ECONOMICS OF ENERGY INNOVATION AND SYSTEM TRANSITION

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The role of green ammonia in sector coupling and seasonal electricity storage

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Department for Business, Energy & Industrial Strategy

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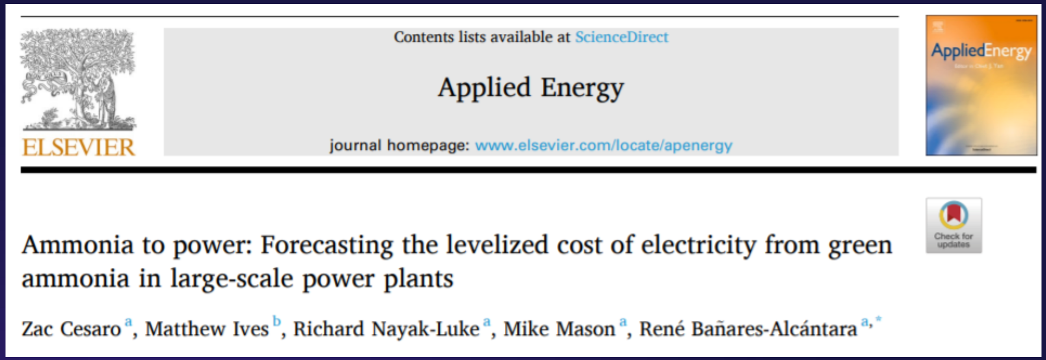
Agenda

1. High level overview: the potential roles of green NH3 in the electricity sector
   - First pass: modelling Power-to-Ammonia-to-Power (P2A2P) on an LCOE basis (journal article published in *Applied Energy* 2021)



Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

ELSEVIER

Ammonia to power: Forecasting the levelized cost of electricity from green ammonia in large-scale power plants

Zac Cesaro[a], Matthew Ives[b], Richard Nayak-Luke[a], Mike Mason[a], René Bañares-Alcántara[a,*]

2. Integrating ammonia into an energy system model of India
   - Context: Why are green hydrogen and ammonia so important in India?
   - Results and key insights of integrating H_2 and NH_3 to 2050 in India

1. What are the potential roles of green NH_3 in the electricity sector?

Green ammonia may provide several roles in future electricity grids

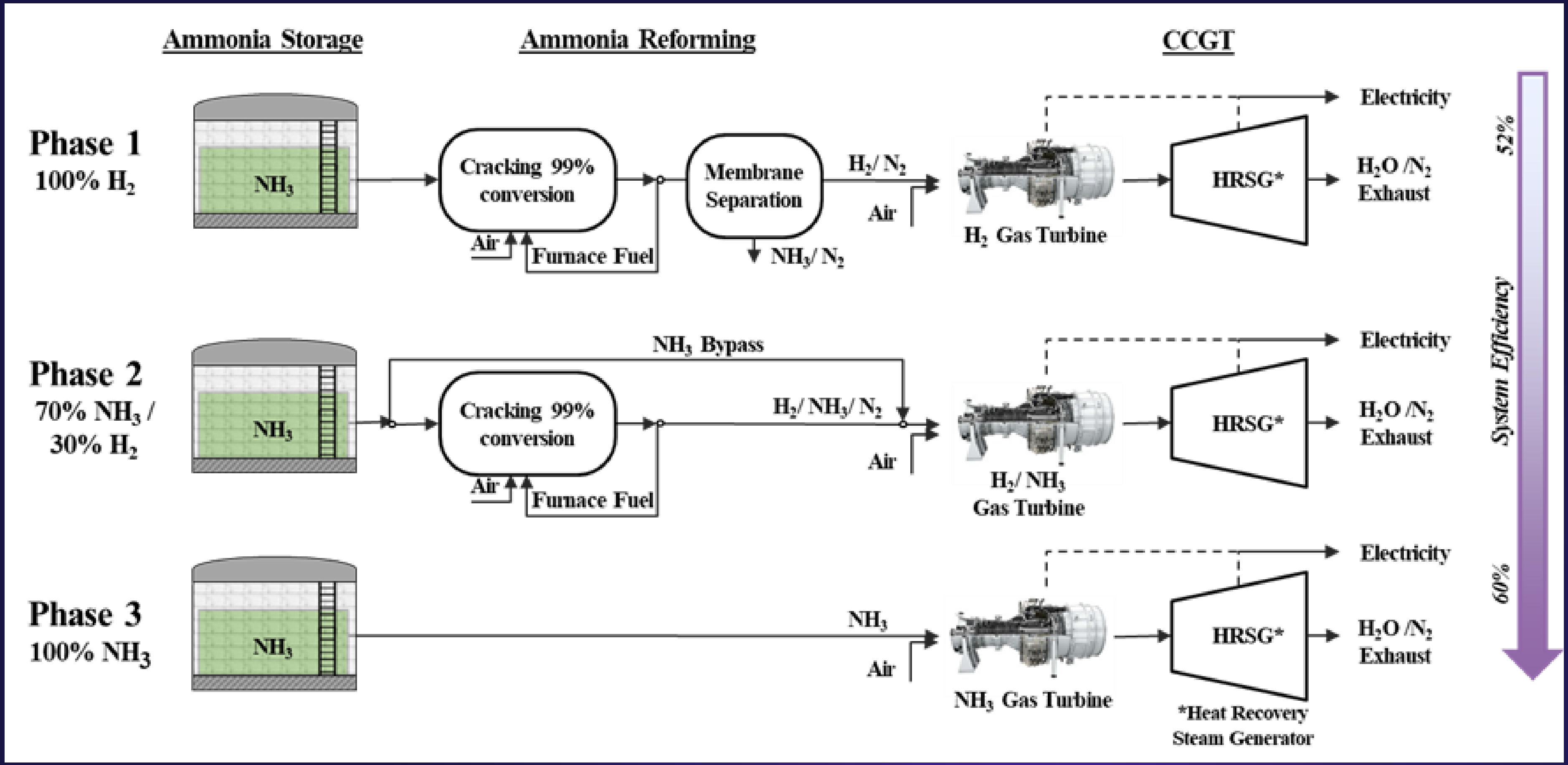
Green NH_3 roles in electricity sector

- Long duration electricity storage / regional electricity trade (P2A2P)
- Sector Coupling: Demand Side Response (DSR)
- System Resilience

Fertilizer

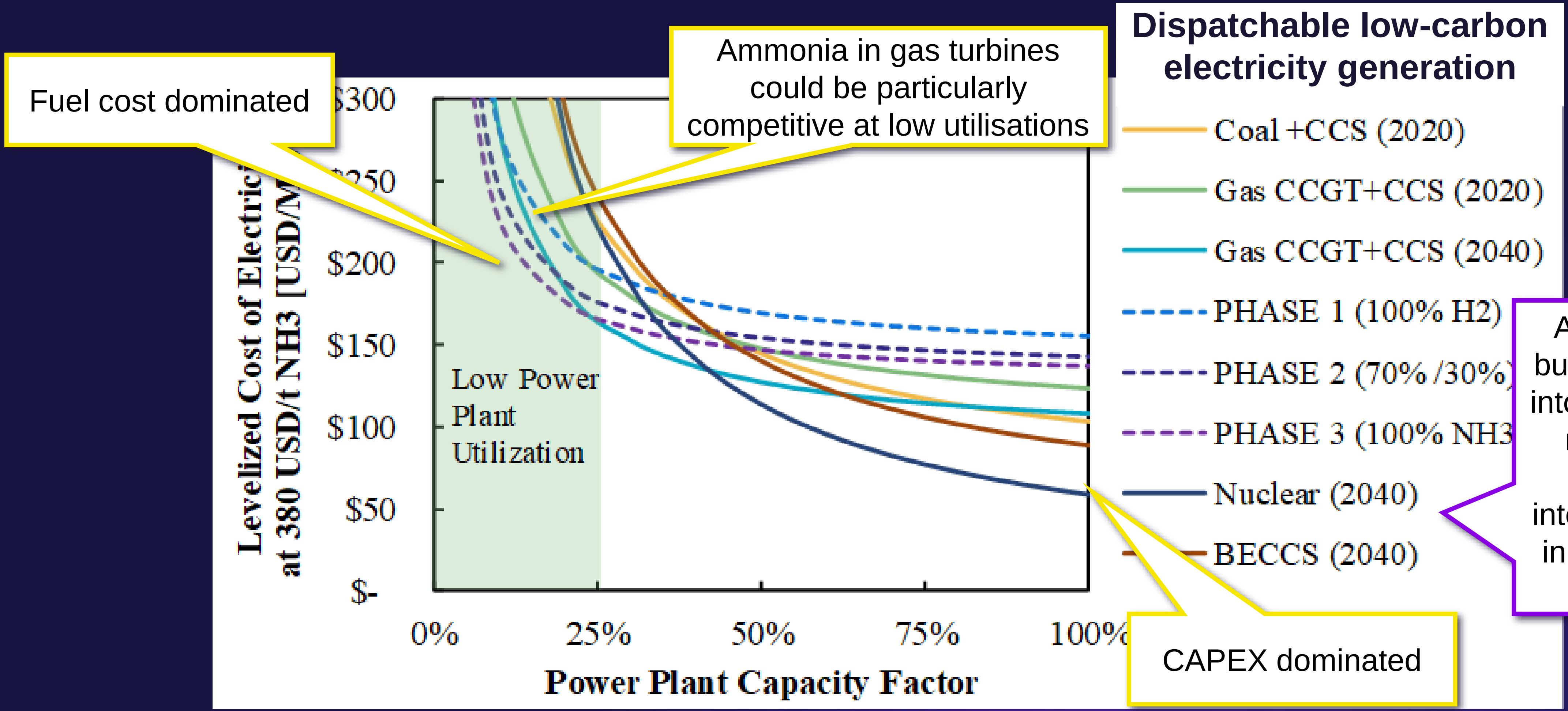
Shipping

Modelling ammonia-to-power configurations



Source: Cesaro et al. "*Ammonia to Power: Forecasting the Levelized Cost of Electricity from Green Ammonia in Large-scale Power Plants*", Applied Energy, 2021.

Key finding: Ammonia competes with CCS, nuclear, and BECCS on an LCOE basis– especially at lower powerplant utilization factors



A useful first step, but need to integrate into **energy systems model (ESM)** to understand the interplay of ammonia in a broader energy system.

Source: Cesaro et al. "*Ammonia to Power: Forecasting the Levelized Cost of Electricity from Green Ammonia in Large-scale Power Plants*", Applied Energy, 2021.

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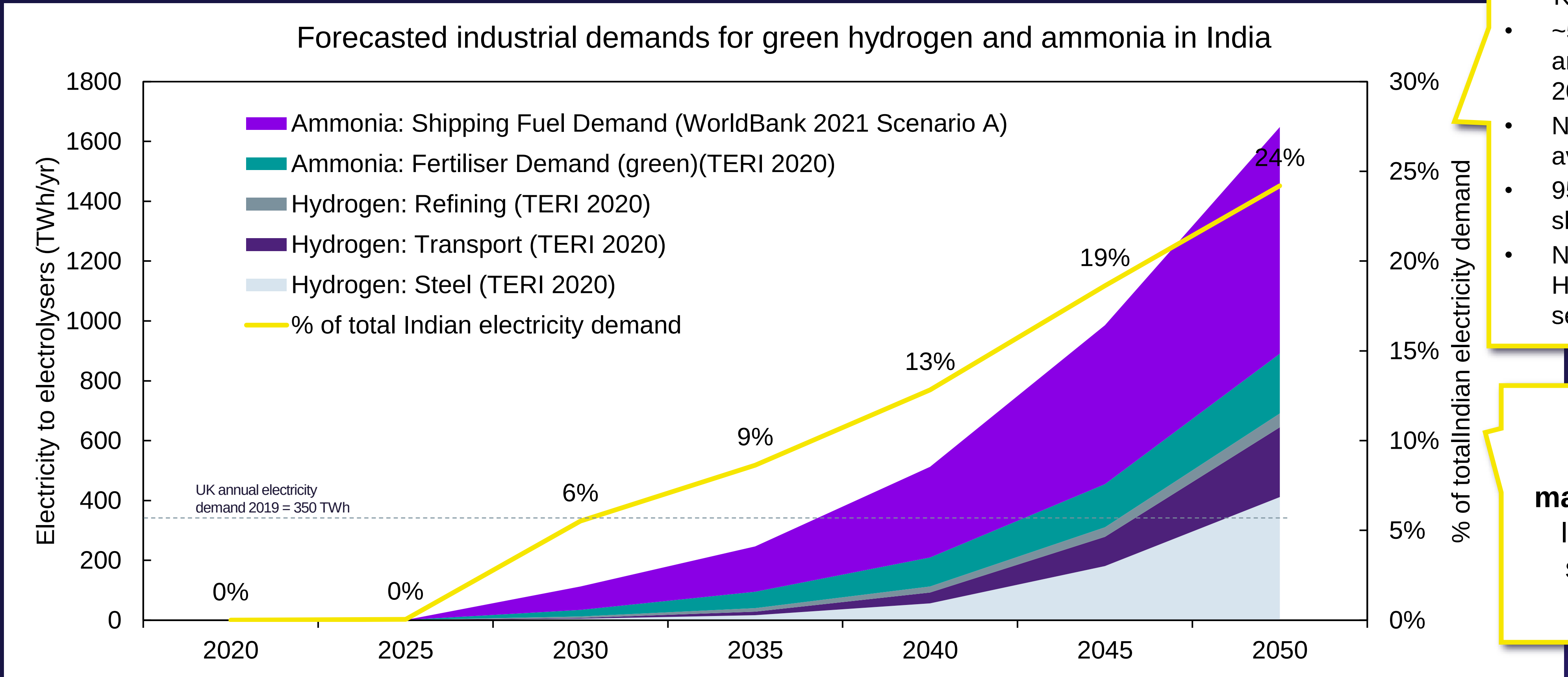
2. Integrating ammonia into an energy system model: case study of India

By 2050, ~25% of electricity in India may be used for green H_2 and NH_3



Key assumptions:

- ~50% decarb. of steel and fertiliser (TERI 2020)
- Not including H_2 for aviation
- 95 MMTPA NH_3 for shipping (WB 2021)
- Not counting any H2/NH3 for the power sector

This is a **non-marginal** part of the Indian electricity sector to model

***Synthetic aviation fuel is not yet included** in this modelling. TERI 2020 assumes **50% of steel, 60% ammonia fertiliser, and 30% refining demand** are met by green hydrogen. World Bank (2021) Scenario A based on **10% of global shipping fuel demand (25% of Asia shipping fuel demand)** met by green ammonia produced in India, i.e. 95 Mt NH3 per yr. Indian electricity demand forecasts from TERI 2020 based on modelling of growth in Residential, Commercial, Transport, Industry and Agricultural sectors.

Sources:

- TERI 2020: Hall, W., Spencer, T., Renjith, G., and Dayal, S. 2020. The Potential Role of Hydrogen in India: A pathway for scaling-up low carbon hydrogen across the economy. New Delhi: The Energy and Resources Institute (TERI)
- WorldBank 2021: *Englert, Dominik; Losos, Andrew; Raucci, Carlo; Smith, Tristan. 2021. The Potential of Zero-Carbon Bunker Fuels in Developing Countries. World Bank, Washington, DC. © World Bank. https://openknowledge.worldbank.org/handle/10986/35435 License: CC BY 3.0 IGO.*

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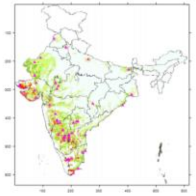
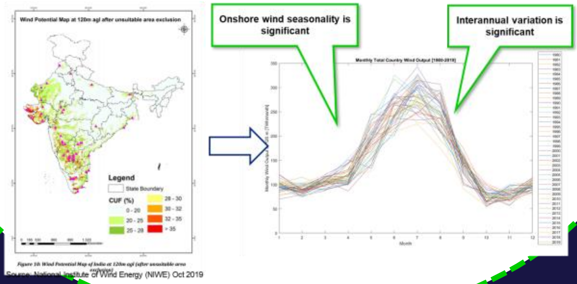
Methodology: New approaches added to ‘traditional’ energy systems modelling to examine the role of H_2 and NH_3

Land-use

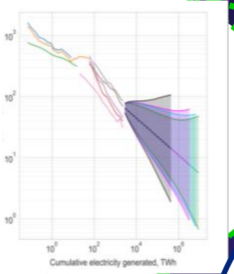
Solar **Wind**



System resilience: Multiple years of wind and solar profiles



Technology learning curves based on global deployment (Way et al. Oxford INET)



Energy Systems Model

Collaborating with Dr. Rasmus Bramstoft (DTU)

BALMOREL
Energy system model

- *Capacity expansion*
- *Hourly dispatch*
- *Cost optimisation*
- *From DTU, in GAMS*

Electricity Supply (Existing, planned, and least cost future)

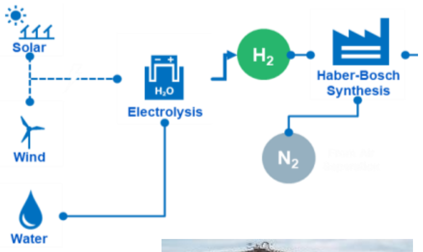
Electricity Demand (Current and forecasted)

Transmission (Existing, planned, and least cost future)

Policy, Taxes, etc. (Existing and predicted)

Network model of P2X (hydrogen and ammonia)

Production, Storage, Transport, Industrial use + Power Generation



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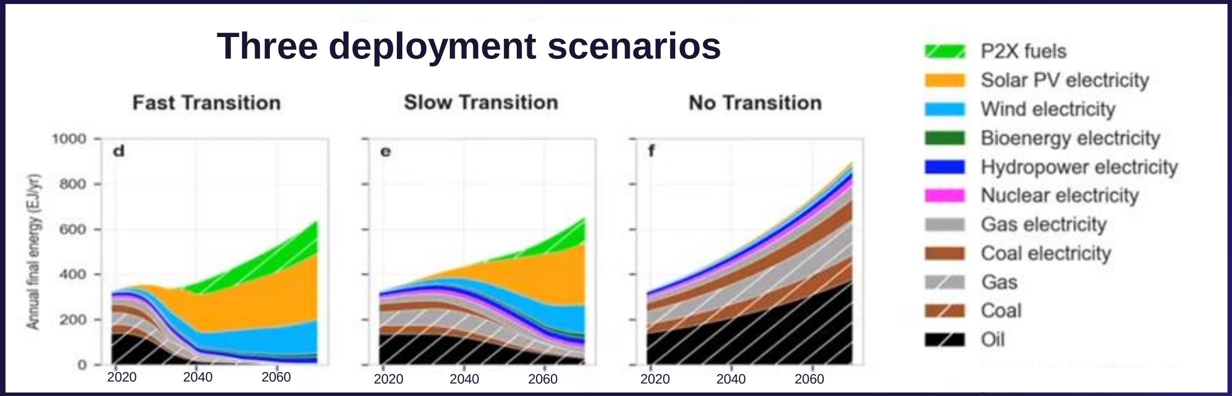
Way, Rupert, Matthew Ives, Penny Mealy and J. Doyne Farmer, “Empirically grounded technology forecasts and the energy transition”, Sept 14th, 2021, INET Oxford Working Paper No. 2021-01

Main scenarios

Technology costs based on global deployment and learning curves



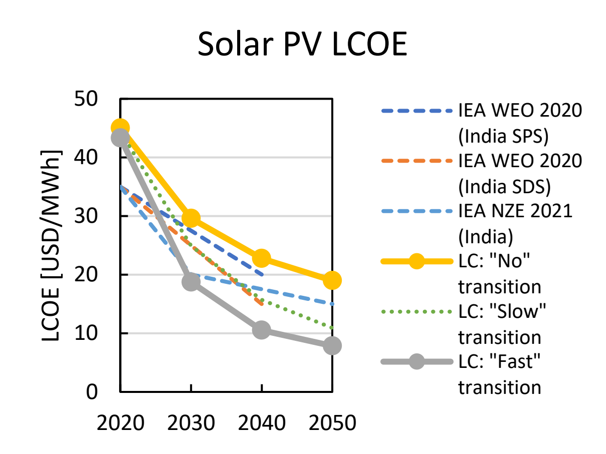
- *Scenarios from Way et al. (2021).*
- *Learning curves are a more reliable method than expert forecasts (Meng et al. 2021)*

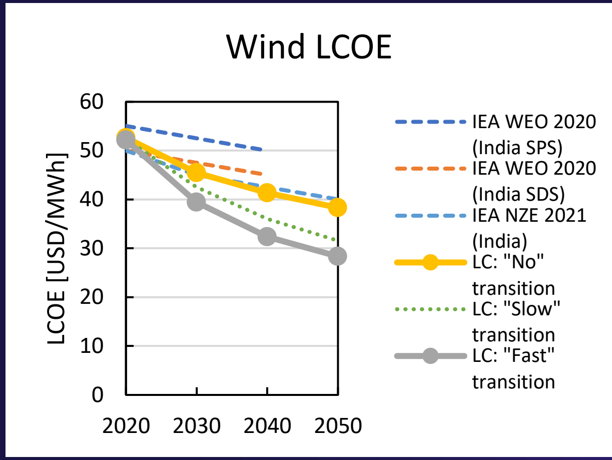
Ammonia production based on "islanded" or "grid connected" configuration

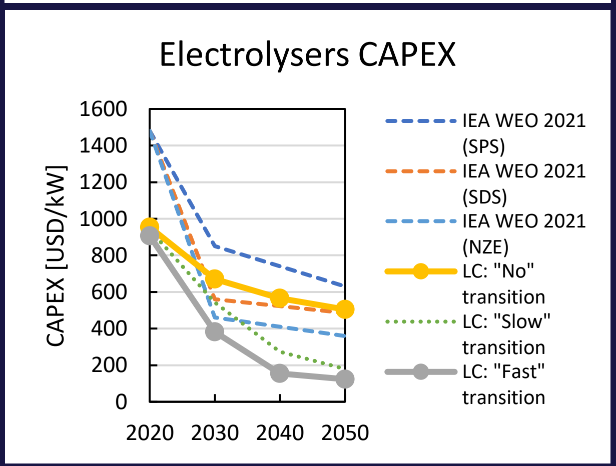
Way, Rupert, Matthew Ives, Penny Mealy and J. Doyne Farmer, "Empirically grounded technology forecasts and the energy transition", Sept 14th, 2021, INET Oxford Working Paper No. 2021-01

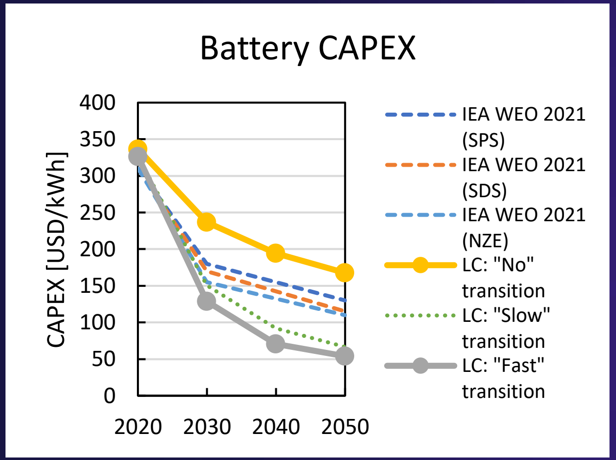
Meng, Jing, Rupert Way, Elena Verdolini, and Laura Diaz Anadon. 2021. "Comparing Expert Elicitation and Model-Based Probabilistic Technology Cost Forecasts for the Energy Transition." *Proceedings of the National Academy of Sciences* 118(27) (June 29, 2021).

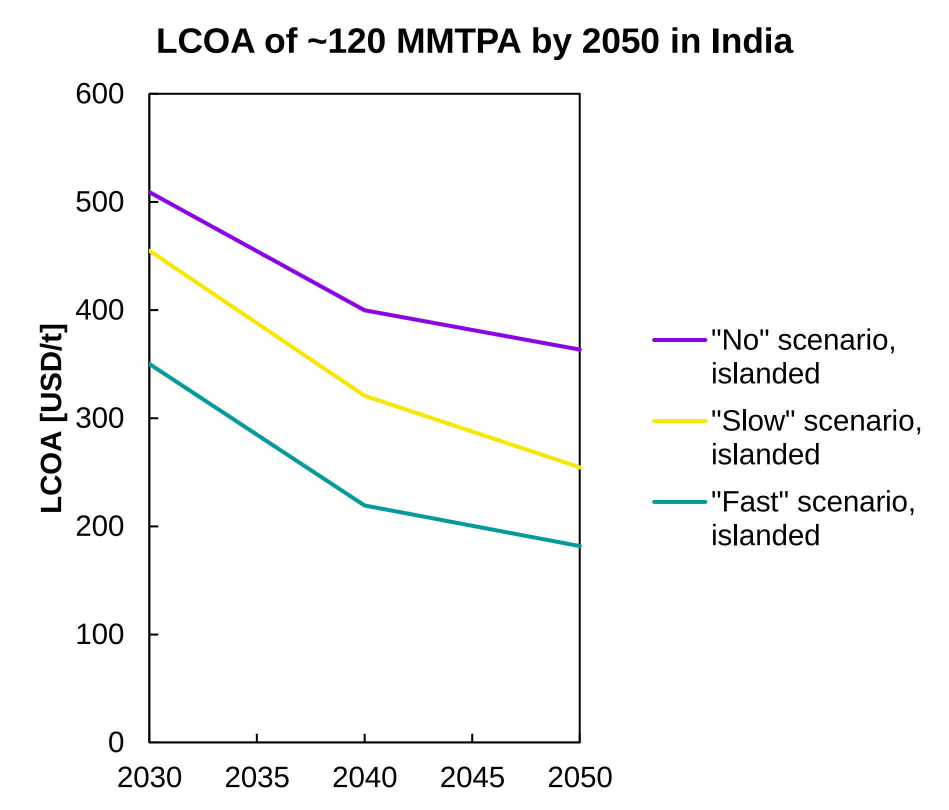
Results: LCOA ranges **\$180 – \$380 /t NH_3** in 2050 based on different global deployment of RE technologies



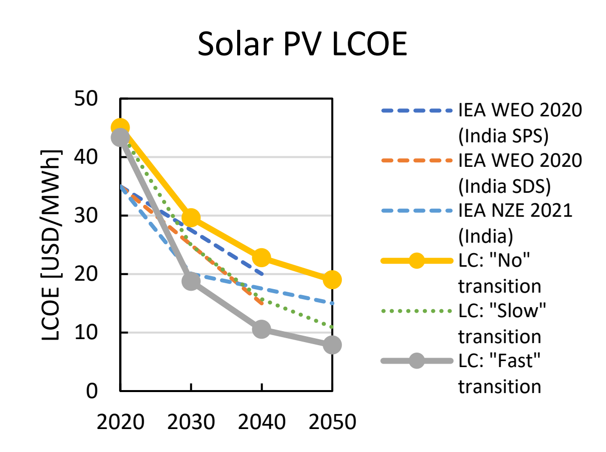


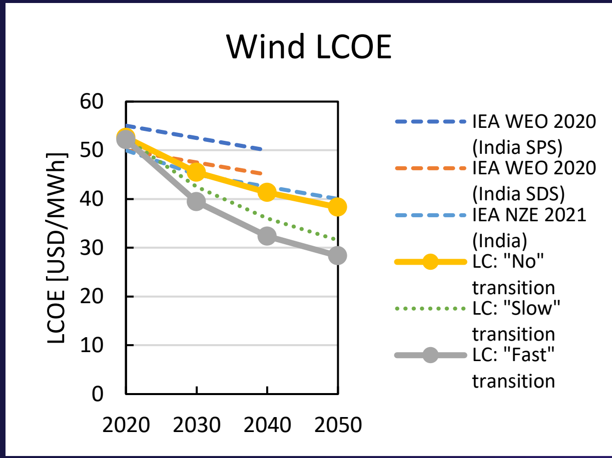


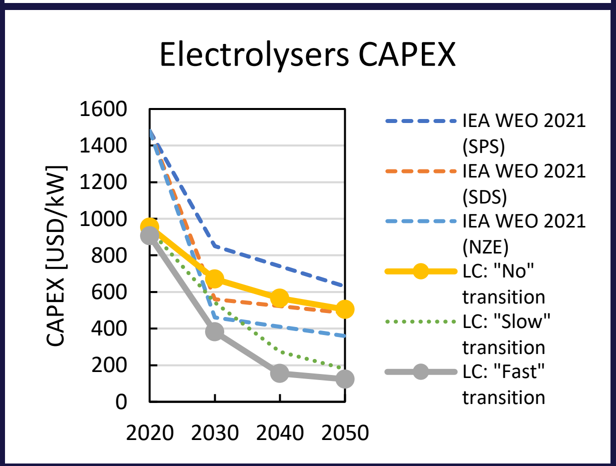


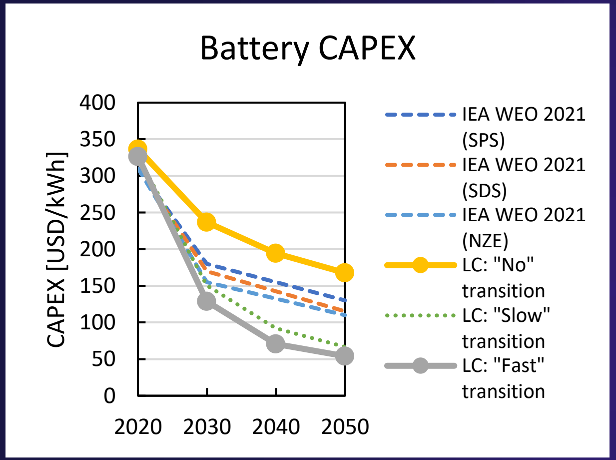


Results: LCOA ranges **\$180 – \$380 /t NH_3** in 2050 based on different global deployment of RE technologies

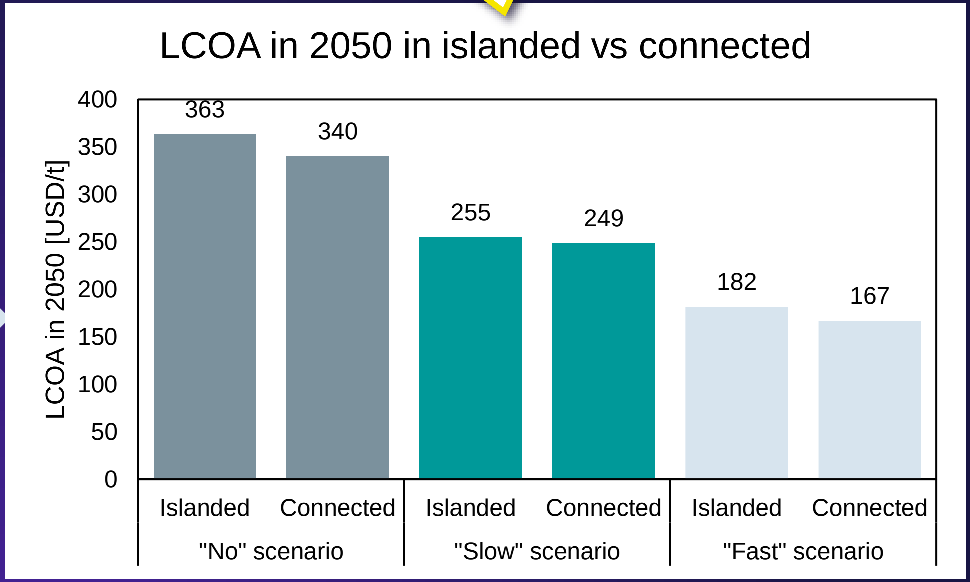








- Connecting HB plants to grid reduces LCOA by **2%-30% depending on year and scenario**



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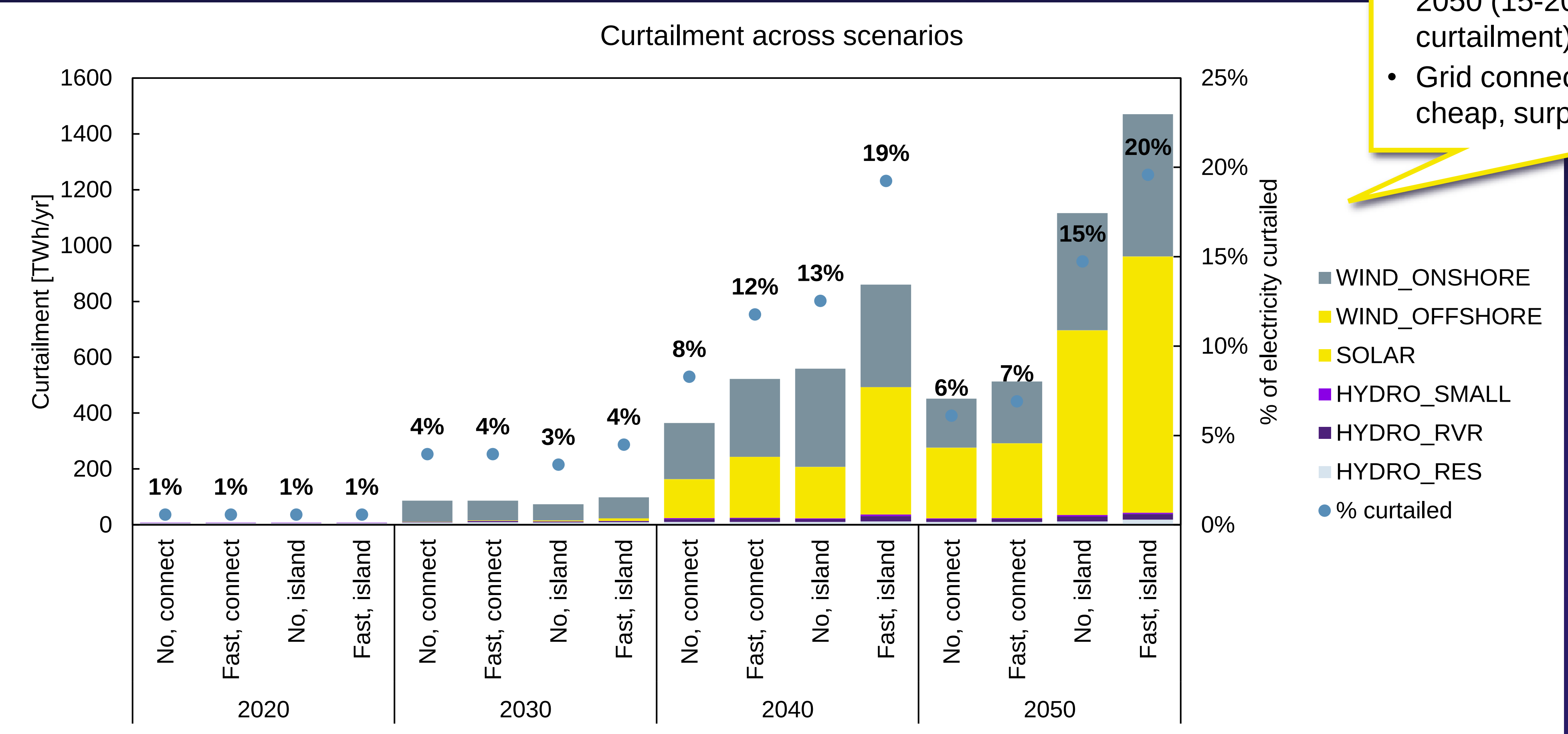
Connecting NH3 production to grid reduces curtailment and takes advantage of cheaper electricity

- Grid connection reduces curtailment by over 500 TWh/yr in 2050 (15-20% vs 6-7% curtailment)
- Grid connected H2/NH3 accesses cheap, surplus electricity



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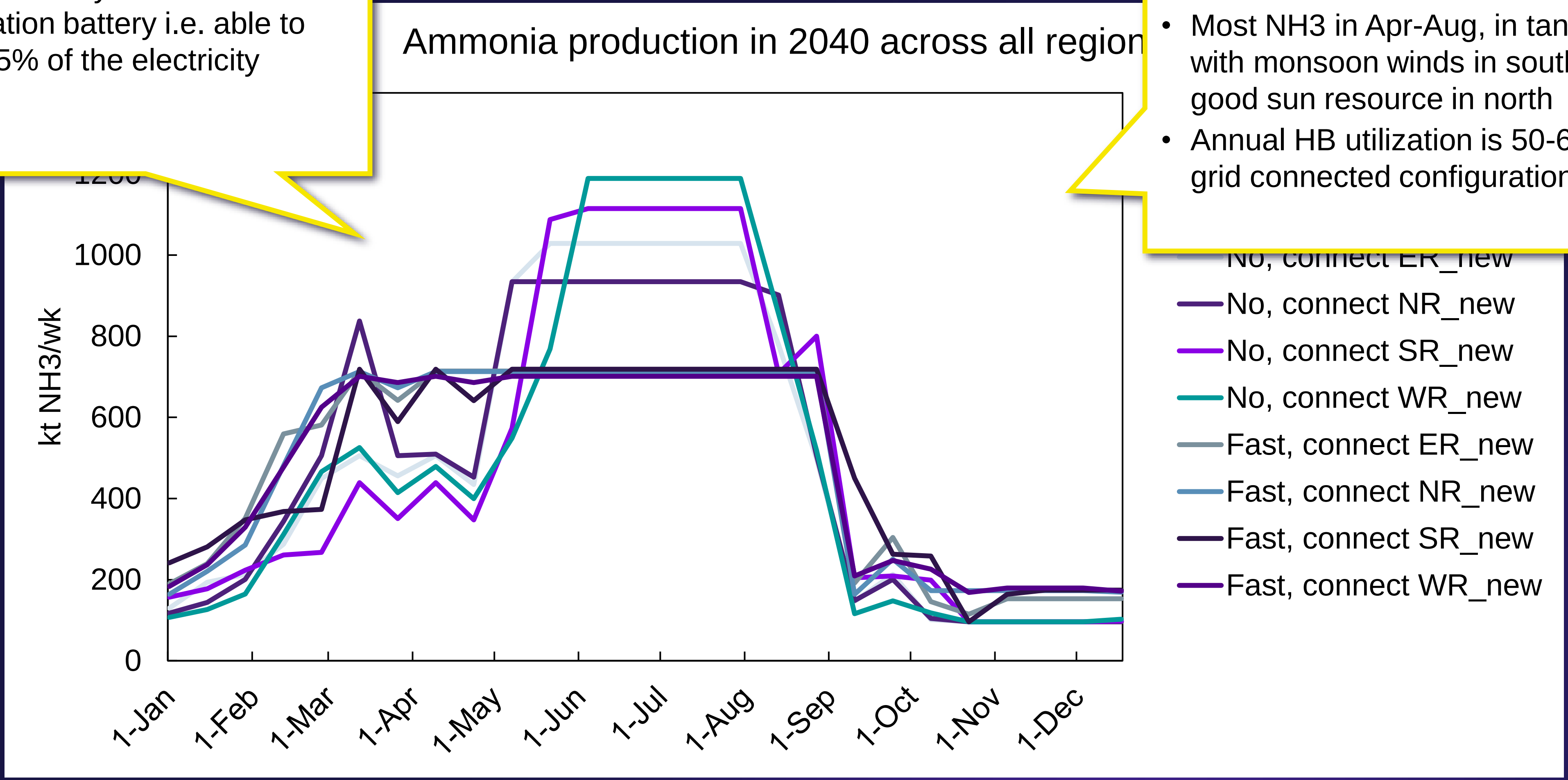
HB plants operate seasonally, and thus eliminate long-term electricity storage requirements, i.e. industrial DSR

- This is effectively a MASSIVE long-duration battery i.e. able to cover ~25% of the electricity demand



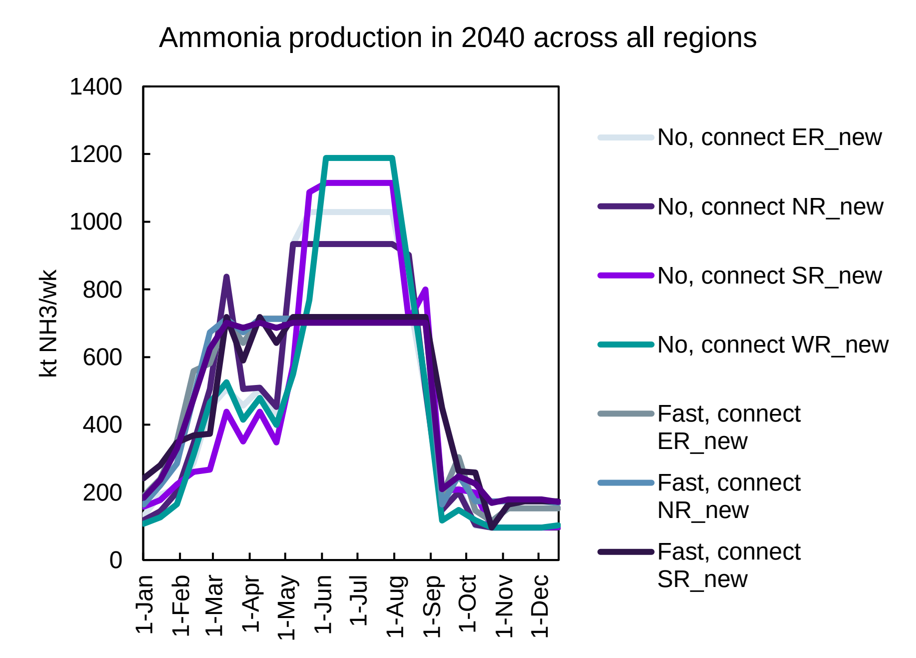
- Assumed HB minimum of 20%
- Most NH3 in Apr-Aug, in tandem with monsoon winds in south and good sun resource in north
- Annual HB utilization is 50-60% in grid connected configuration

Headline results and conclusions

- Islanded plant LCOA in 2050 is 180 USD/t – 380 USD/t

- Grid connecting NH_3 production has many benefits
  - Reduces LCOA and reduces system curtailment
  - Eliminates long-term storage requirements via industrial demand side response – **enables** a wind-solar-battery based system
  - Remaining questions:
    - Is it practical to achieve such a coordinated DSR?
    - How might the policy and market mechanisms work to promote grid connecting?
    - Are there other additional benefits e.g. frequency response?

- Ammonia plants are operated seasonally
  - We assume a minimum load of 20% - however parallel smaller reactors could also achieve this seasonal operation
  - Remaining questions: is this practical to operate plants in this manner?



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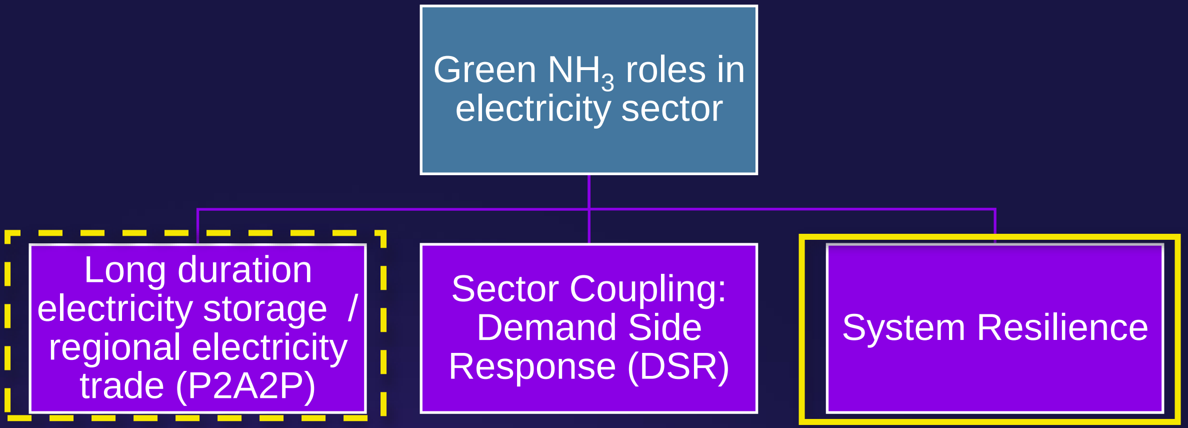
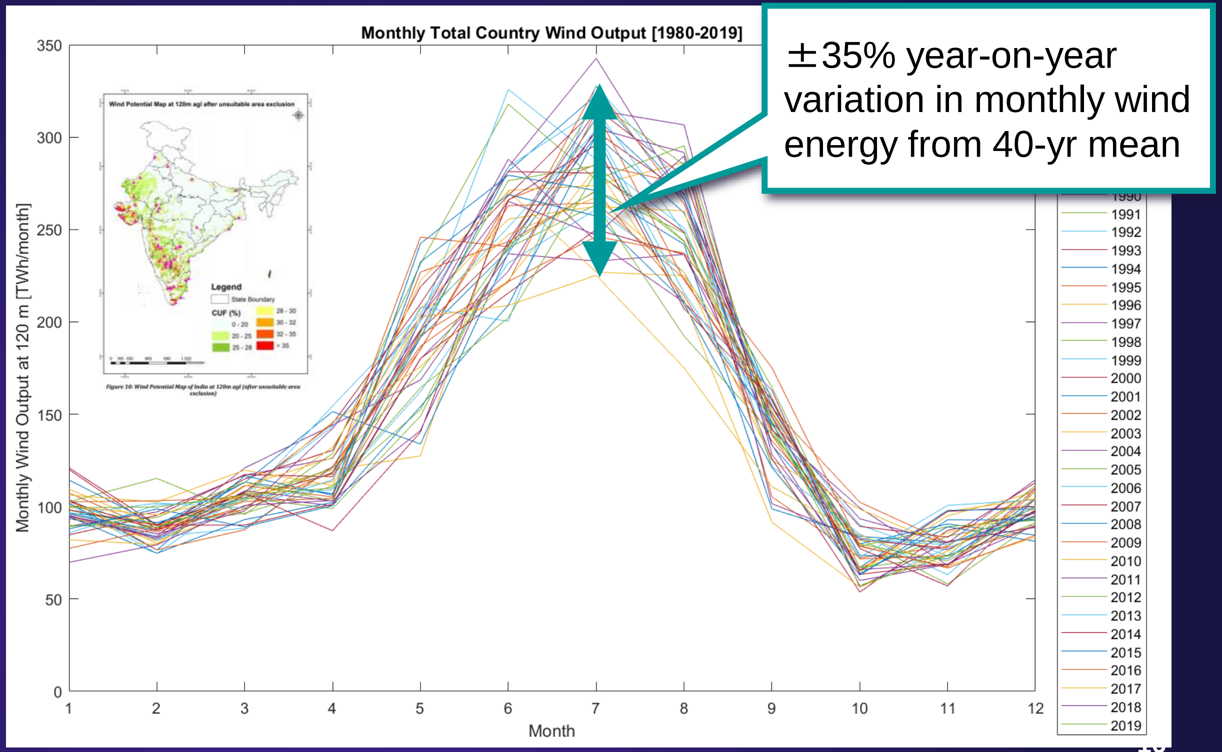
Remaining work

- Ammonia-to-power Gas Turbines are used only in a few scenarios – still exploring
  - Limited transmission expansion scenarios
  - High wind deployment scenarios

- Remaining work: Modelling for System Resilience
  - Interannual variability of wind and solar
  - Resilience to system shocks (e.g. transmission line outage)





Sources: National Institute of Wind Energy (NIWE) Oct 2019, ERA5 Reanalysis data

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Thank you for your attention!

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