ECONOMICS OF ENERGY INNOVATION AND SYSTEM TRANSITION

UNIVERSITY OF OXFORD

'How to accelerate clean energy innovation and system transition in industry (steel/hydrogen): *The risks and opportunities of the India Hydrogen Mission for energy and industry*

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with thanks to Zac Cesaro

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Overview

1. Green hydrogen and ammonia in India

2. Using ROA modelling approaches in a ‘traditional’ energy system model

3. Results and key insights

Part 1: Green hydrogen and ammonia in India

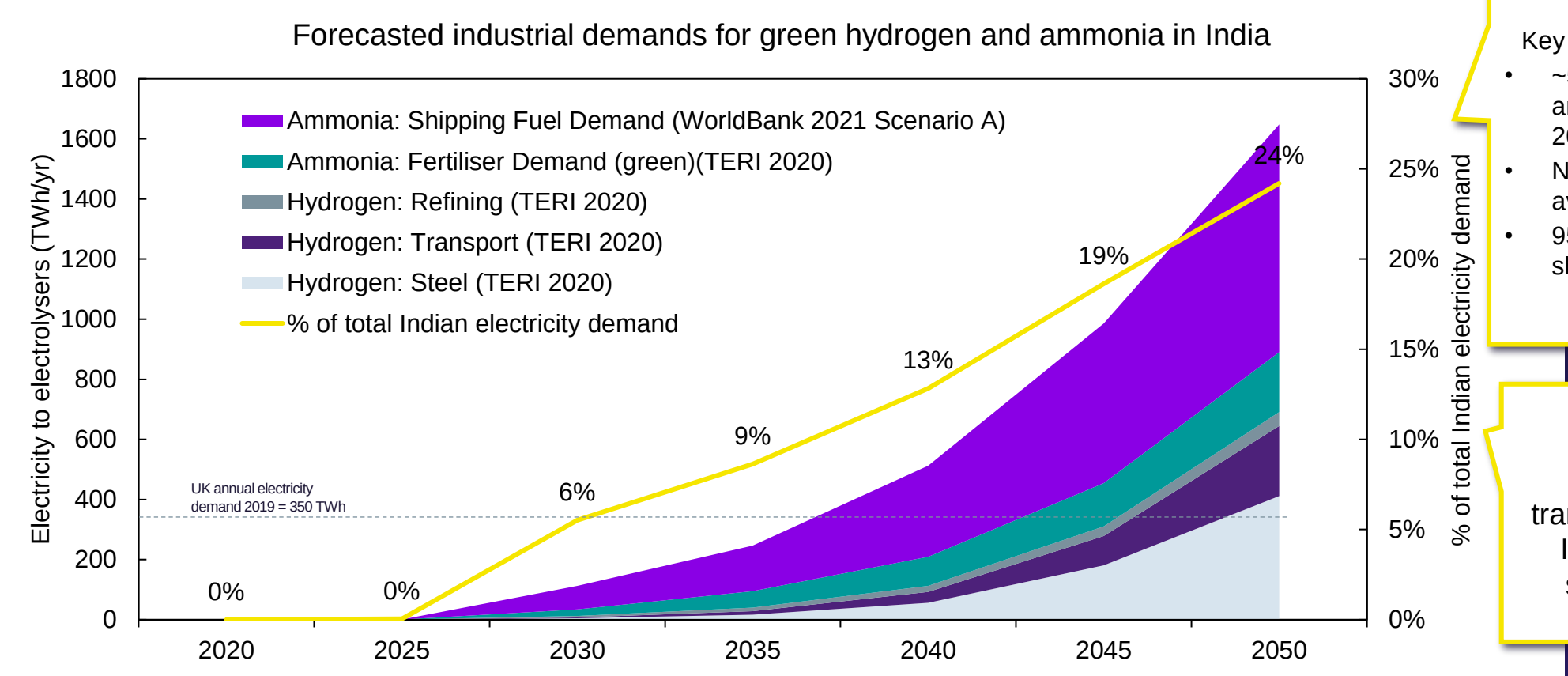
Disruptive changes to the energy system

India announced the *National Hydrogen Mission* (NHM)

- India is the world's largest importer of fossil-fuel based ammonia and imports LNG to make over half of the domestically produced ammonia
- The NHM is designed to accelerate the deployment of hydrogen technology
- And to establish India as a global manufacturing hub for electroylzers and fuel cells
- The intended use of green hydrogen mostly for industry, specifically fertilizer (ammonia), steel, shipping and petrochemicals
  - Draft legislation of refining H2 to be 10%/25% green in 2024/2029 and ammonia fertiliser to be 5%/20% green in 2024/2029 (The Economic Times 2021)

Sources:
- Ministry of New and Renewable Energy: Budget 2021-22 augments Capital of SECI and IREDA to promote development of RE sector. National Hydrogen Mission proposed. publisher: Press Information Bureau (PIB): Government of India (2021). https://pib.gov.in/PressReleasePage.aspx?PRID=1696498 A
- India to Require Refiners, Fertiliser Plants to Use Some Green Hydrogen'. *The Economic Times*. *The Economic Times*, https://economictimes.indiatimes.com/industry/renewables/india-to-require-refiners-fertiliser-plants-to-use-some-green-hydrogen/articleshow/85179977.cms?from=mdr. Accessed 20 Sept. 2021.

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



Key scenarios features:

- ~50% decarb. of steel and fertiliser (TERI 2020)
- Not including H_2 for aviation
- 95 MMTPA NH_3 for shipping (WB 2021)

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

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.*

Part 2: Applying Risk-Opportunity Analysis (ROA) to modelling green hydrogen and ammonia in India

Modelling disruptive change

Applying ROA approaches to modelling hydrogen and ammonia in India

Modelling disruptive change

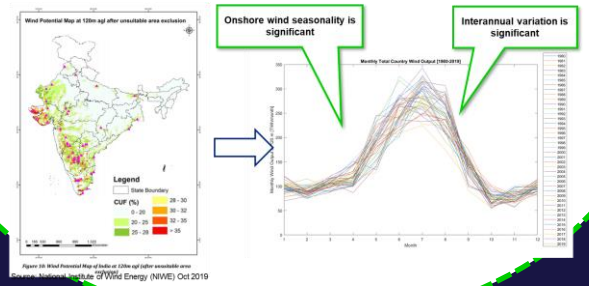
Inclusion of ROA features:

- **Positive feedbacks**: Learning-by-doing cost reductions
- **Complexity modelling**: Network effects of ammonia/hydrogen infrastructure, import and export
- **System resilience** to uncertainty, shocks and tail-end probability events (e.g. Texas cold weather event)
- **Multi-dimensional criteria**: Land-use, energy security, labour effects, coal stranded assets, etc.

Grubb, et al. *The New Economics of Innovation and Transition: Evaluating Opportunities and Risks*. Nov 2021. Available from https://eeist.co.uk/

Methodology: Applying ROA approaches to 'traditional' energy systems modelling to examine the role of H_2 and NH_3

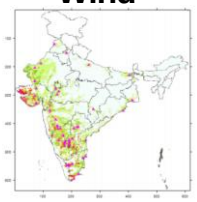
System resilience: Multiple years of wind and solar profiles



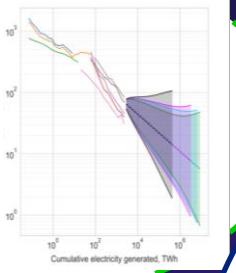
Land-use

Solar

Wind



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*

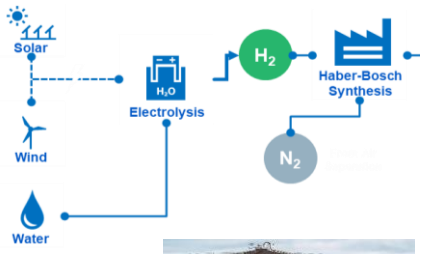
Electricity Supply (Existing, planned, and least cost future)

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



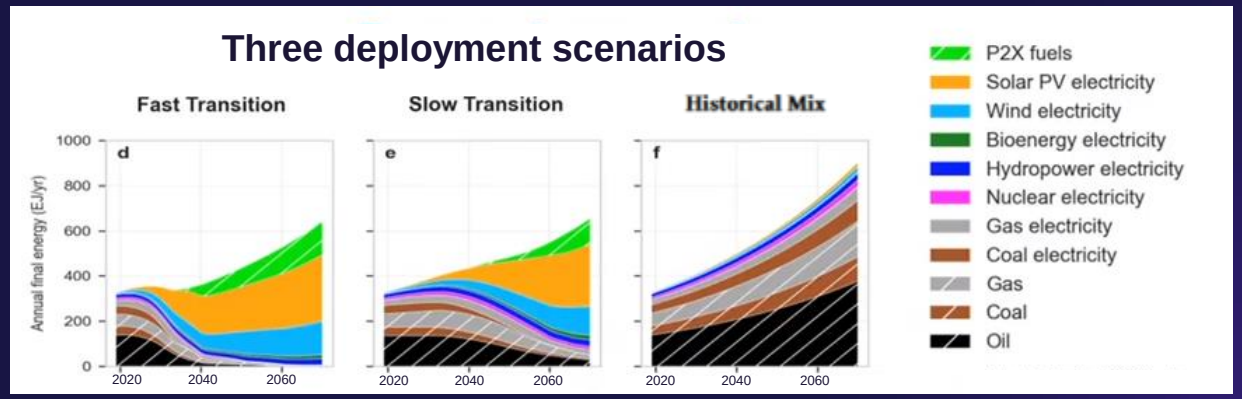
NH_3 Gas turbine

* Way, Rupert, Ives, M., Mealy, P., and J. D. Farmer, "Empirically grounded technology forecasts and the energy transition", 2022, Joule

Part 3: Results and key insights of integrating green hydrogen and ammonia to 2050 in India

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)*

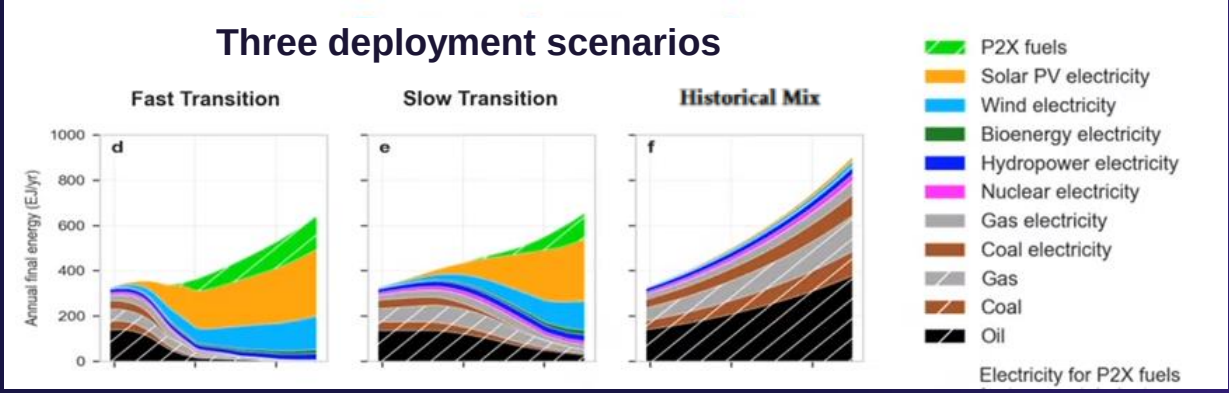
Network effects: Ammonia production based on “islanded” or “grid connected” configuration

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

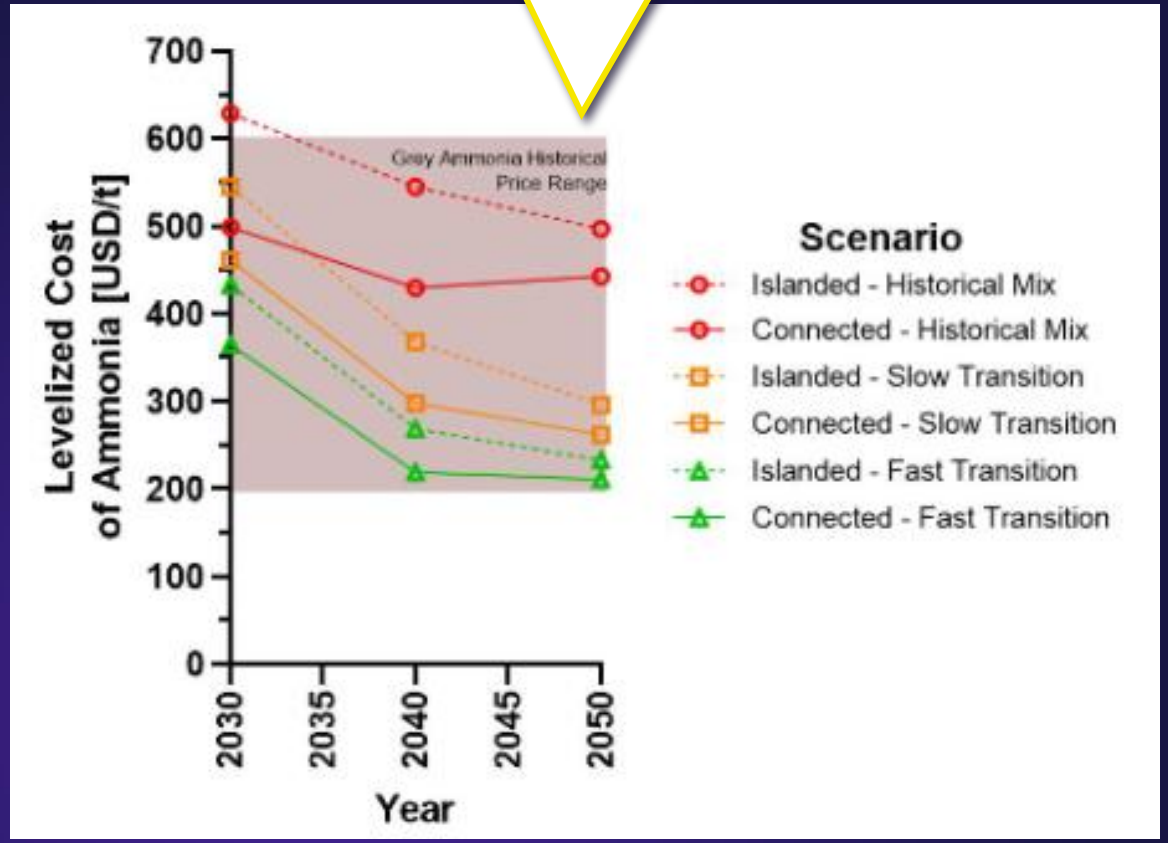
Meng, Jing, Rupert Way, Elena Verdolini, and Laura Diaz Anadon. 2021. “Comparing Expert Elicitation and Model-Based Probabilistic Technology Cost Forecasts for the Energy Transition.” *Proceedings of the National Academy of Sciences* 118(27) (June 29, 2021).

Key result: The risks associated with the National Hydrogen Mission within the range of risks associated with the historical grey ammonia price range

- Historical Mix: A future in which the world keeps the current energy mix (~10% energy from RE in 2050). i.e. does not match India's gamble on RE
  - LCOE of green NH4 at high end of historical range
- Fast Transition: In a future in which the world keeps pace with India (>90% energy from RE in 2050)
  - LCOE of green NH4 at low end of historical range

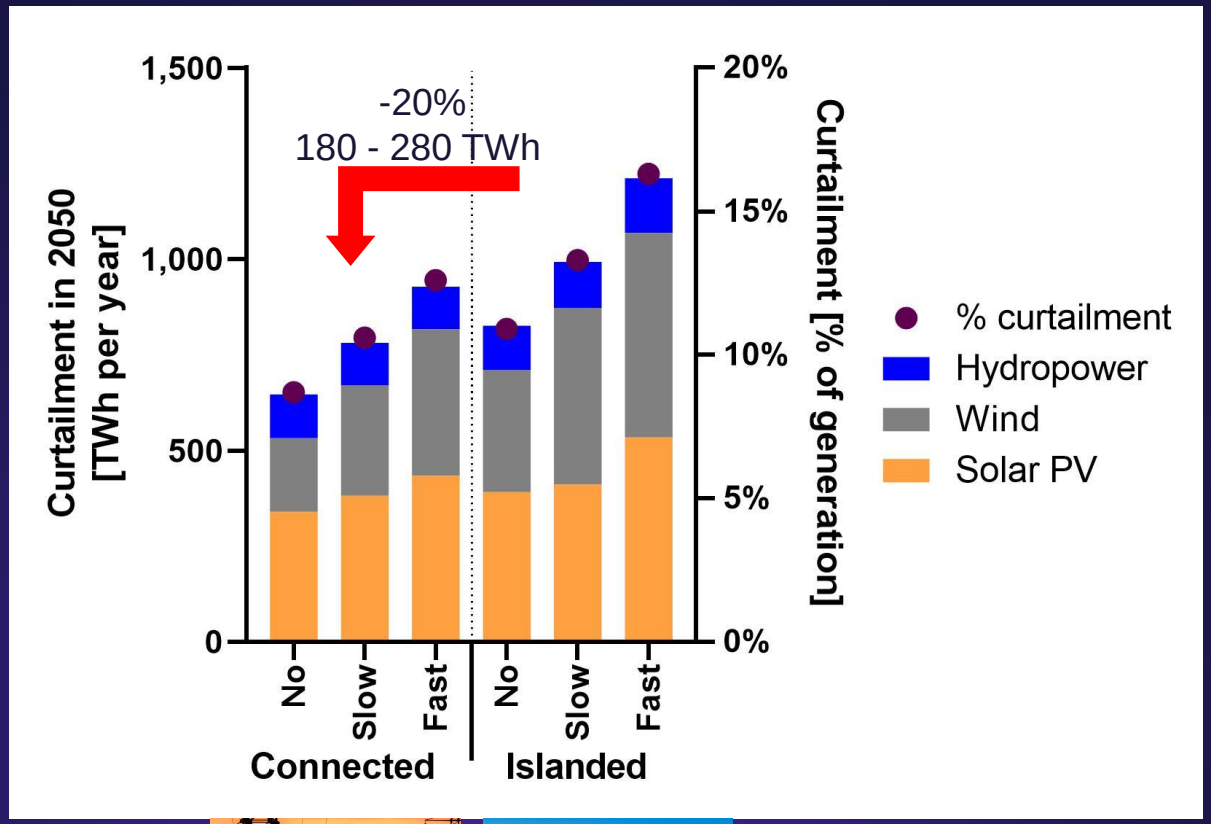


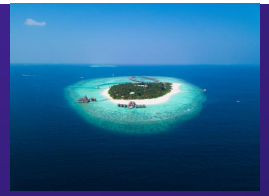
Grey area: Historical price range of grey H2



Key result: Connecting H_2 and NH_3 production is an opportunity for a better system than islanding production off the grid

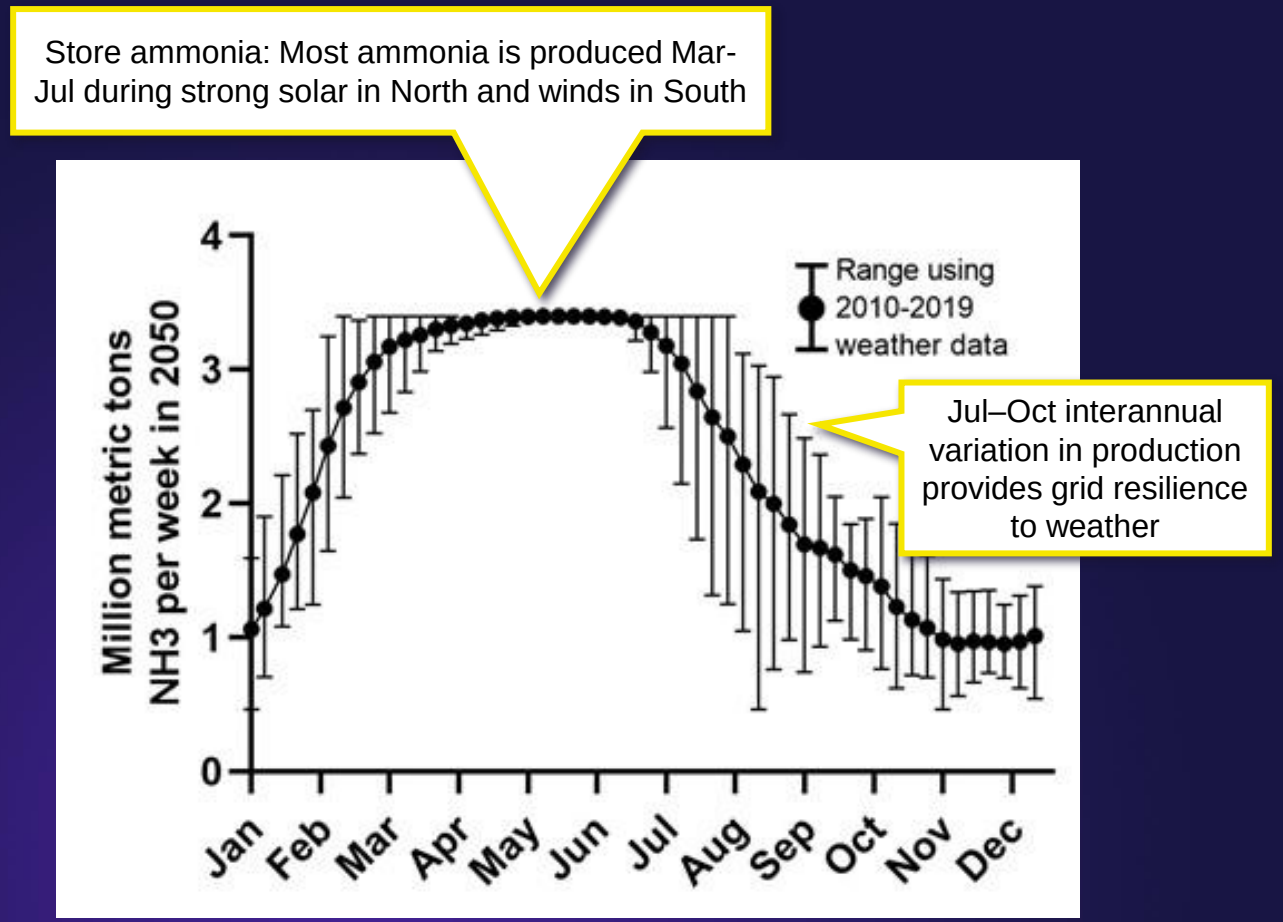
- Curtailment reduced by ~20% in all scenarios (saving 180 - 280 TWh of curtailment across scenarios)
- Reduces Levelized cost of Ammonia (LCOA) by 10-25%
- Reduces total system cost by ~5% across scenarios
- Provides system resilience to seasonal and interannual weather variations





Key result: Green hydrogen stored as ammonia enables a major decarbonisation of India's industry

- Hydrogen and ammonia account for ~25% of grid electricity demand by 2050
- The green hydrogen/ammonia produced supplies:
  - ~50% decarb. of steel and fertiliser (TERI 2020)
  - ~10% of global NH3 demand for shipping (WB 2021)
- Seasonal operation and storage reduces costs by accessing cheap, otherwise curtailed electricity
- Ammonia synthesis companies are building the first 'Agile Haber Bosch' plants today to pair with variable renewables



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