Ammonia-Based Energy Storage (NH3-BEST)

EERC

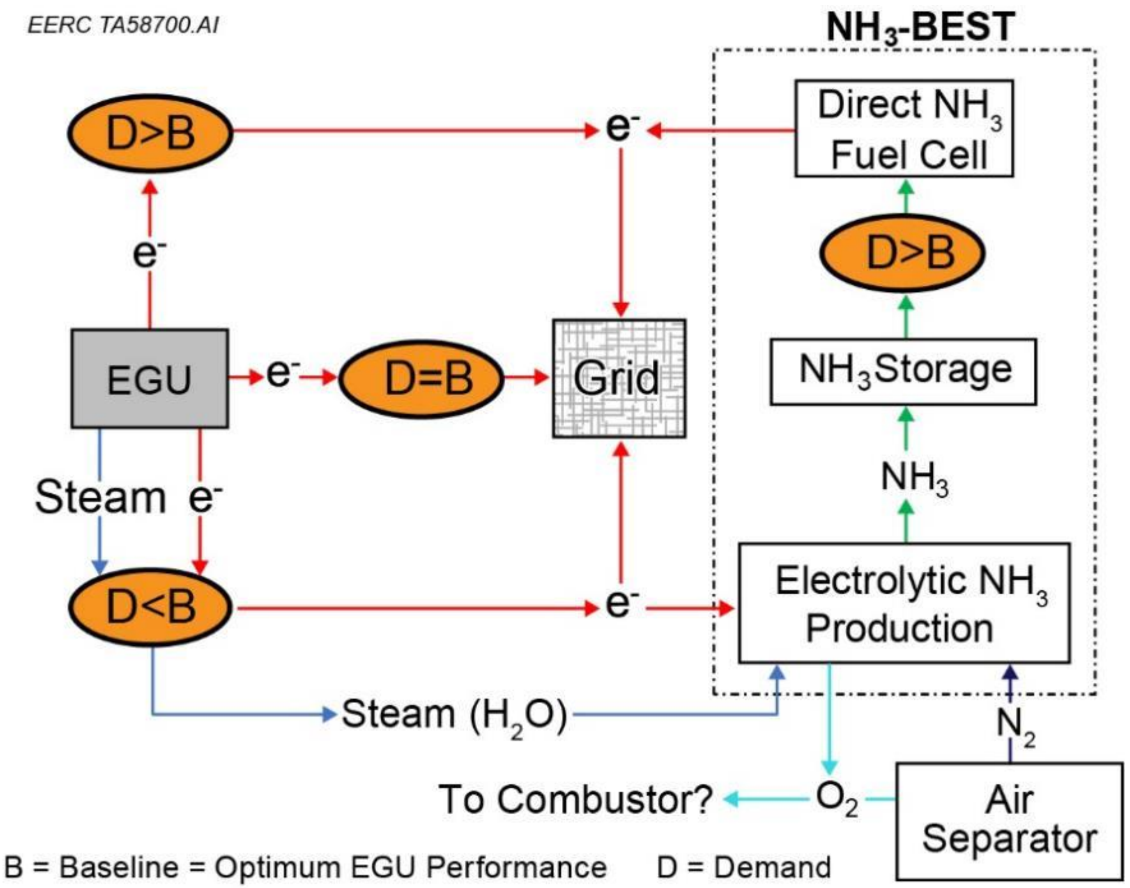
Critical Challenges. **Practical Solutions.**

+ Project Utility Partners:
Basin Electric
Minnkota Power
Ottertail Power

Presented at:

U.S. Department of Energy
National Energy Technology Laboratory
FY22 FECM Spring R&D Project Review Meeting
5 May 2022

Integrated Energy Storage via NH_3-BEST



NH_3-BEST integrated with EGU

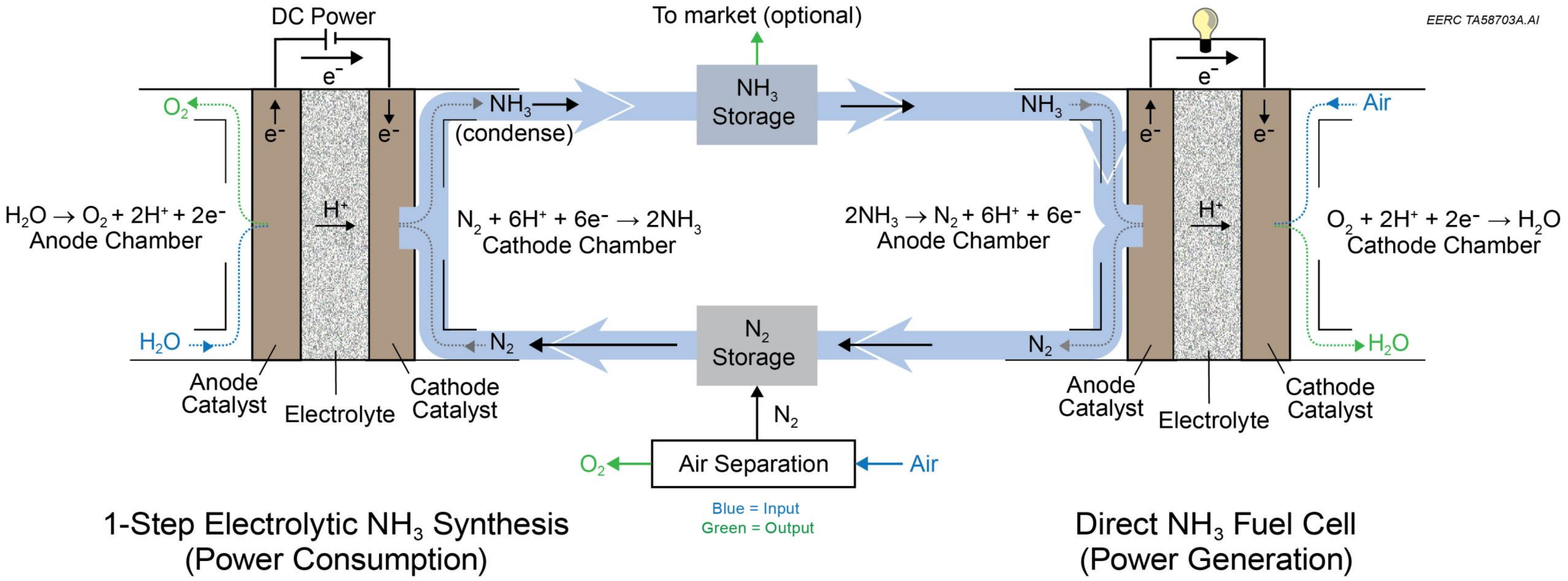
<u>Ammonia assets as energy storage medium</u>

- High hydrogen/energy content
- Low storage cost
- Near-zero explosivity hazard
- Carbon-free composition means no CO_2 emitted when converted to electricity, via fuel cell or combustion
- Long-established globally fungible commodity, offers economic flexibility via selling and/or buying to capitalize on market conditions or address production/supply challenges

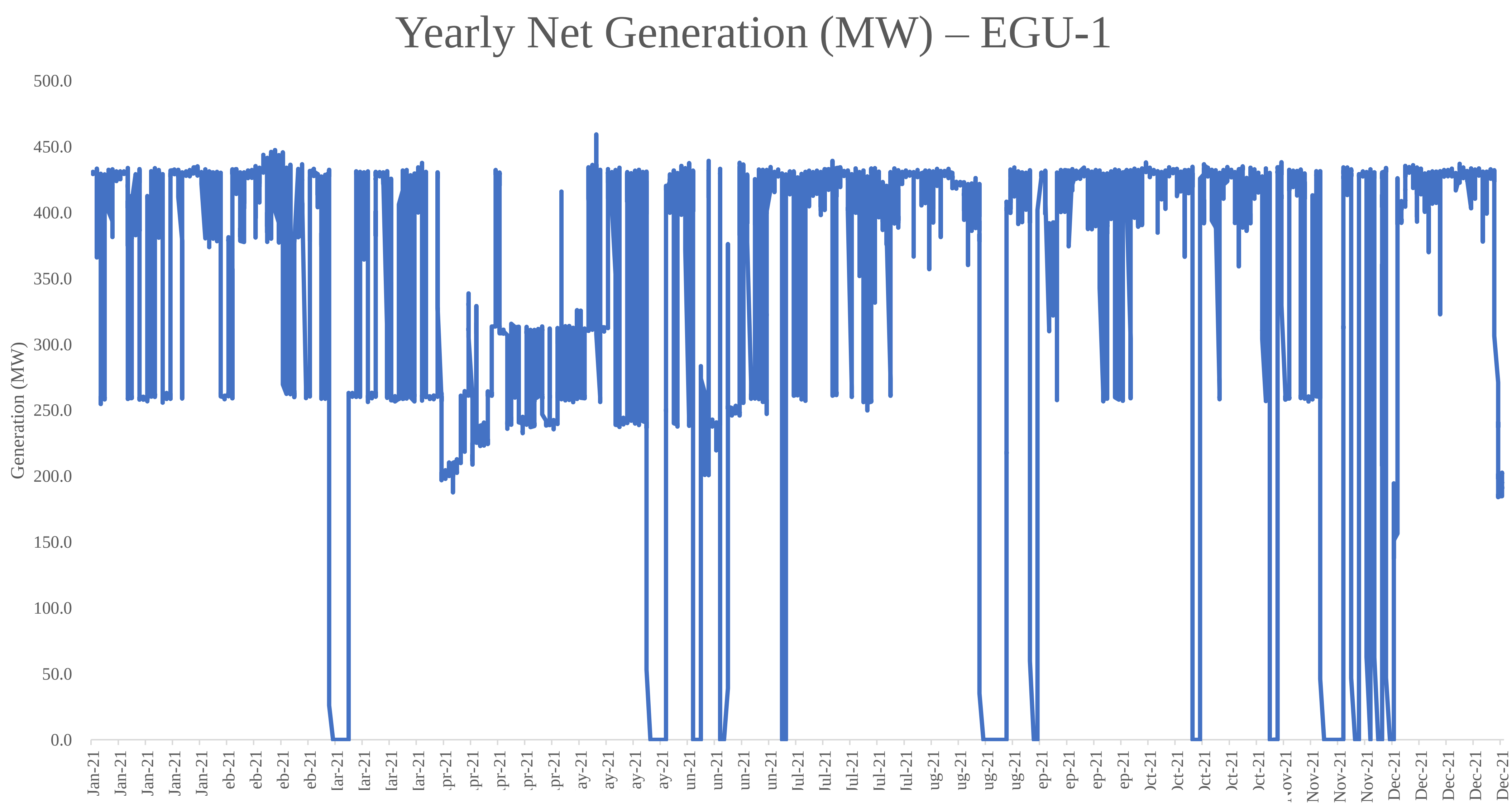
<u>Major project outcomes</u>

- Preliminary design of NH_3-BEST subsystem and associated EGU integration requirements
- Modeled demonstration of NH_3-BEST performance, including estimated round-trip efficiency and preliminary economics when integrated with an EGU
- Road map for bringing ammonia energy storage to commercial deployment

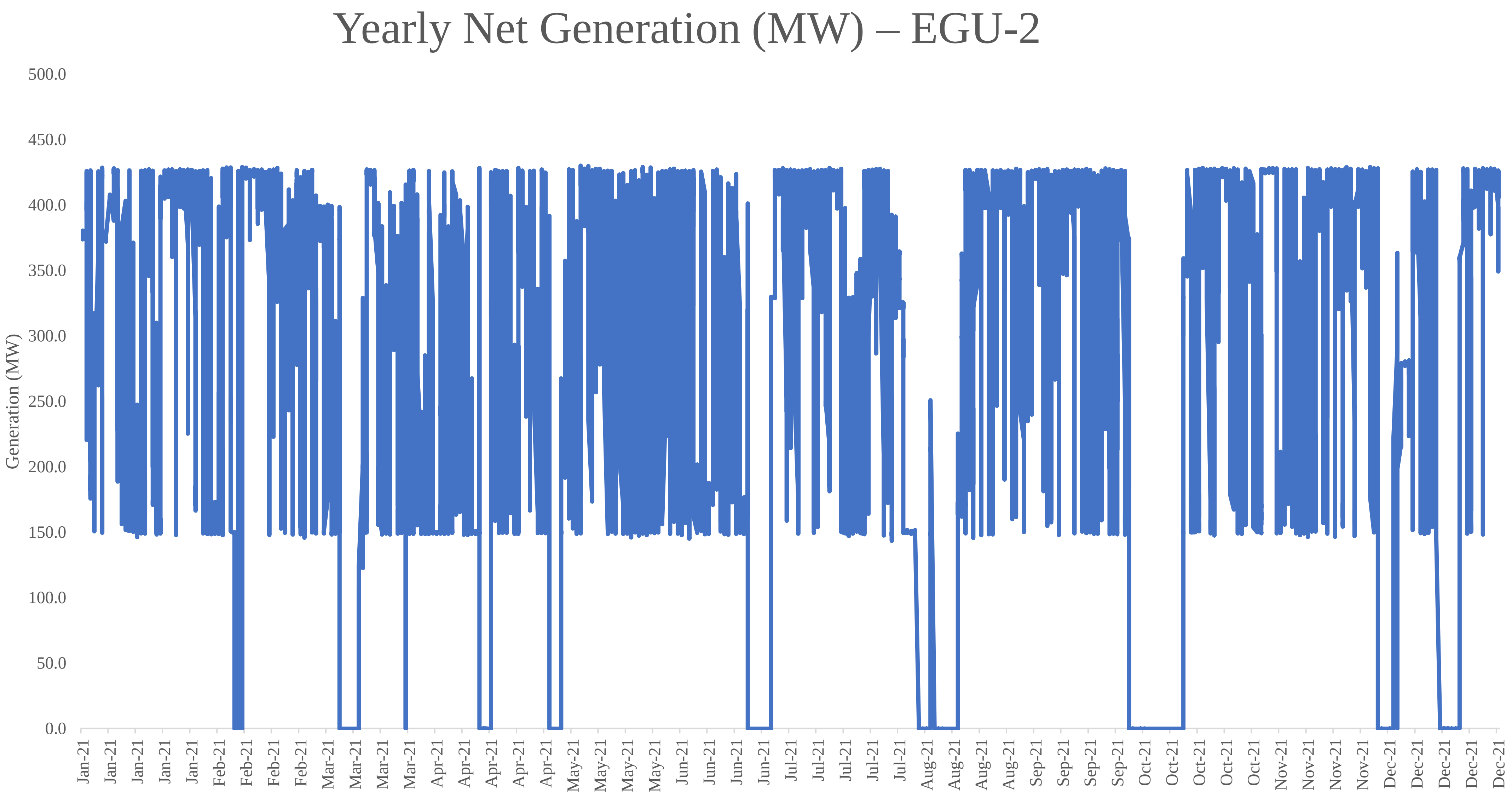
NH_3-BEST Unit Operations



Under development at EERC | Commercially available | Under development around the world



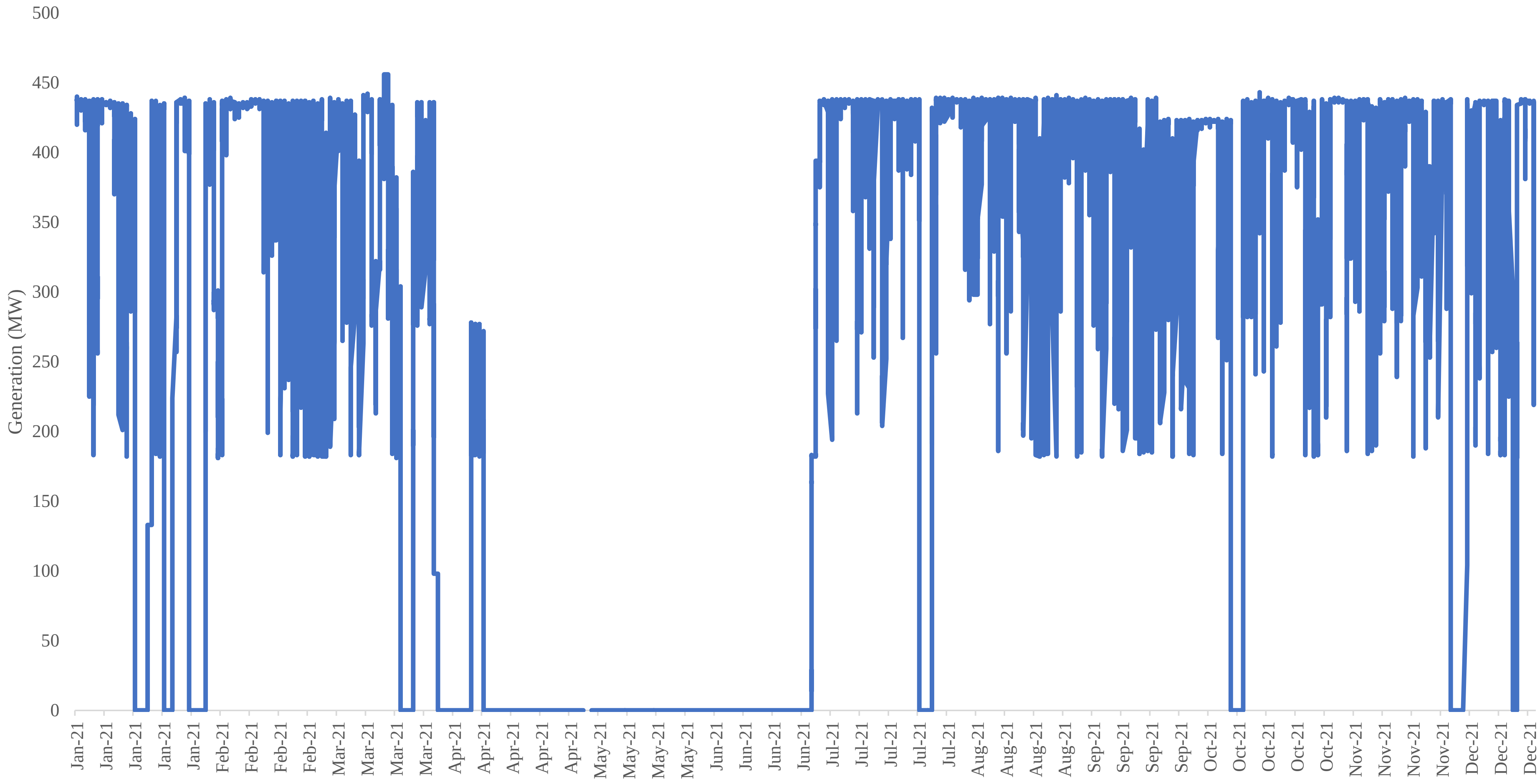
Nameplate Capacity: 435 MW
Major Deep Cycle: 250 MW (185 MW spread)



Nameplate Capacity: 427 MW

Major Deep Cycle: 150 MW (277 MW spread)

Yearly Net Generation (MW) – EGU-3



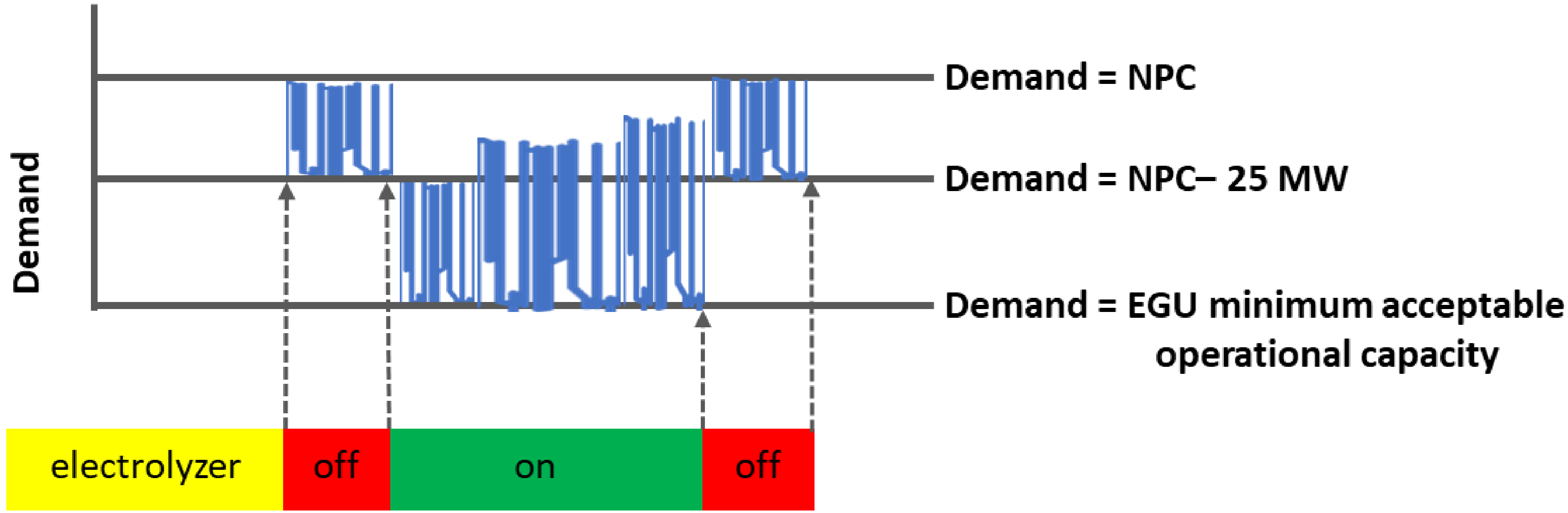
Nameplate Capacity: 437 MW

Major Deep Cycle: 180 MW (257 MW spread)

Objectives/assumptions for building NH3-BEST model

- Plant/EGU operates at nameplate capacity (NPC)
- Plant follows load until demand drops to 25 MW below NPC (NPC – 25 MW)
- When demand drops to NPC – 25 MW, NH3 electrolyzer kicks in, plant ramps up to NPC, and excess power is diverted to NH3 production and storage
- During NH3 electrolyzer operation, EGU runs at NPC, with electrolyzer modulating all demand fluctuations, until demand increases to NPC
- When demand increases to NPC, electrolyzer shuts down until demand again drops to NPC – 25 MW
- Stored NH3 utilization options:
  - Sell into NH3 fertilizer market
  - Conversion to power in direct NH3 fuel cell (or NH3 turbine) to meet grid call for more power
  - Pipeline to *planned* Hydrogen Hub (near EGU-2) resulting from conversion of DGC coal gasification plant (major NH3 producer) to natural gas-fueled hydrogen plant

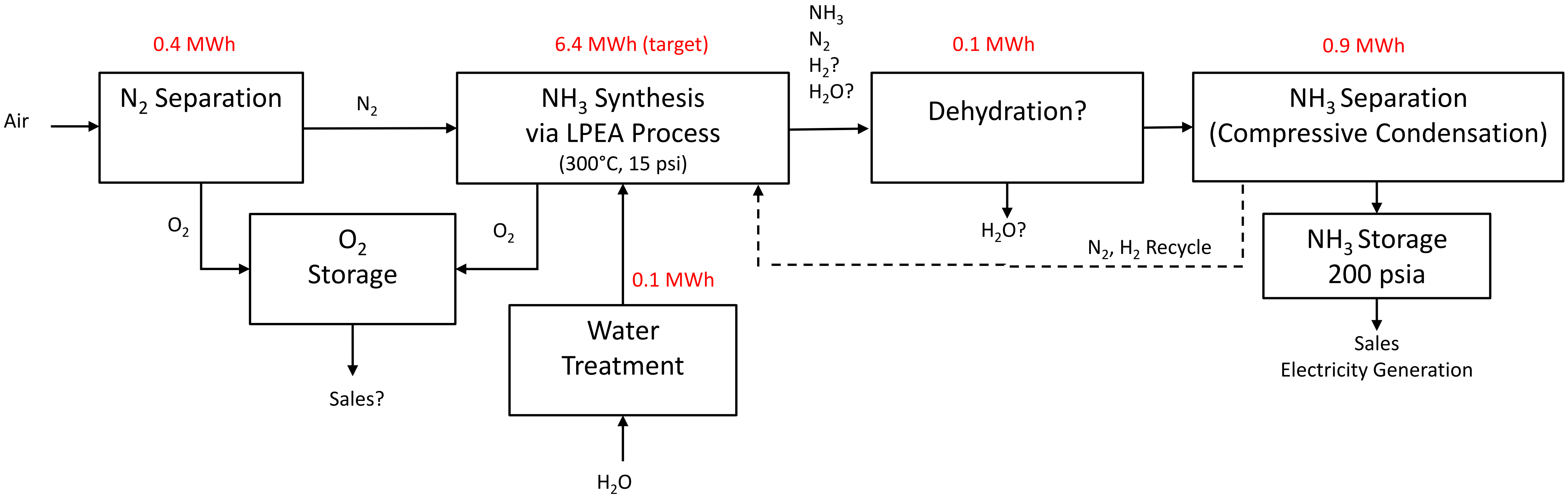
Ammonia synthesis unit (electrolyzer) operational strategy



EERC Low-Pressure Electrolytic Ammonia Production (LPEA) via Integrated (in single cell) Water Electrolysis/N2 Reduction

Targeted availability 2024 – total energy input requirement of 7.9 MWh/tonne NH_3

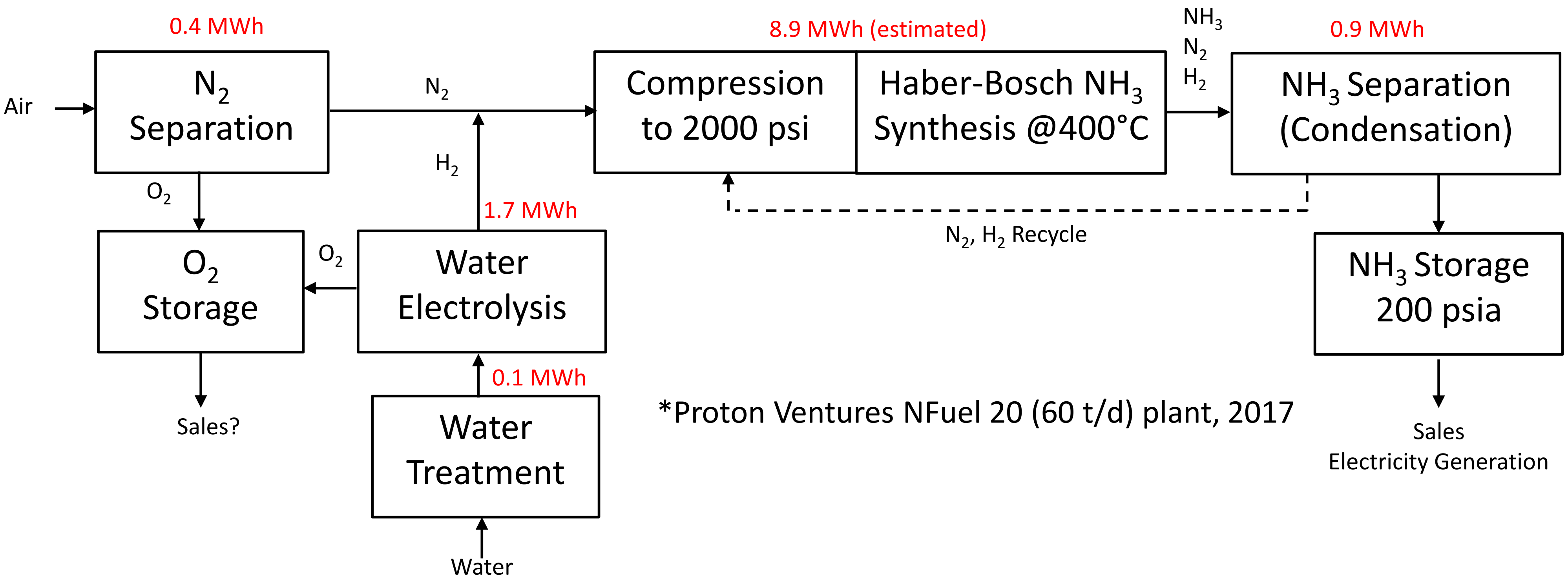
All energy values based on amount needed to produce 1 tonne NH_3



NH3 Synthesis via Water Electrolysis + Electrically Driven Haber-Bosch

Technology available today – total energy input requirement of 12 MWh/tonne NH_3*

All energy values based on amount needed to produce 1 tonne NH_3



*Proton Ventures NFuel 20 (60 t/d) plant, 2017

Ammonia Production			
Technology Pathway	Commercial Readiness	Energy Consumption, MWh/ton NH3	Production Cost*, $/ton NH3
Electrolysis + electrically driven Haber Bosch	Today	10.6** **12.0** (Proton Ventures, 2017)	297 (336 @12MWh/t)
Electrolysis/N2 reduction (EERC target)	2024	7.9	221
SMR/Haber Bosch (current state of the art)	Today	8.5	238

According to the U.S. Energy Information Administration (EIA), annual average electricity prices in 2020 were:

- Residential 13.15¢per kWh
- Commercial 10.59¢per kWh
- Transportation 9.90¢per kWh
- Industrial 6.67¢per kWh

*Based on $28/MWh electric rate determined as follows:
From: Otter Tail Power Electric Rate Schedule – 2019,
Winter (May–October) Residential Rate = 5.446 ¢per kWh.
So, using 5.446 and EIA Residential/Industrial (13.15/6.67) ratio,
North Dakota Industrial Rate estimated at $28/MWh.

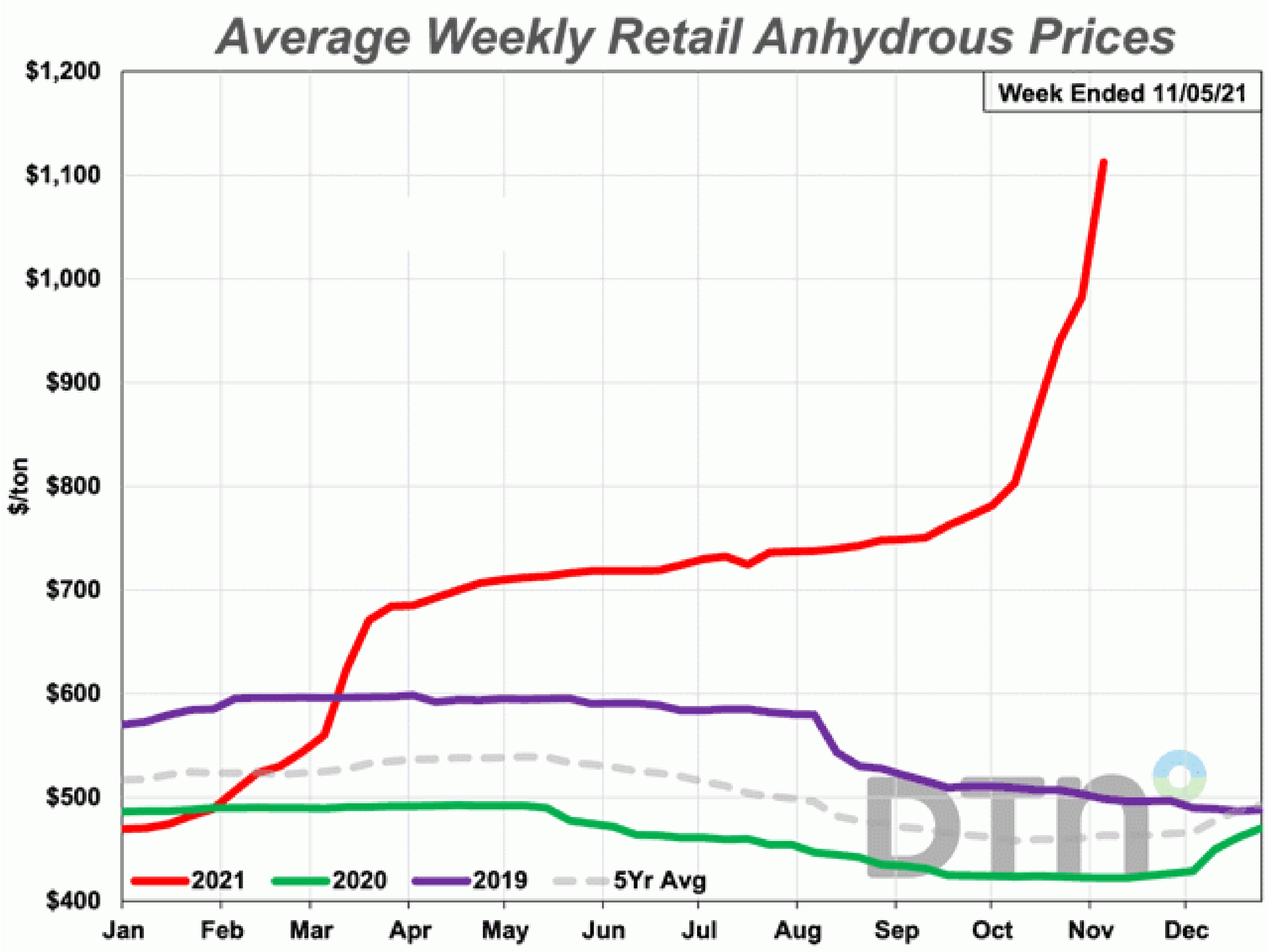
**MacFarlane, 2020, A roadmap to the ammonia economy; and Torrente-Murciano, 2020, Current and future role of Haber Bosch ammonia in a carbon-free energy landscape.

Ammonia Production for EGU Load Smoothing: Technology Implications

Technology Pathway	Commercial	Challenges, Considerations, Limitations	Attributes: Known and Likely
Electrolysis + electrically driven Haber Bosch	Today	Max plant size available today? cost? Economics of intermittent operation	Economics workable @≥10 t/d, near HB-competitive @ ≥60 t/d. Modularity for scale-up as needed.
Electrolysis/N2 reduction (EERC target)	2024	≥300°C H^+ exchange electrolyte needed for temp/heat to break N2 bond. Water electrolysis at anode, NH3 synthesis at cathode → tough kinetics.	Direct use of H+ (versus going through H2 intermediate) in single electrolytic reactor means lower capex/opex, energy consumption
SMR/Haber Bosch (Included for comparison)	Today	Economic viability→≥1000t/d→big capex Constant operation for economic viability	Mature technology, near max energy efficiency

Next steps for building NH3-BEST models (LPEA and Electrolysis + HB)

- Establish (preliminary) capacity of NH3 synthesis reactor
- Establish accurate efficiency, reactant utilization, and overall energy consumption values for all NH3-BEST unit operations (NH3 synthesis module plus balance-of-plant units)
- Establish capacity, capex, and opex values for all NH3-BEST unit operations
- Establish utility-sanctioned electricity cost values
- Integrate NH3 synthesis/storage (front end) with NH3 utilization (back end) options:
    1) Power generation via direct NH3 fuel cell (SOFC viable today? near term? operating temp impact on response time?)
    2) Power generation via NH3 turbine (Mitsubishi says 2025 for 40-MW unit)
    3) Sell to regional and/or export markets (Japan building ammonia energy economy)
    4) Pipeline to planned Beulah ND hydrogen hub (facility currently producing NH3 from coal)



From: Progressive Farmer/DTN, 10 November 2021

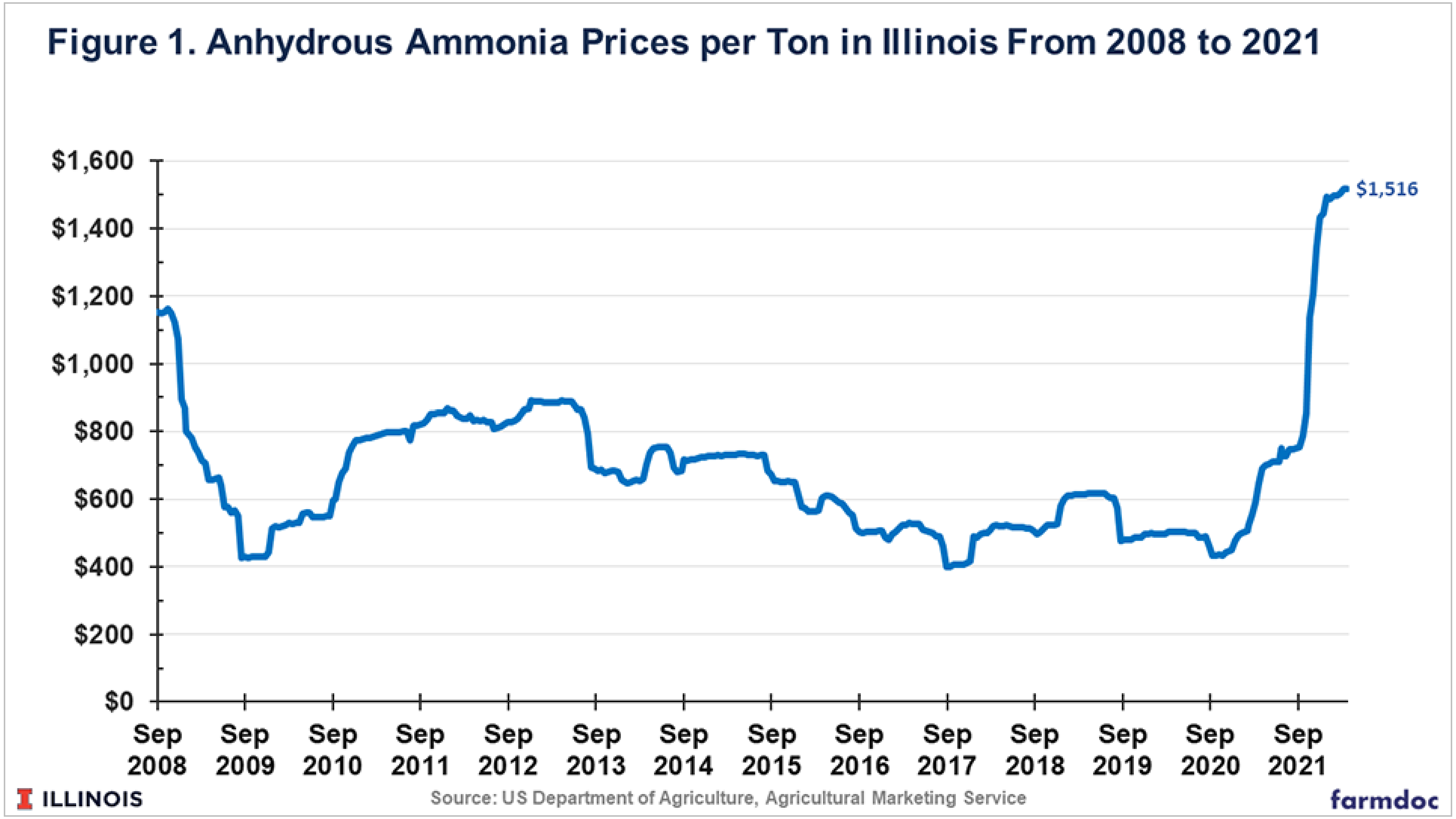
Also from Progressive Farmer/DTN:

January 2022: $1230/ton

“Considering the current status of the market, prices would appear to have peaked in February with the latest and largest Tampa ammonia settlement on record, leaving us with a stable-to-softening short-term price outlook heading into spring.”

2/11/2022

As ammonia utility expands from fertilizer to fertilizer + fuel/H2 carrier, what happens to price?



Illinois ammonia price was $**1,498** on February 10, $**1,503** on February 24 (Russia invaded Ukraine).
On March 23, price was $**1,516**