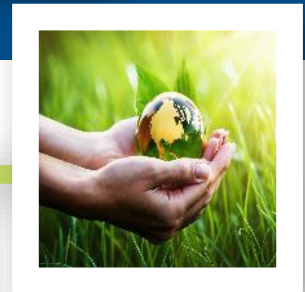


Decarbonizing Ammonia Production

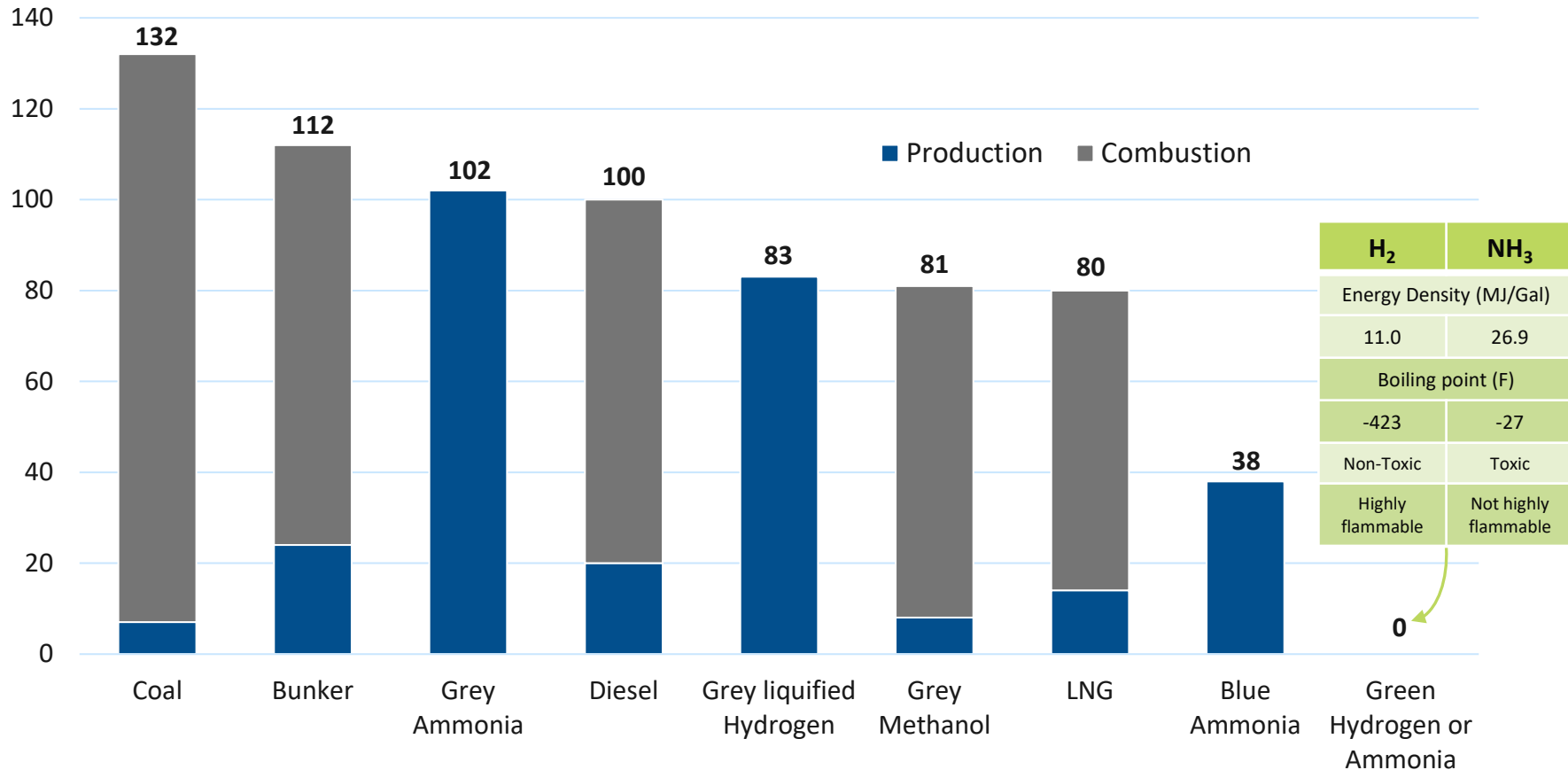
March 30, 2021



Why is low carbon ammonia an essential fuel to decarbonize societies in the future?

Levelized CO₂e Emissions from the Life Cycle of Various Fuels

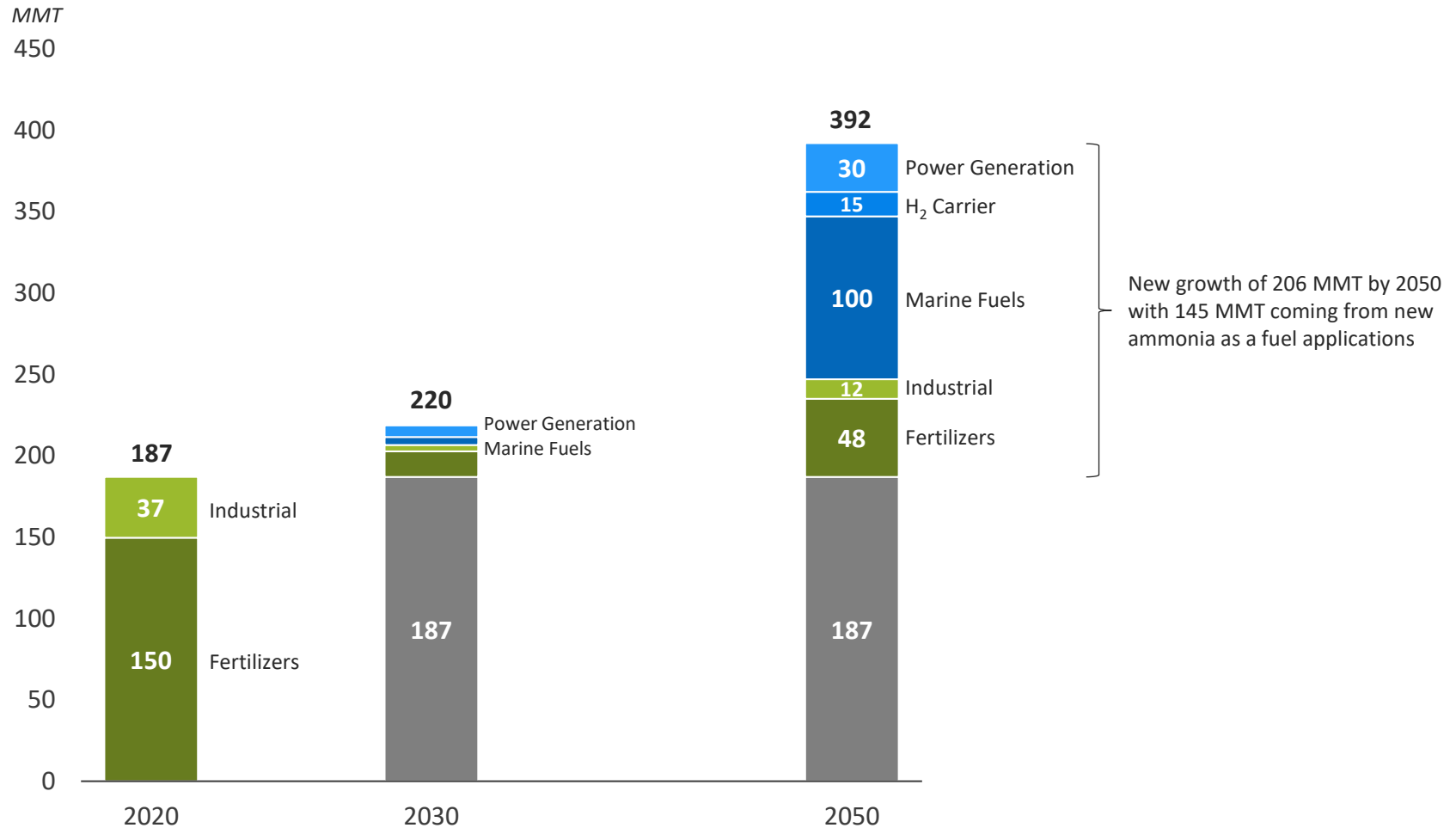
Grams of CO₂e per MJ of fuel



Source: EIA, EPA, Progress in energy and Combustion Science, Vol 69 Nov 2018

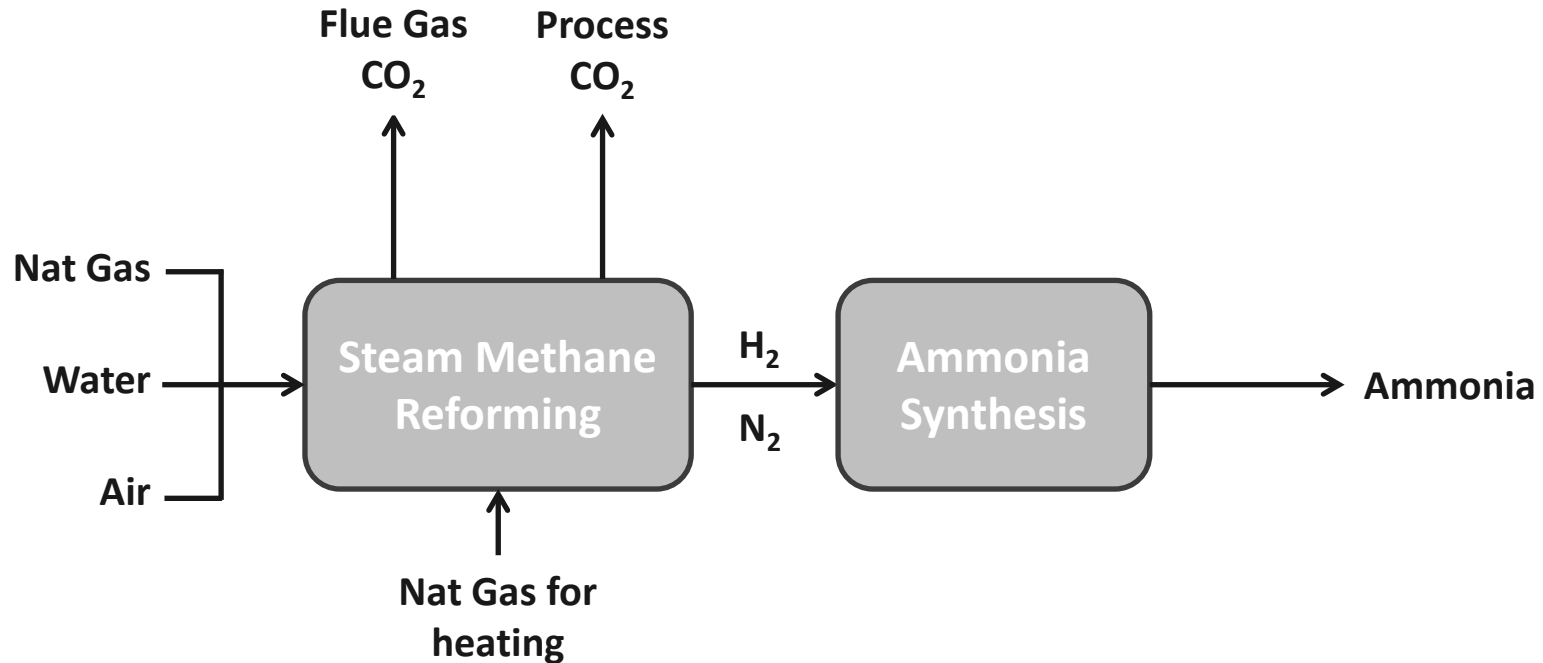
Ammonia demand expected to double by 2050, driven by new uses like power generation, hydrogen carrier and marine fuels

Global Ammonia Demand Forecast



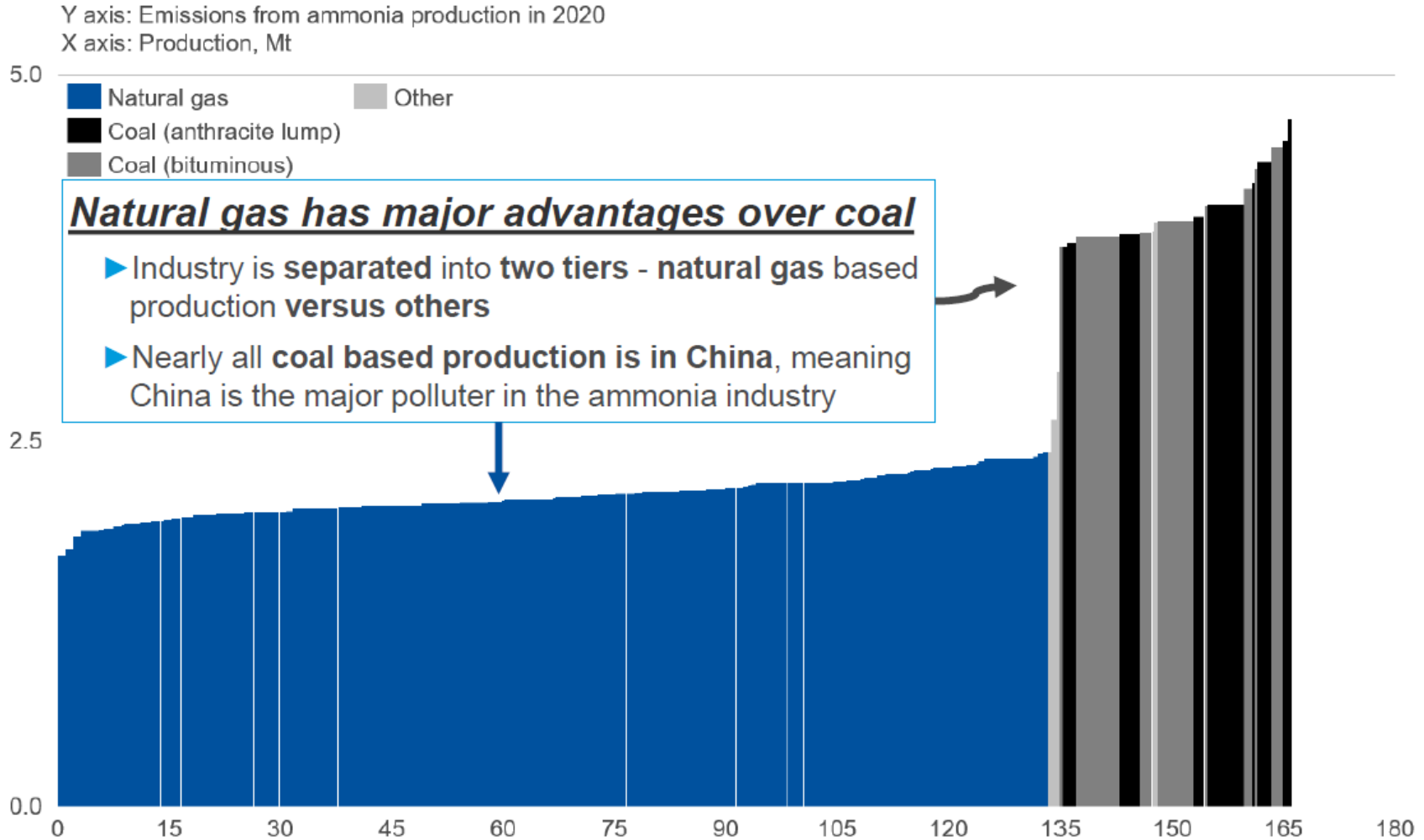
Source: Argus Consulting, International Energy Agency, CRU Nitrogen Research, IRENA

Conventional ammonia production in the U.S.



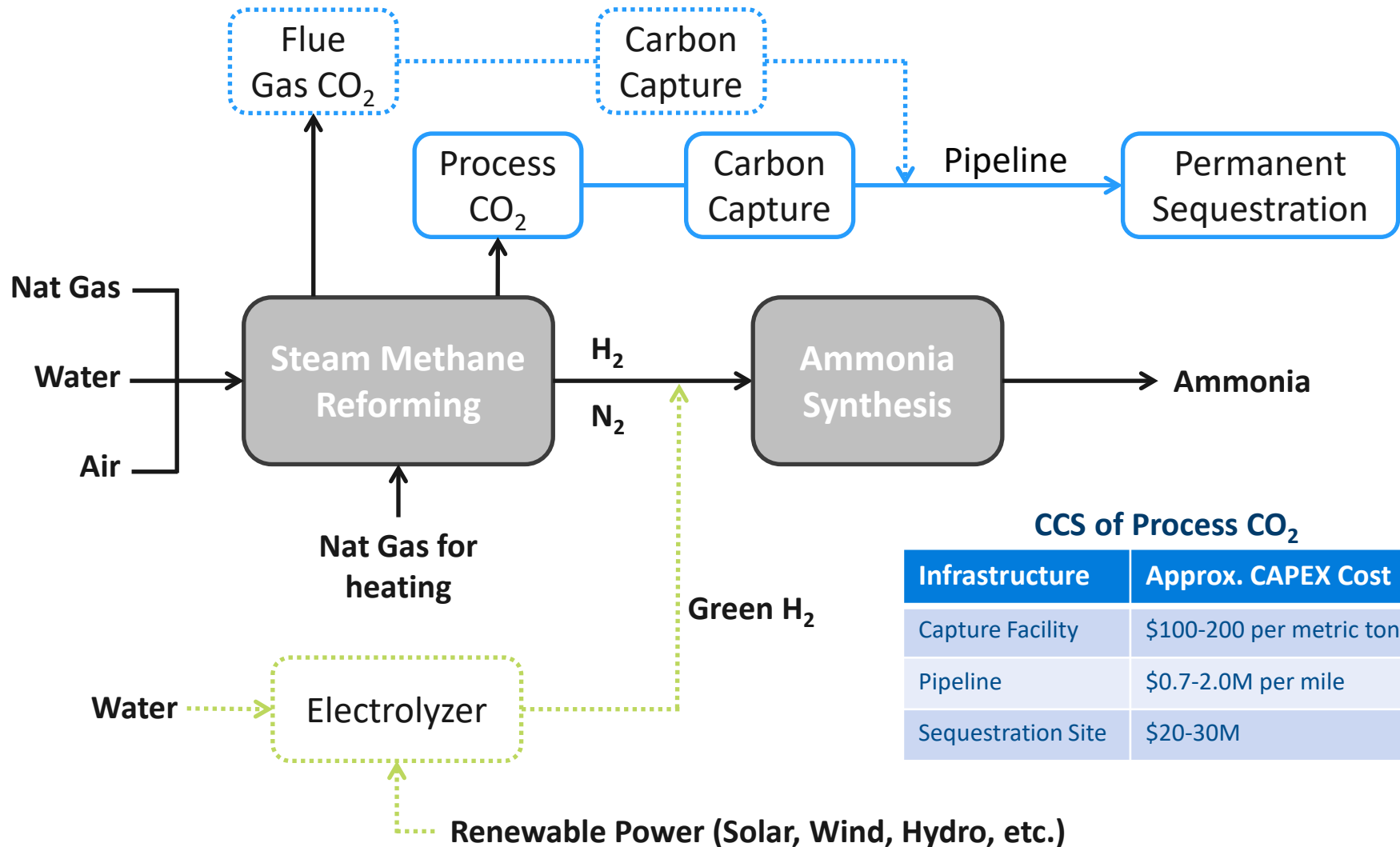
- The production of a metric ton of conventional ammonia from natural gas releases ~1.9 tons of CO₂
 - 1.2 tons from process related CO₂ with 90-94% purity
 - 0.7 tons from combustion (flue gas) related CO₂ with 8-10% purity

Global ammonia emissions curve in terms of CO₂ emissions per ton of ammonia produced



Source: CRU Nitrogen Research

Retrofitting existing facilities to produce low carbon ammonia

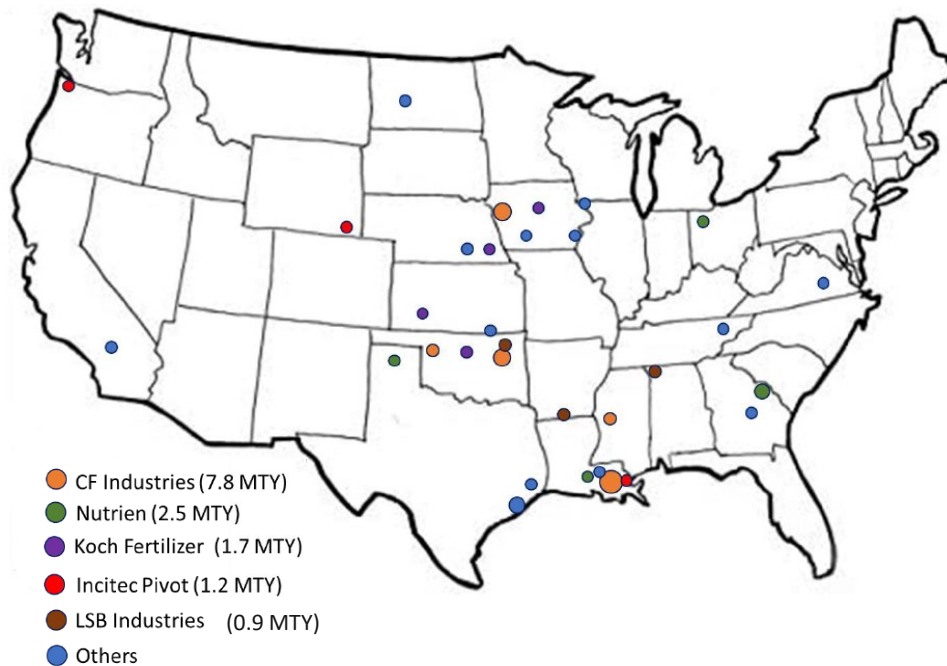


CCS of Process CO₂

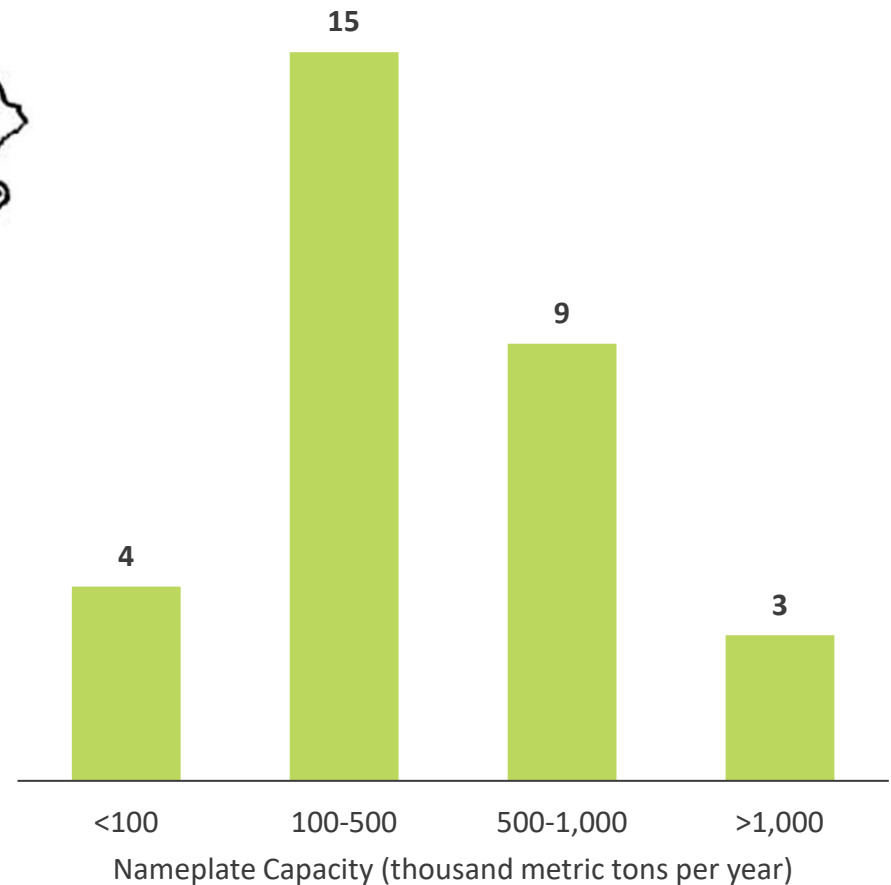
Infrastructure	Approx. CAPEX Cost
Capture Facility	\$100-200 per metric ton
Pipeline	\$0.7-2.0M per mile
Sequestration Site	\$20-30M

Most ammonia plants in the U.S. produce less than 500k tons per year and are located in the Midwest

U.S. Ammonia Plant Locations

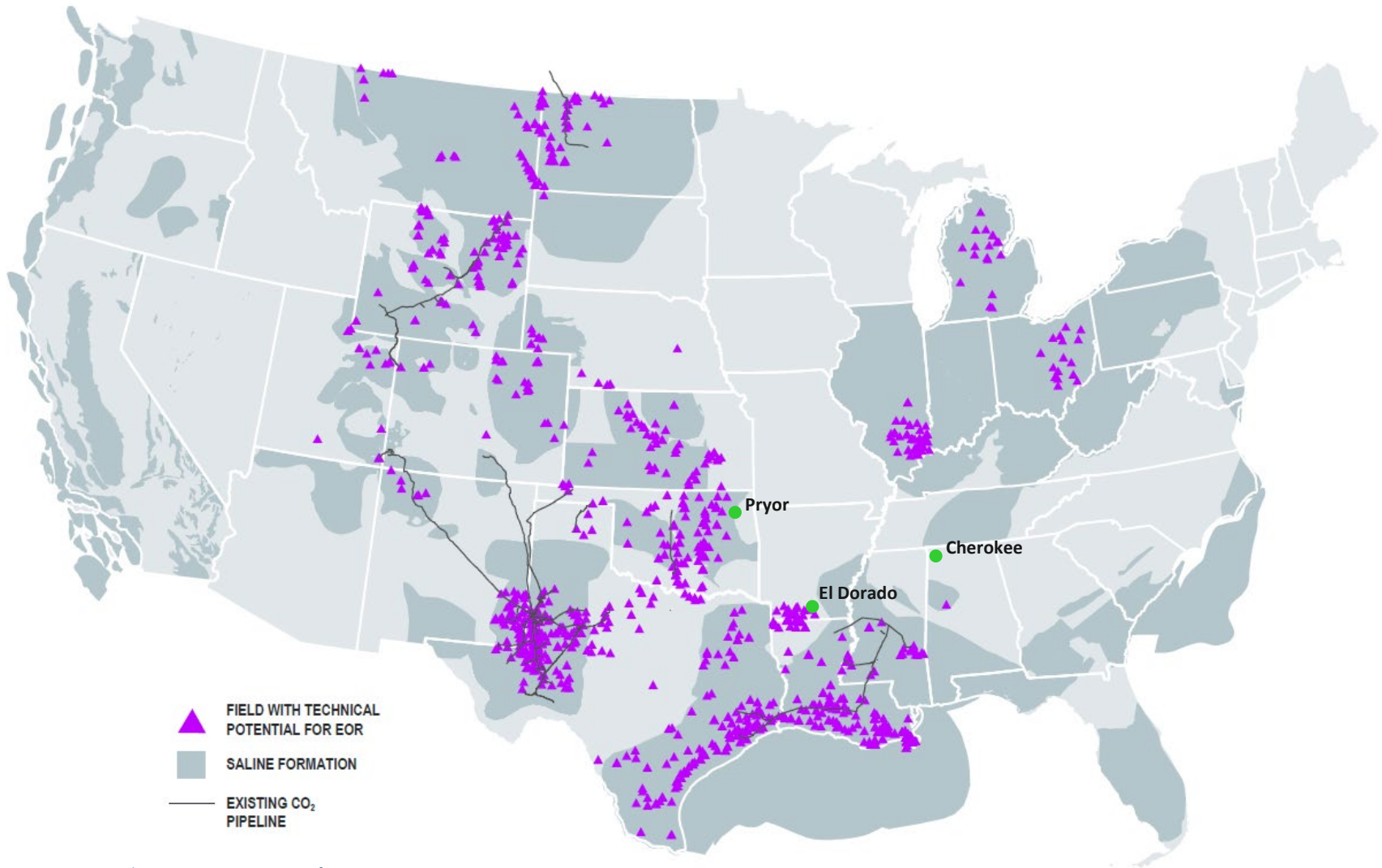


U.S. Ammonia Plants by Size



Source: The Fertilizer Institute (TFI), Nutrien Fact Book 2020

Deep geologic saline formations and existing oil fields with carbon capture and sequestration potential in the U.S.



Source: Great Plains Institute, University of Wyoming

Conclusions

- Ammonia production is easier to decarbonize than carbon-based fuels
- Liquid ammonia is superior to liquid hydrogen
 - Higher energy density per volume
 - Less cooling required (higher temperature)
 - Far less flammable
- Challenges to decarbonize existing ammonia infrastructure
 - Flue gas emissions cannot be captured economically
 - Process emissions can be captured economically but are highly dependent on:
 - Volume of CO₂ emitted
 - Distance between the emitter and the sequestration site (pipeline)
- Most of the carbon emitted from ammonia production today cannot be economically captured under the current 45Q tax credit incentives