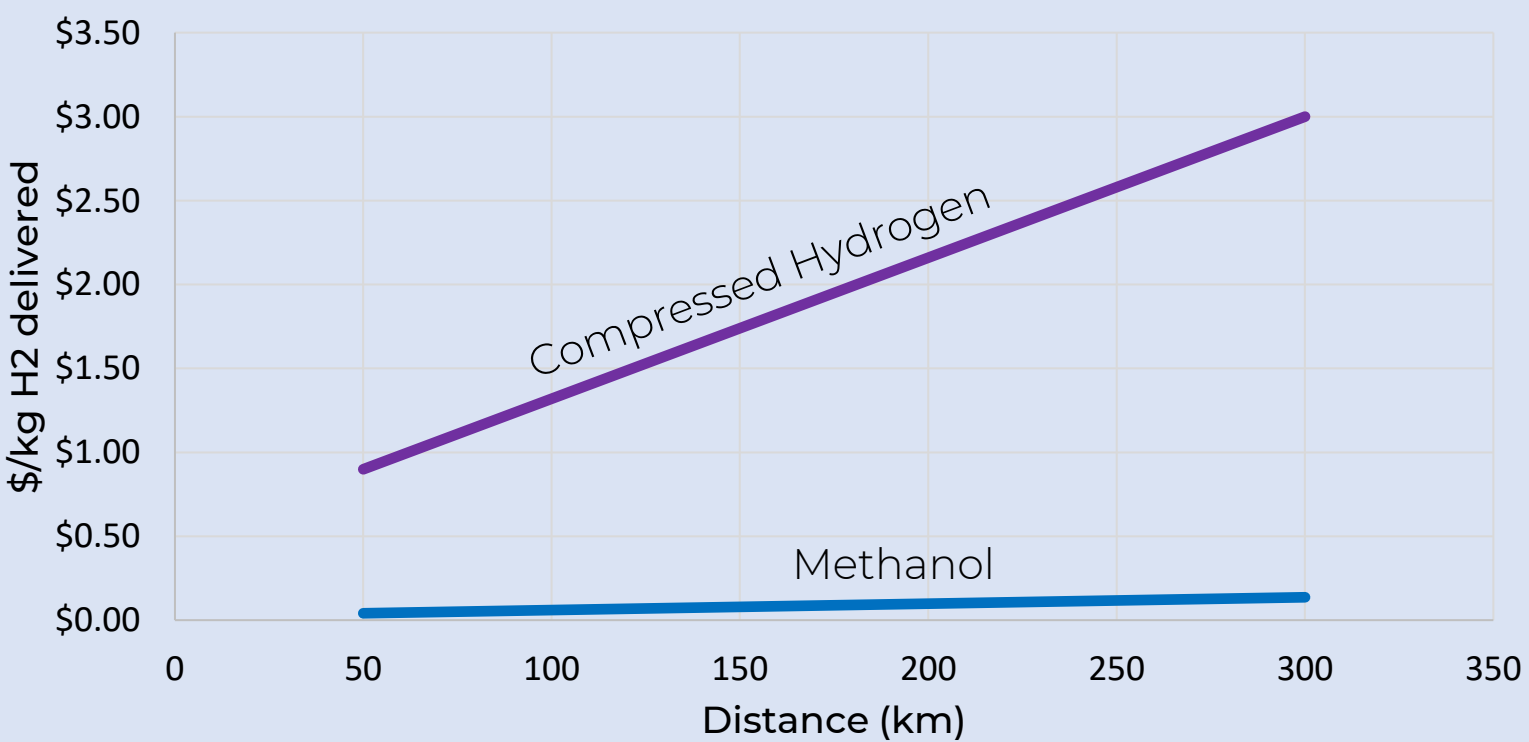
- Current technologies for hydrogen generation from ammonia require both catalysis and pressure swing adsorption (PSA) for hydrogen purification, requiring a large centralized processing plant.
- There are also significant losses in the conversion and compression stages near the point of hydrogen use that amount to over half of the embedded energy in the Ammonia feedstock⁵.



- Using methanol as a feedstock for the Element 1 hydrogen generator, all reforming and purification takes place in one unit and does not require compression since the hydrogen is made directly at the point of use and does not need to be transported



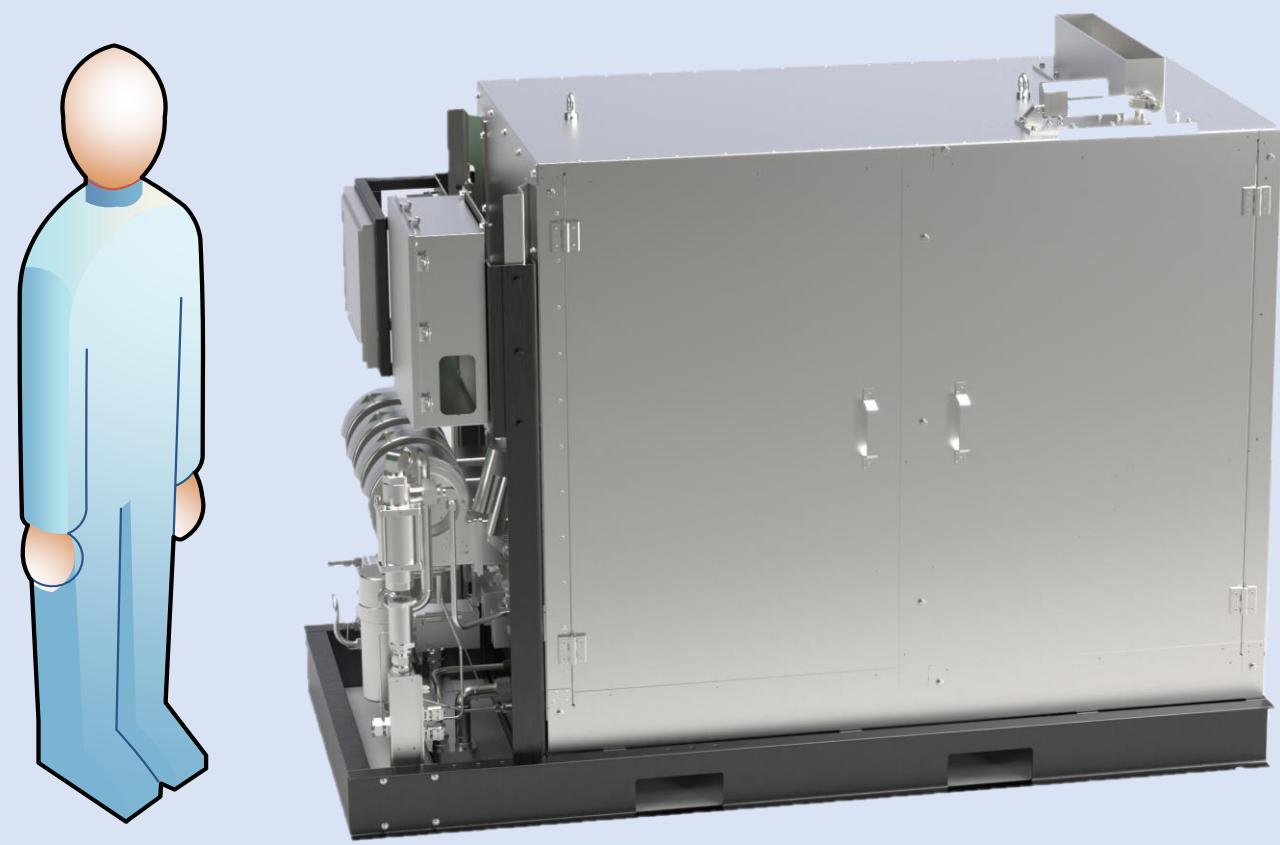
- Transportation costs for liquid hydrogen per kg, remains consistent under 300 km based upon quantities and standard volume tanker trucks. This cost is included in the levelized cost of manufacturing.
- Distant location for conversion to hydrogen requires compression and transportation of hydrogen from the site of conversion to the point of use, incurring significant cost per kg-H₂ delivered, as seen in the graph below⁶.



Simple and Robust H₂ Generation at Point of Use

Element 1 M18 hydrogen generator specifications:

- Uses a feedstock blend of 62.5% methanol by weight with balance of DI water.
- Can easily be located at point of use due to portable and modular design.
- Capable of producing 1800 sLm (235kg/day) –H₂ at 10 psig (0.7 barg) and delivery pressures up to 30 psig (2.1 barg).
- H₂ purity meets ISO 14687 standards with ≥ 99.97% (dry basis) with <0.2 ppm CO.
- Compact design of 3.15 m³.
- Consumes only 600W during rated H₂ output.



Element 1 hydrogen generation technology can be used in stationary and mobile applications:

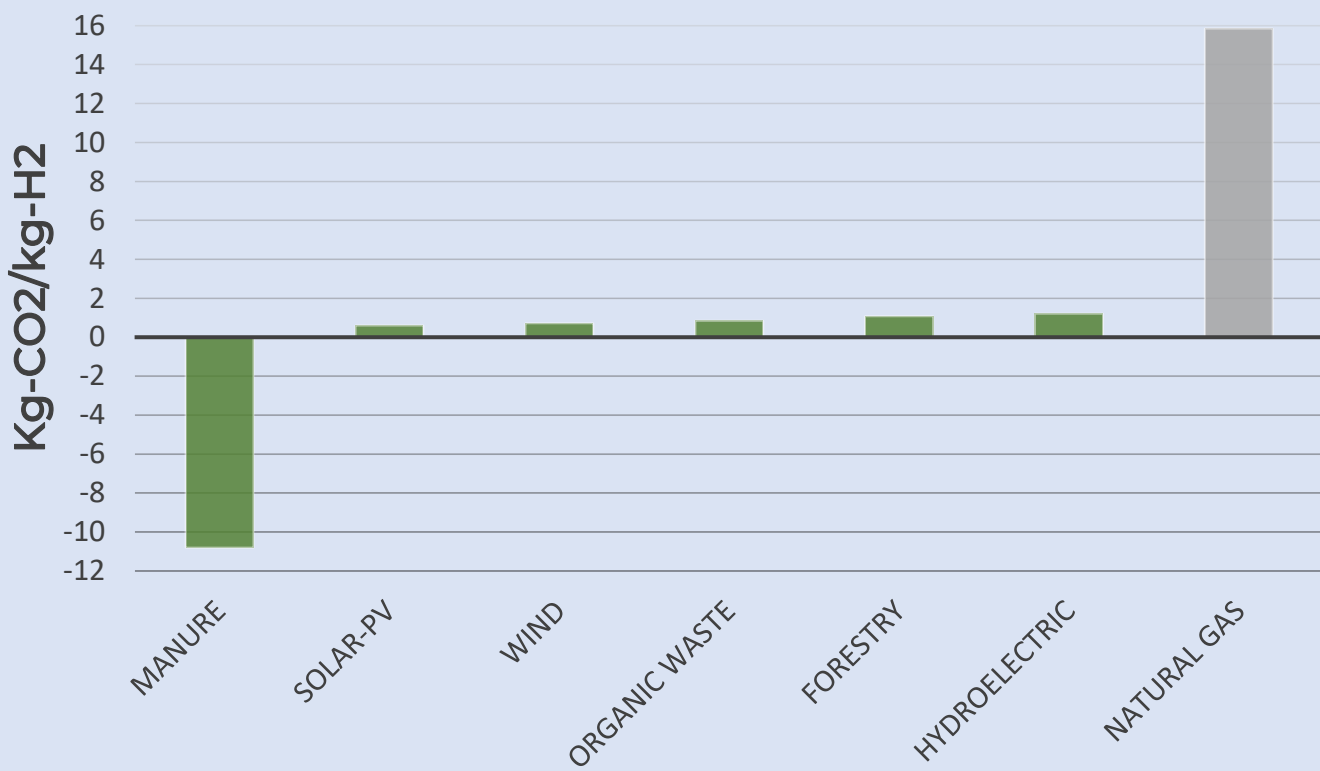
- BEV charging stations
- H₂ fueling stations
- Maritime cold ironing/reefer power
- Maritime vessels/shipping
- Long-haul trucking
- Locomotive

Distinct advantages of Element 1 hydrogen generation technology and methanol feedstock over ammonia and liquid hydrogen:

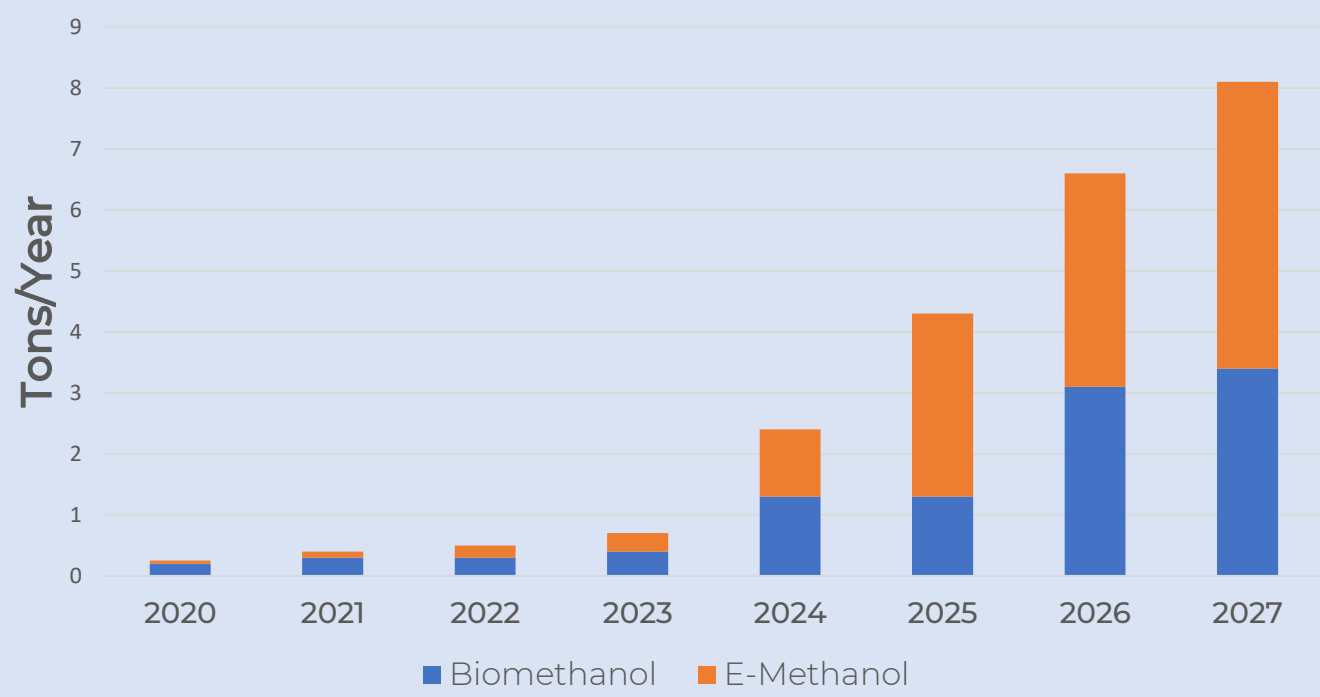
- Methanol does not need to be refrigerated or compressed for transportation or storage
- Transportation infrastructure already exists
- Risk of irreversible damage to fuel cell from trace amounts of NH₃ is eliminated
- Greatly reduced risk of impact from a spill or leak for methanol in place of ammonia

Future Developments and Opportunities

Carbon Intensity by Methanol Source⁴



Projected Renewable Methanol Production Capacity⁴



Conclusions

- While technologies for hydrogen carrier production will improve over the next several years to greater reduce cost and carbon emissions, current technologies for hydrogen producing markets across the globe require scalable, efficient, and on-site hydrogen generation.
- Use of Element 1 technology will be critical to not only bridge the gap in conversion to hydrogen technologies, but also contribute to industry efforts in making hydrogen production and hydrogen-based electric generation accessible long before infrastructure is in place for the broader adoption of high-efficiency, low-carbon technologies.
- While there is no definitive hydrogen carrier for all applications, implementing methanol along with Element 1 technology is a viable solution for increased flexibility in varying hydrogen-driven markets with different needs.