Power-to-X

Concepts and Implications for Market Participants and System Operators

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1. What is Power-to-X?
2. The Energy Transition and the Need for Flexible Resources
3. Challenges to Grid Reliability
4. Challenges to Load Forecasting, Resource Adequacy, and Market Design

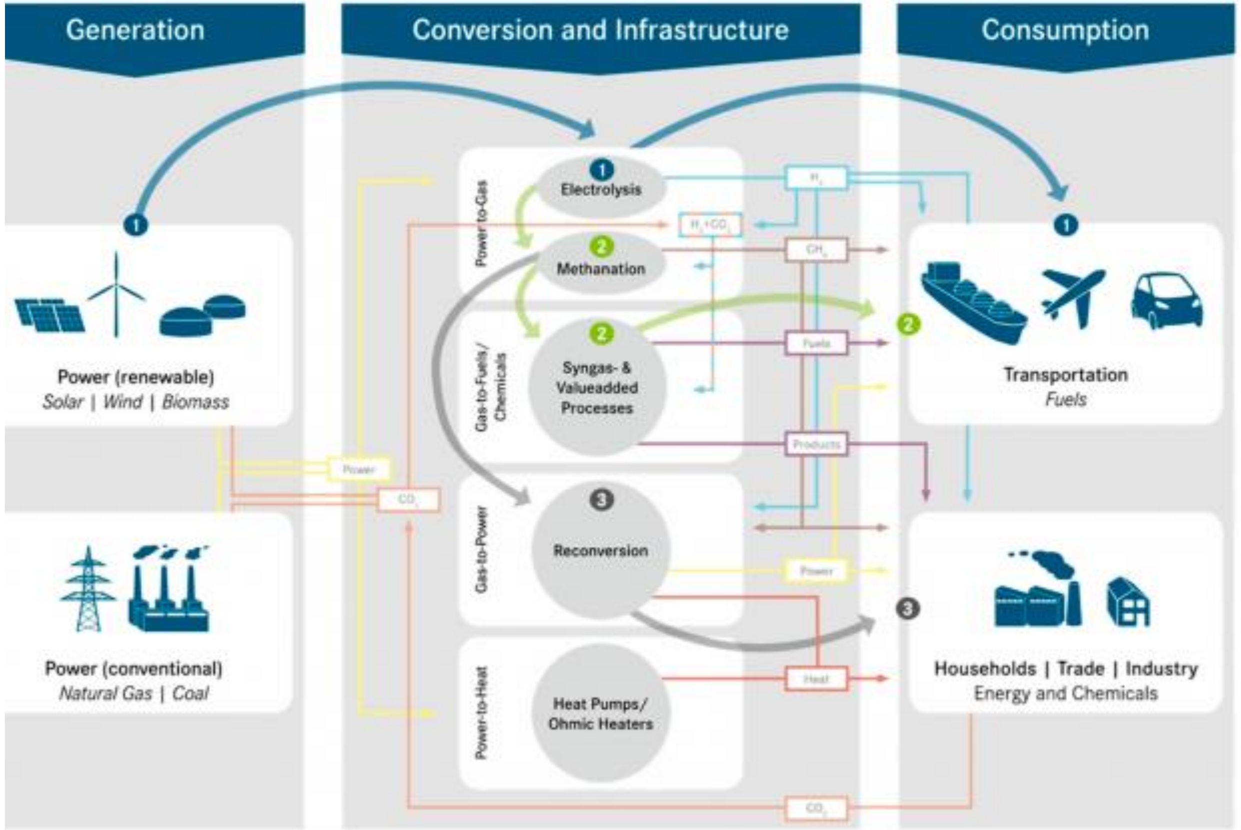
What is Power-to-X?

- "Power-to-X" (P2X) is the generalized concept for using carbon free electricity to produce other things like synthetic fuels such as hydrogen or ammonia

- P2X has the potential to stress the reliability of the bulk power system if it results in large swings in demand over short timescales or increases aggregate demand beyond what the grid can consistently supply.

- If P2X can follow dispatch instructions from the grid, it can improve the reliability of the grid and balance against intermittent generation from renewables

- ERCOT's experience with Large Flexible Load's provides useful insights for the challenges posed by P2X



The Energy Transition & Need for Flexible Resources

How do controllable loads help accelerate the renewables transition?

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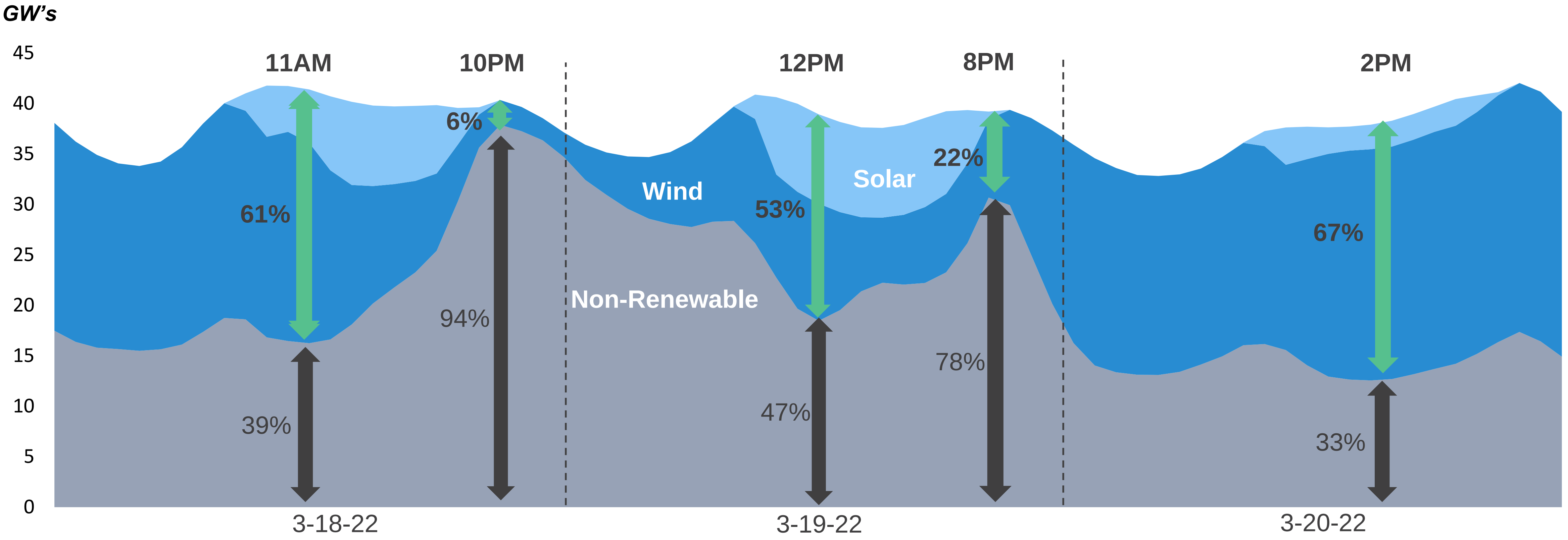
Grid is being challenged to absorb rapid fluctuation in renewable generation

Flexible loads can help balance supply and demand

Hourly Balancing Challenge for ERCOT – March 18, 2022 – March 20, 2022



Batteries and load flexibility can provide short-term balancing throughout the day

Sources: ERCOT

Flexibility in the Grid is Essential to a Net Zero Future

Technological options and solutions for power system flexibility

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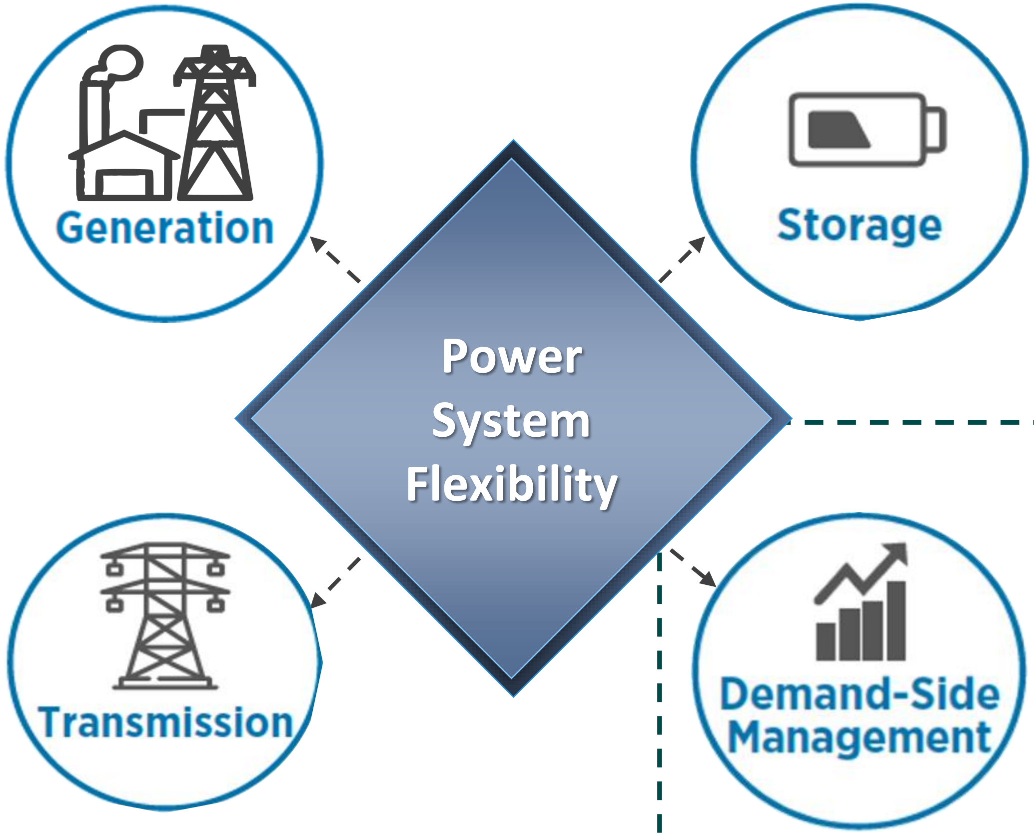
Supply Solutions

Flexibility from Generation

Flexibility from Transmission



Demand Solutions

Flexibility from Storage

- Pumped hydro
- Batteries
- Mechanical storage (ie: flywheel, gravity-based, etc.)

Flexibility from Load

- Demand response from commercial and domestic sectors
- Large scale demand management
- **Lancium is the only load-only controllable load operator in the market**

How flexible are power-to-X loads?

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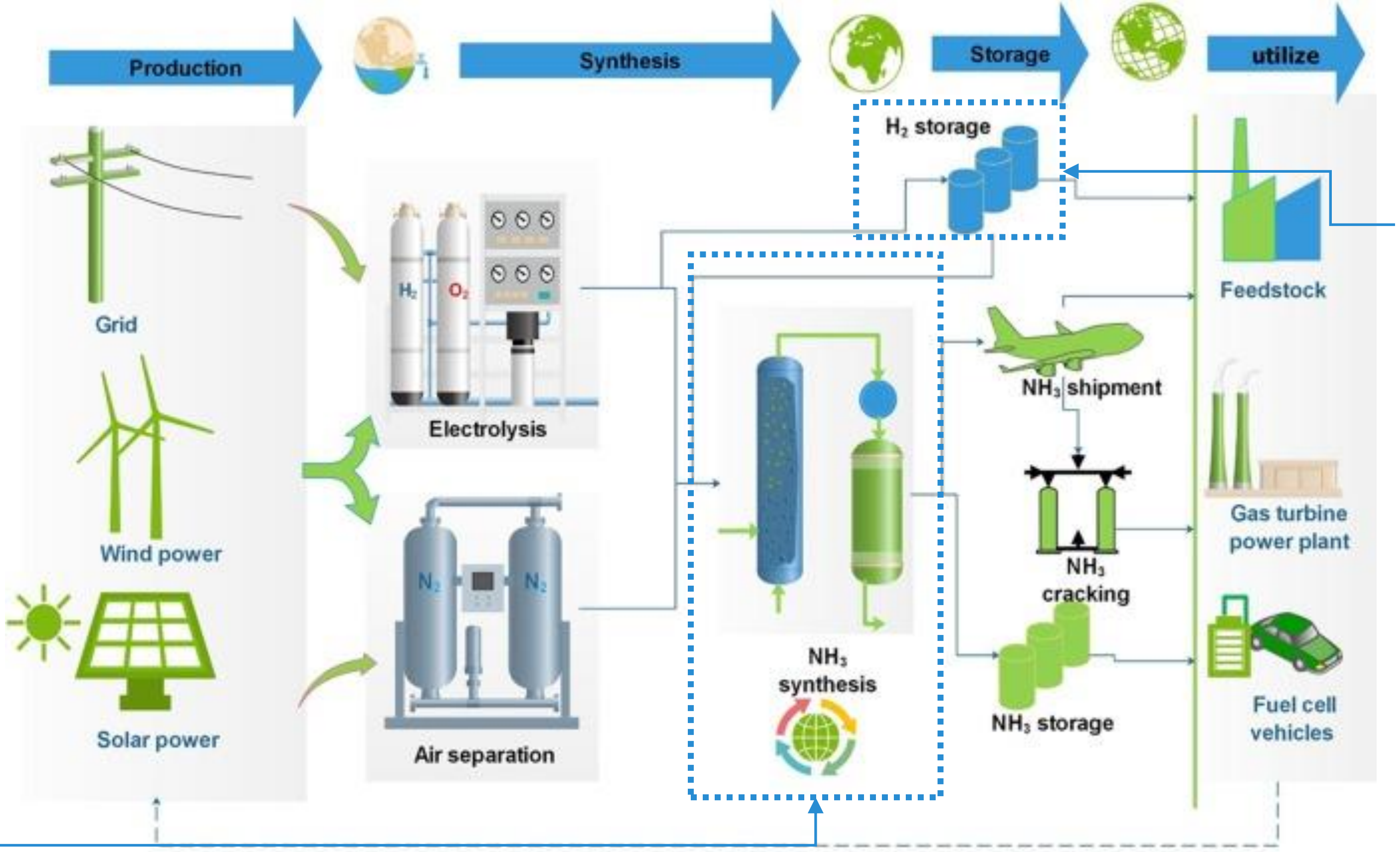
- **Different processes have different operational characteristics, eg, electrolysis is likely to be more flexible than ammonia synthesis**
- **Only a subset of P2X loads are likely to be able to follow real-time base points, ie, demand instructions from the grid**
- **Other loads may be able to follow commitment instructions on a longer time scale, plausibly through a multi-interval SCED. A multi-interval SCED could “re-configure” loads between states with different average load levels similar to switching between configurations of a combined cycle generator**
- **ERCOT currently requires Controllable Load Resources (CLRs) to be able to provide Primary Frequency Response similar to generators, limiting the extent to which P2X loads that can operate as CLRs.**
  - There are proposals to implement a non-PFR category of CLR that receives dispatch instructions from SCED but can’t provide (all) ancillary services. Tradeoffs between market design and reliability
  - Mixed workload resources may have portions of their load that are frequency responses and others that aren’t, ie, electrolysis vs. ammonia synthesis

P2X loads vary in how quickly they can adjust their demand



Hydrogen storage can be used to maintain ammonia synthesis when electrolyzer load is curtailed

Ammonia synthesis is a thermal process that can't ramp as quickly as electrolysis

Image source: Chahade and Dincer 2021

Challenges to grid reliability posed by P2X

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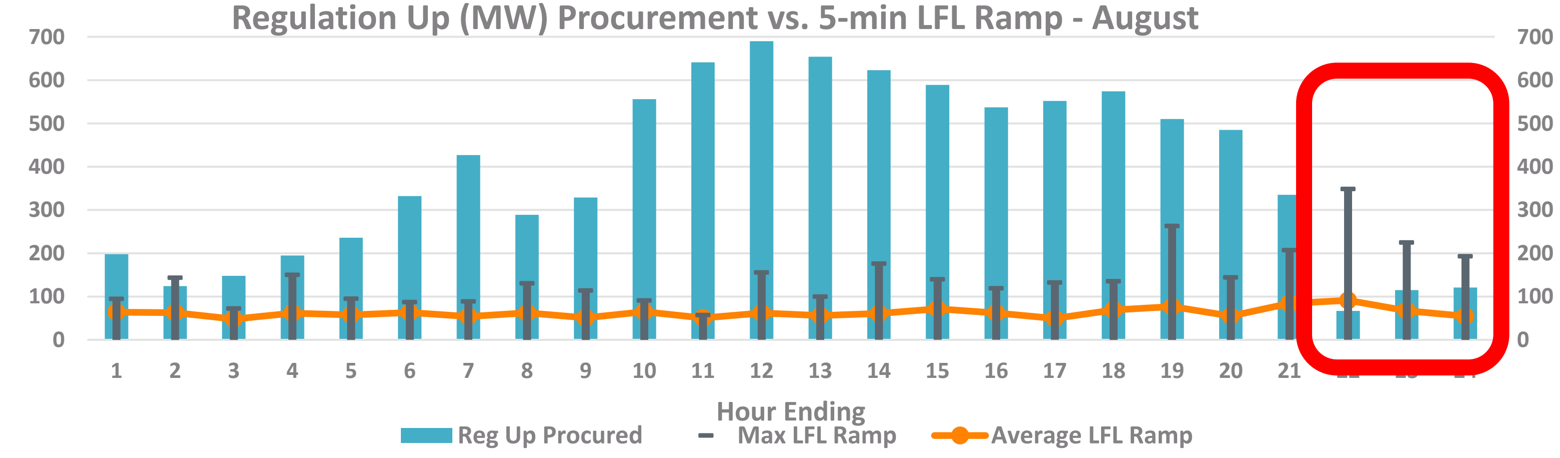
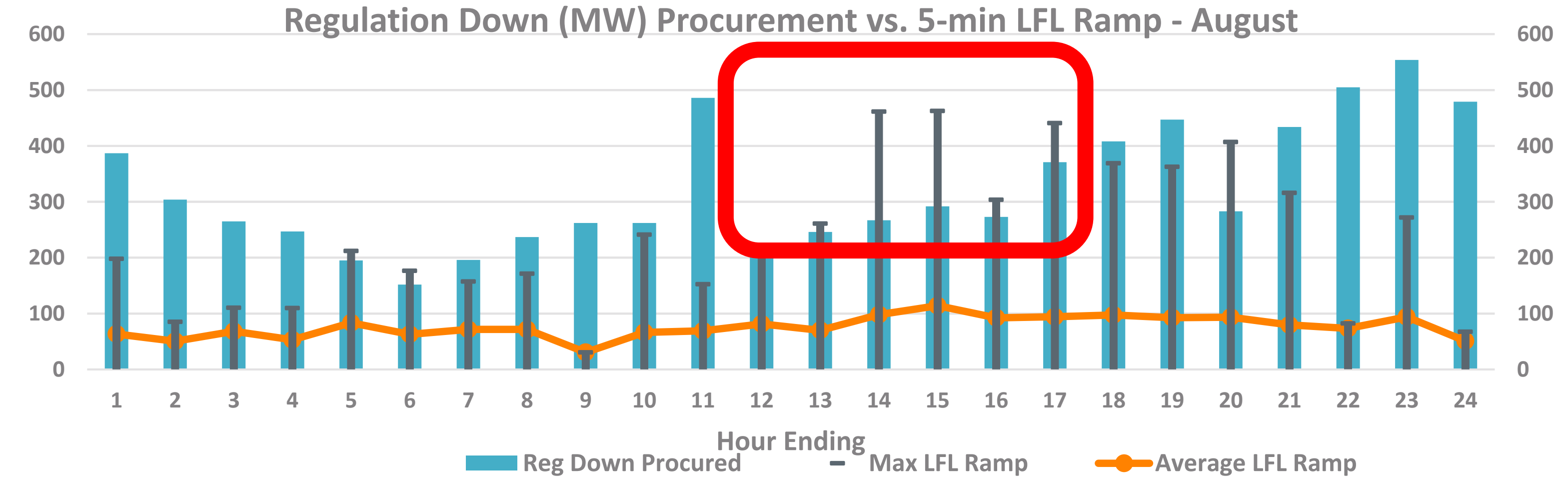
Challenges to Grid Reliability Posed by P2X

- **Rapid decreases in load can cause over-frequency, congestion, and voltage stability issues**
- **To this point, grid reliability has mainly focused on challenges associated with generation outages, ie, most of the quantity of ancillary services is for UP reserves**
- **Examples**
  - Ramp rates – P2X loads might quickly reduce their power consumption due to their inherent operating characteristics or in response to electricity prices. If they ramp more quickly than the dispatch signal from the grid, the imbalance has to be made up through frequency regulation
  - Voltage ride-through (VRT) – many loads are designed to shut off in response to voltage deviations to protect equipment
- **How can grid operators manage these challenges?**
  - Ramp rate restrictions or voltage ride-through requirements may be feasible for some loads, but they are physically impossible for many other loads (eg, steel arc furnace) and may be outside of an ISO's legal jurisdiction to impose
  - Alternative solutions may be increased procurement of down regulation or adding more voltage support for the grid in areas experiencing voltage instability, but how much and who pays for it?

ERCOT has been tracking the ramping behavior of Large Flexible Loads (LFLs)

Aggregate Data for August 2023 (Source: Neel, ERCOT)





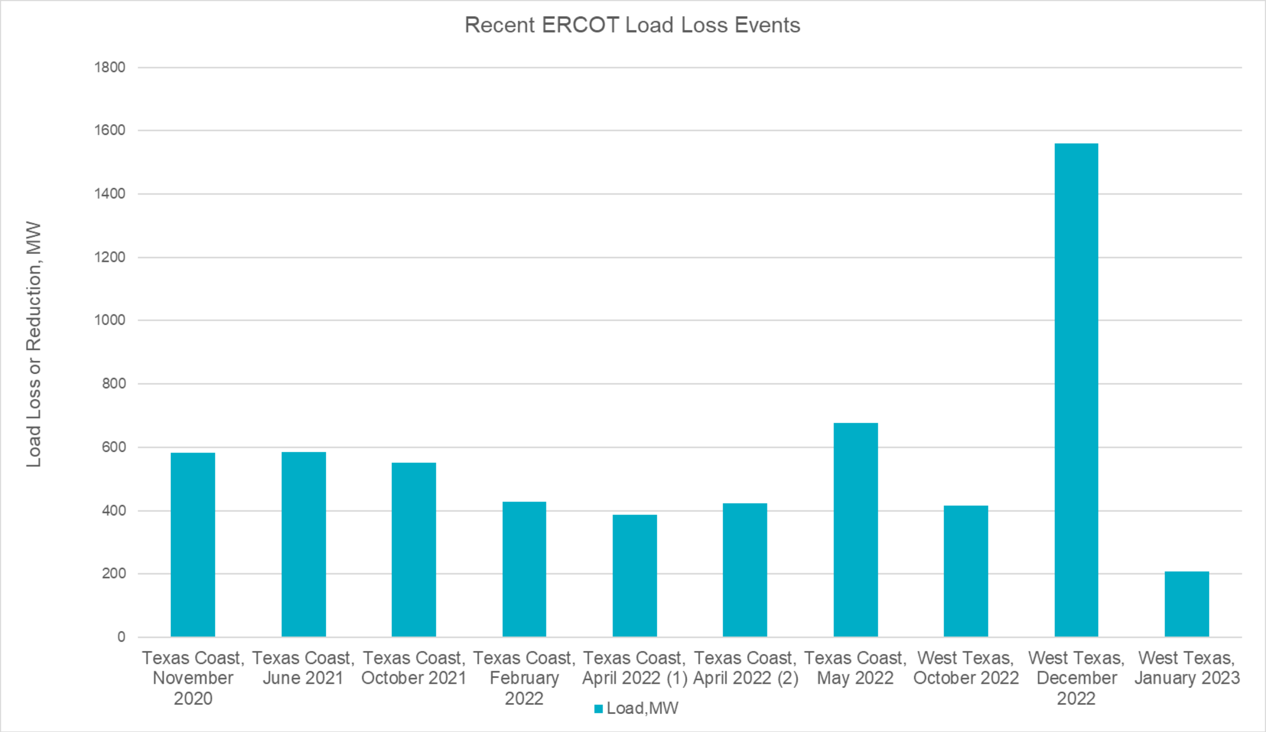
- **Large Flexible Load (LFL) up-ramp in the late evening already exceeds current regulation-up procurement.**
- **HE 22 has seen up-ramps 4x greater than currently procured reg-up.**
- **Early afternoon (HE 12 – 17) has seen down-ramps in excess of available reg-down.**
- **Current operations could potentially exacerbate the need to procure additional regulation services at a higher expense to the system.**

The ERCOT system has experienced multiple VRT events that caused loads to drop out due to a voltage depression

Source: Billo, ERCOT

Largest load loss event to-date:

- Multiple faults on 138 kV lines near Odessa at 3:50 AM on December 7, 2022
- Reduction in load of ~1,600 MW
- Load reduction included mix of LFLs, oil/gas load, and other industrial loads
- Two thermal generators tripped during the event, totaling 112 MW
- System frequency spiked to 60.235 Hz



The pros and cons of large loads

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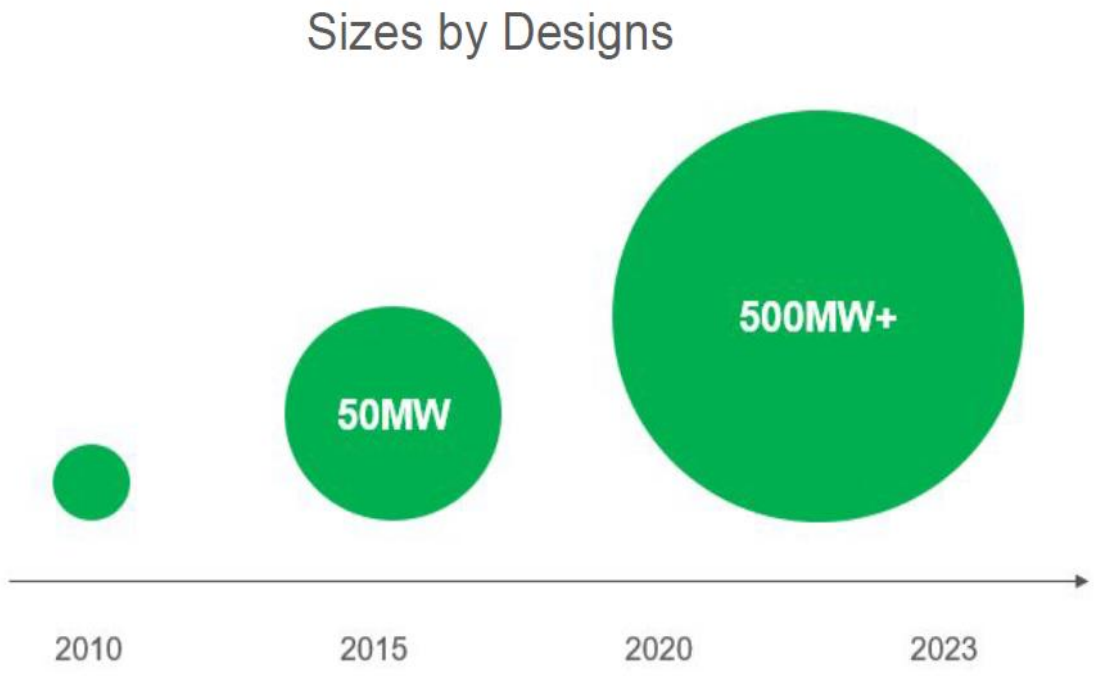
- Larger loads have the benefits of economies of scale, particularly with regard to balance of plant such as transmission, water, etc, but they may come at the cost of increased reliability concerns from the perspective of the grid
- P2X projects are being announced with scales ranging from 100s MWs to 10s GWs
- Such large projects may need to be integrated with generation capacity, ie, microgrids, similar to “private use network” (PUN) concept in ERCOT



Data centers keep getting bigger

P2X projects are being announced with scales ranging from 100s MWs to 10s GWs

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HIF Global gets green light to build world's largest e-fuels facility in Texas — with 1.8GW of green hydrogen production

Environmental permit means construction can go ahead in 2024 on plant that will produce enough e-gasoline to decarbonise 400,000 petrol cars

25 April 2023 15:37 GMT *UPDATED 25 April 2023 15:37 GMT*

By Leigh Collins

European Energy takes control of 3,600MW solar hydrogen project in Australia

By NS Energy Staff Writer 16 Dec 2022

POWER CLEAN TECHNOLOGY PLANT

The Pacific solar hydrogen project aims to produce more than 100,000 tonnes of green hydrogen per annum, using renewable electricity that could power 1.5 million households

P2X projects are being announced with scales ranging from 100s MWs to 10s GWs

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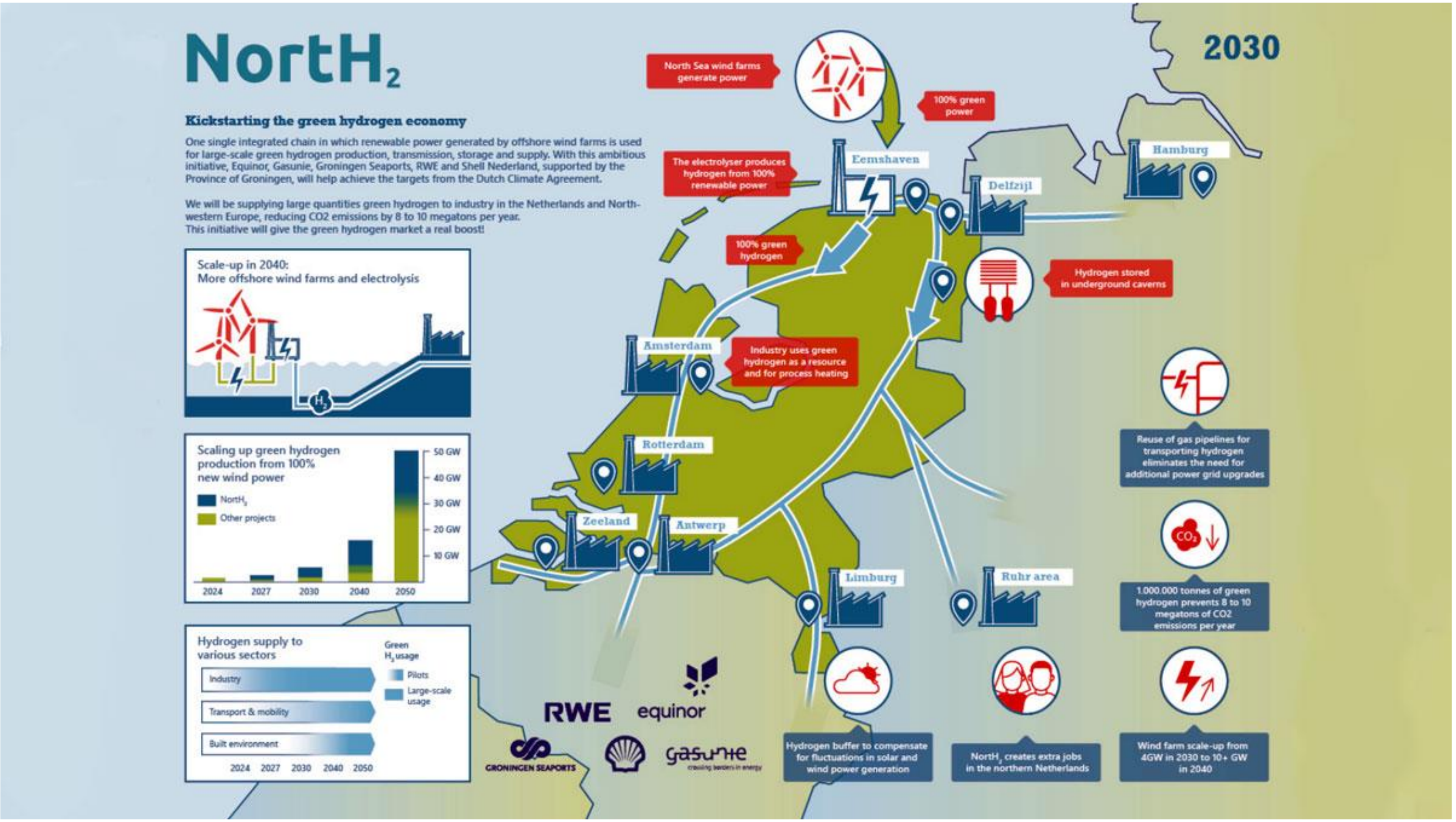

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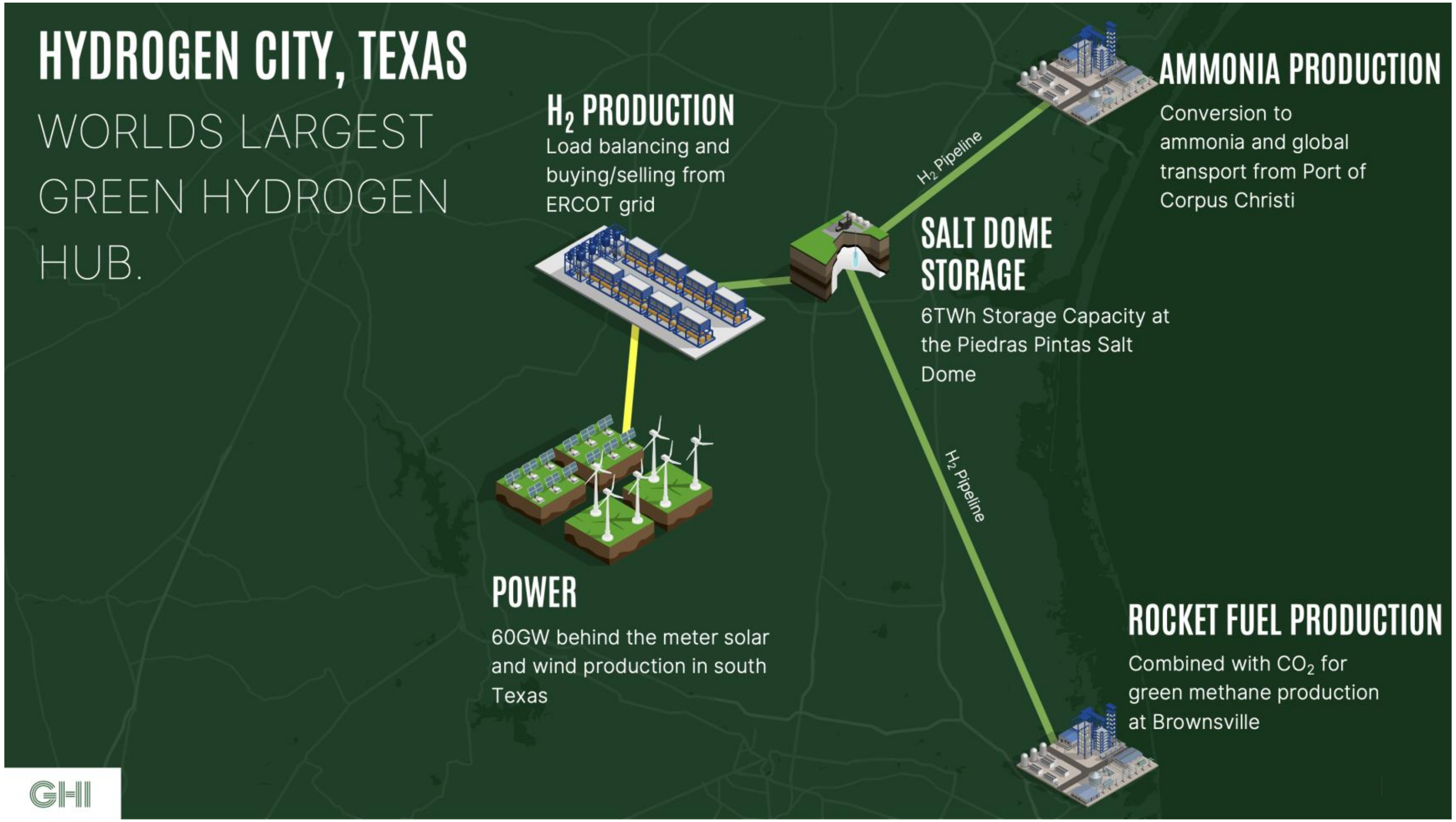

Challenges to load forecasting, resource adequacy, and market design

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How should P2X be evaluated with respect to load forecasting?

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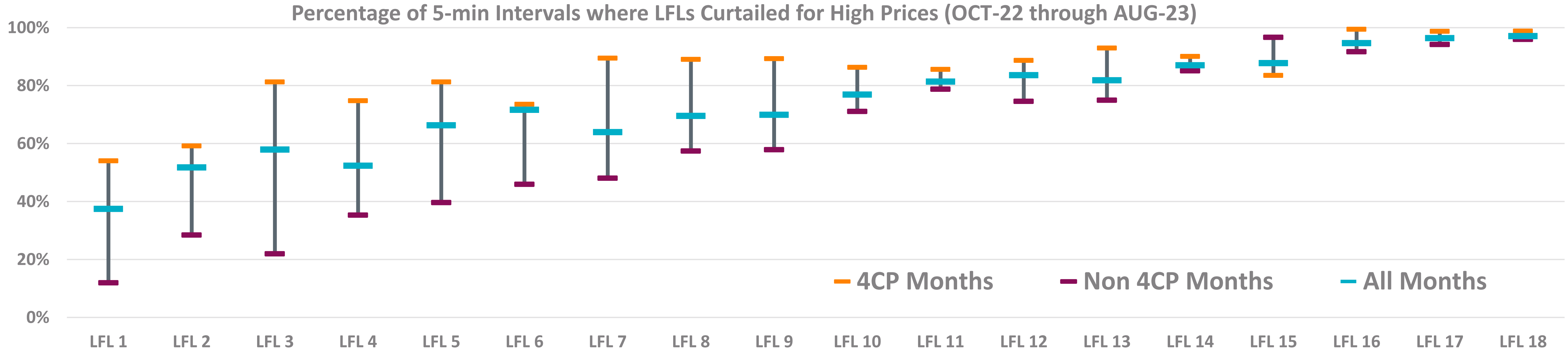
Unlike generators, which are homogenous in their output (ie, electricity) and generally have verifiable input costs, P2X loads have heterogenous outputs, making their economics are less straightforward

- Different end products (H2, NH3, etc) might have different contracted or spot prices that are hard to validate, and the price load pays for electricity influences demand to the extent that loads are price responsive
- Contracted deliveries may impact price responsiveness
- Load projects may have ability to adjust output of different end products, which influences both their physical and economic operating parameters



Source: Neel, ERCOT

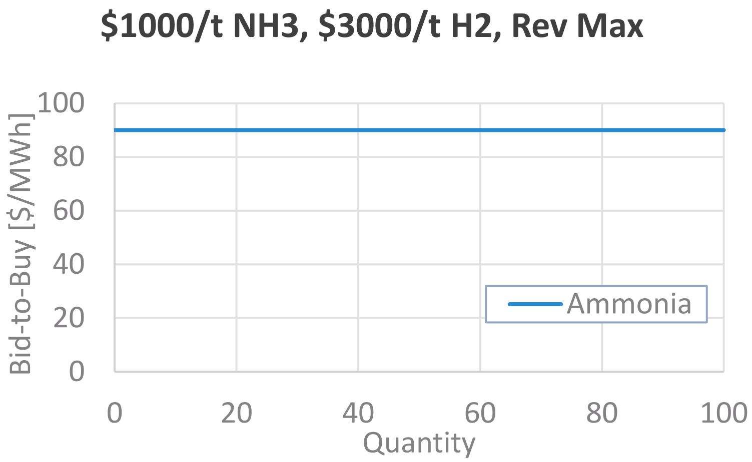
Break-even price is a function of the price of X and energy intensity

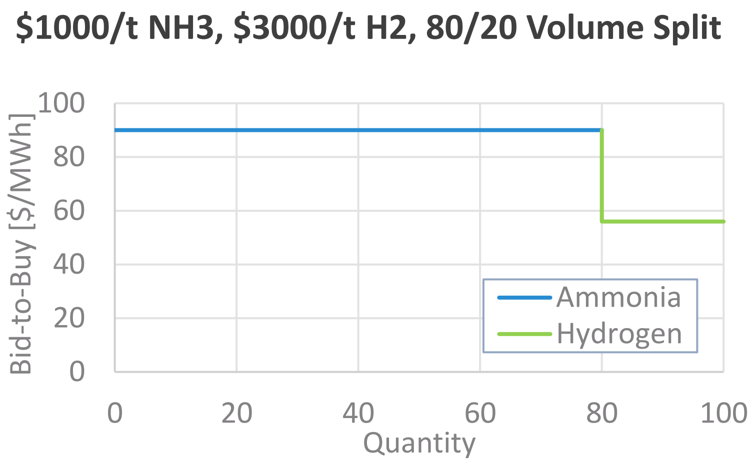
Ammonia

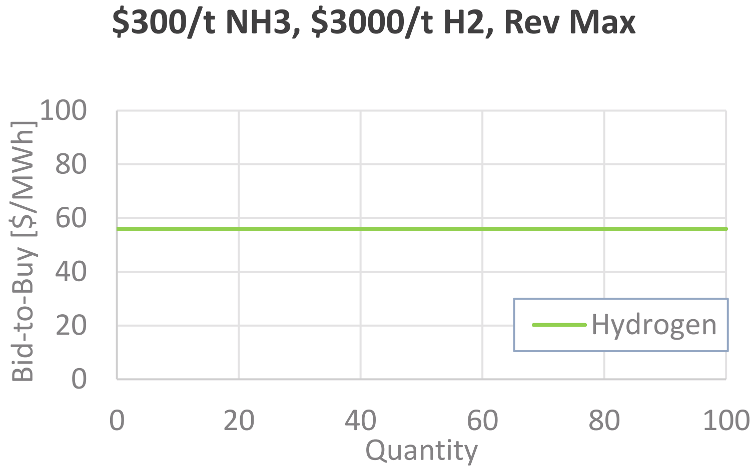
- 11 MWh/t NH_3
- \$1000/t NH_3 -> \$90/MWh, \$300/t NH_3 -> \$27/MWh

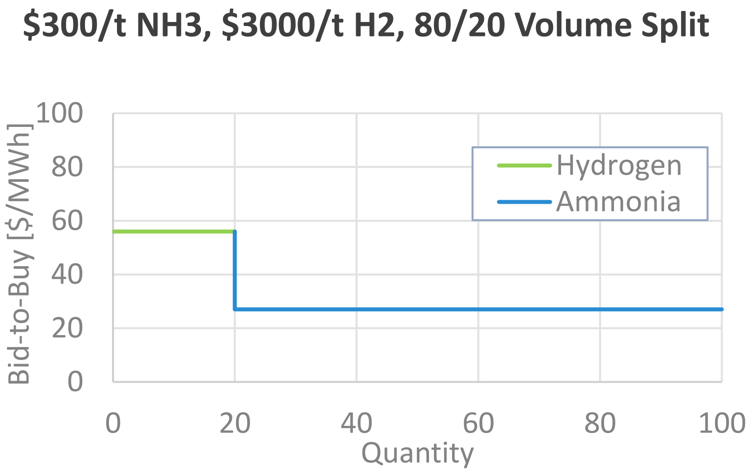
Hydrogen

- 53 MWh/t H_2
- \$3000/t H_2 -> \$56/MWh









The locational paradox

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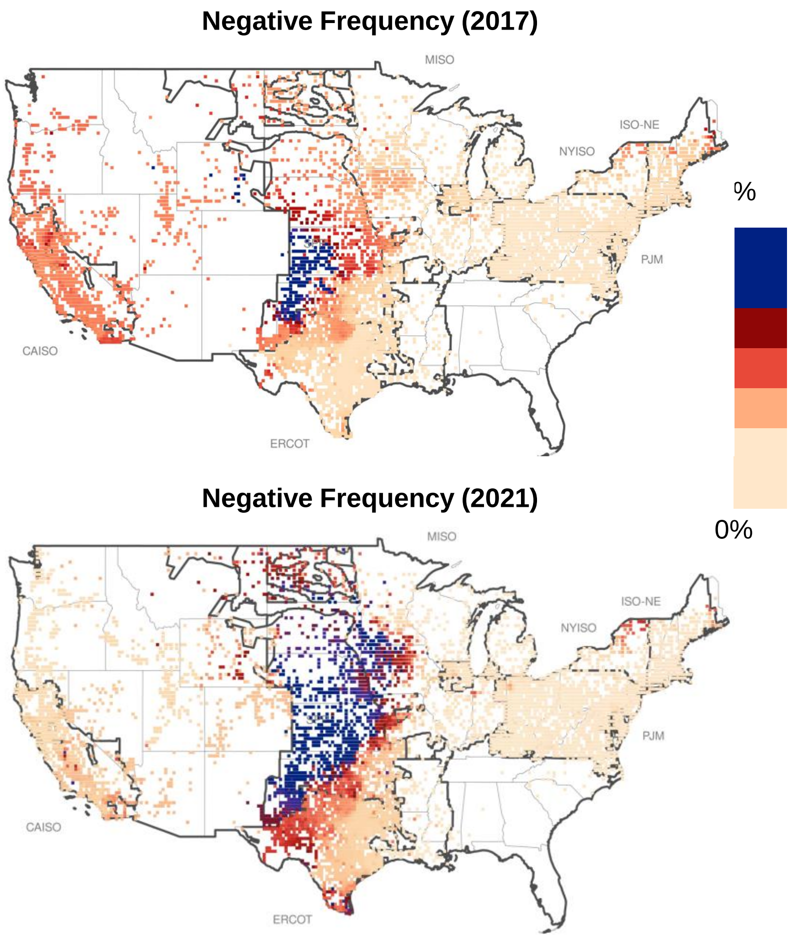
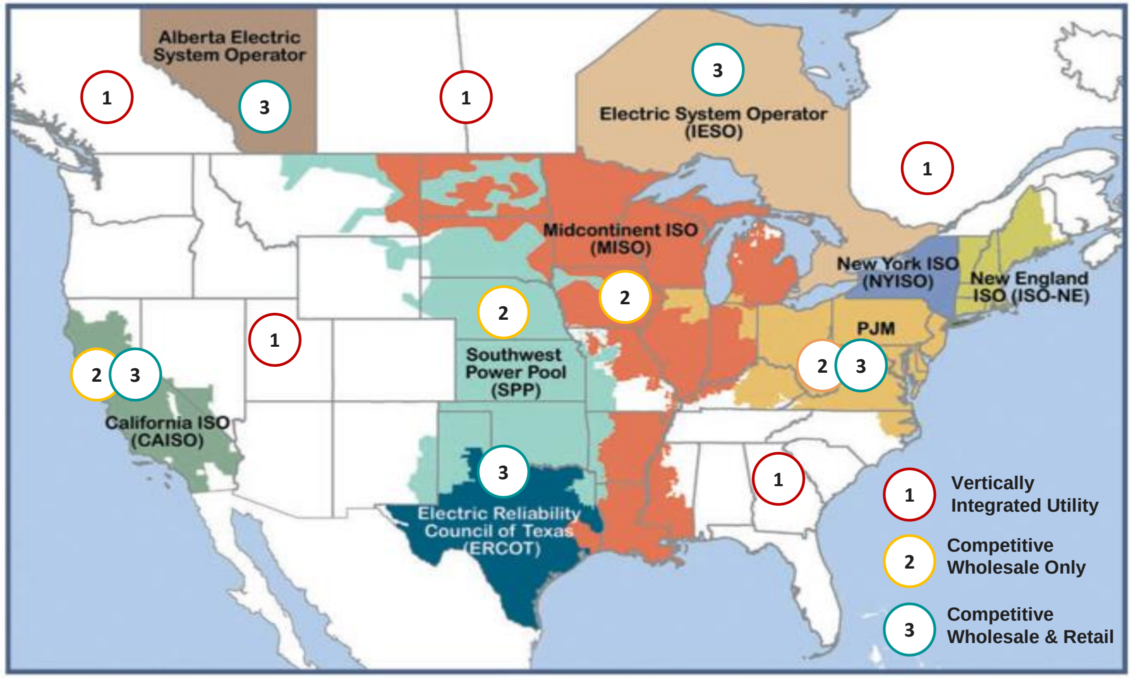
- **With nodal pricing, CLRs are incentivized to site in areas with the most favorable LMPs, which are generally far from population centers or other load centers (eg, Gulf Coast petrochemical complexes), meaning they are generally further away from customers**
- **For P2X loads, transportation can be a substantial component of the cost of getting their production to market, ie, there are tradeoffs between the cost of electricity and transportation**
- **At the same time, these low-priced nodes are often in the less built out sections of the grid, making them more susceptible to voltage stability or congestion issues**
- **Nodes with low historical LMPs may need significant transmission upgrades for new interconnections**
- **Many nodes with favorable wholesale nodal prices are in regulated retail markets where their ability to respond to price signals is less valuable**
    - Fixed rates with no/limited exposure to the wholesale market
    - IOUs need to file rate case for new rate structures
    - Co-ops, non-profit by definition, have little incentive to enter novel commercial agreements that could incur additional costs to their other owner-customers



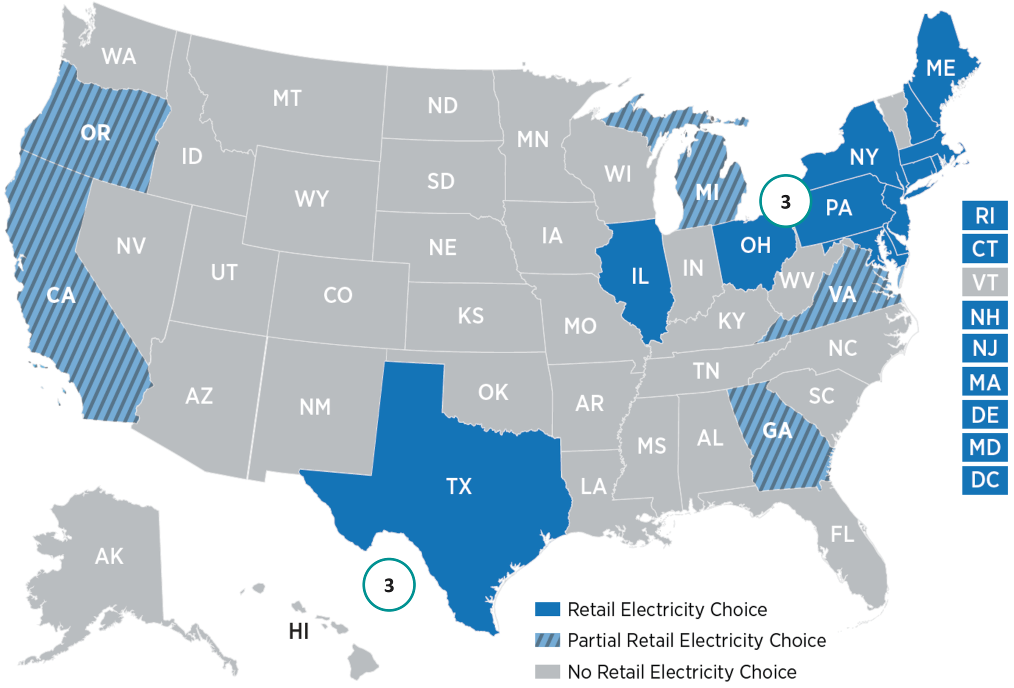
U.S Electricity Markets – Wholesale vs. Retail

Regulated vs Deregulated Markets

Wholesale Electricity Markets



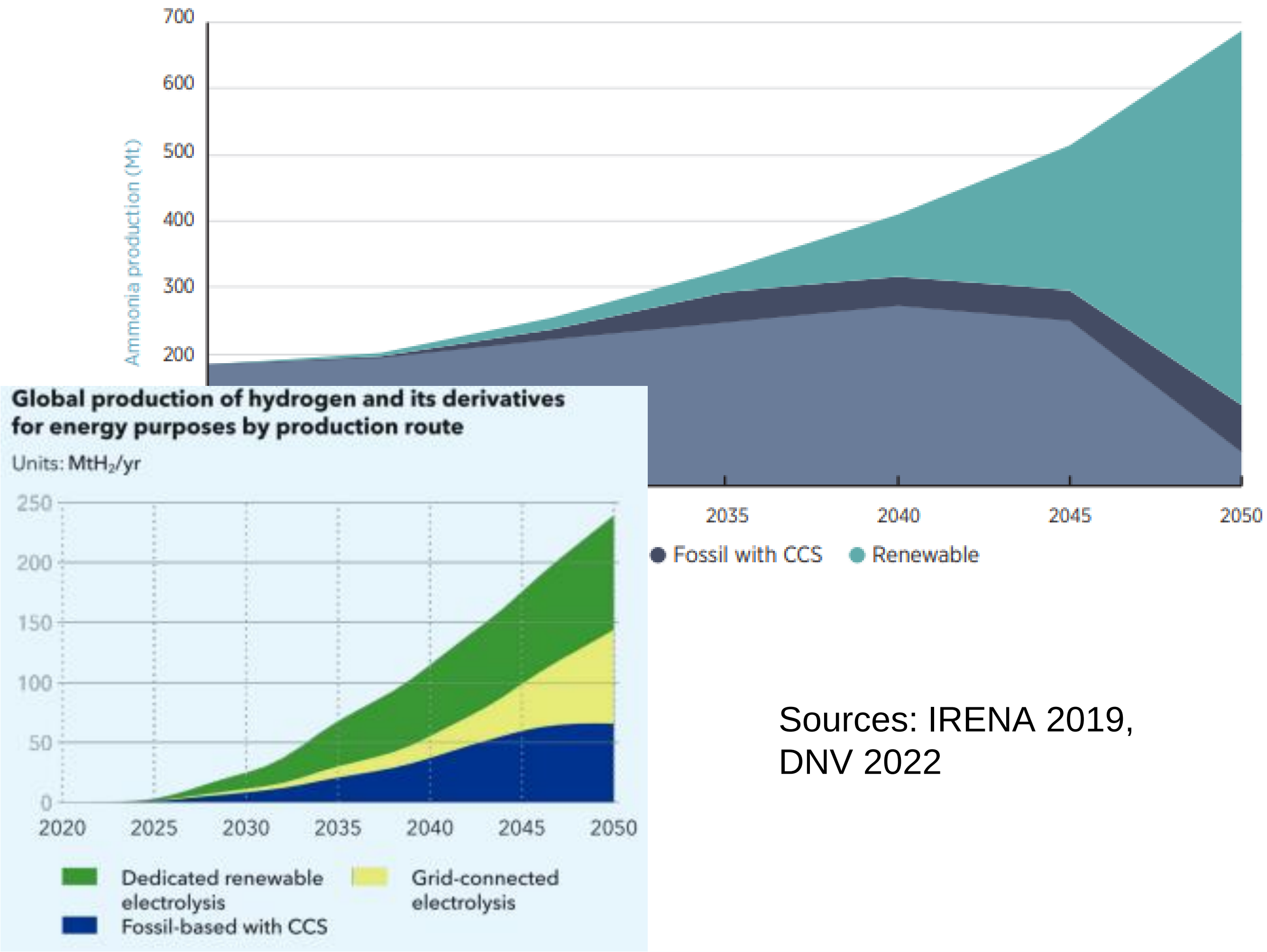
Retail Choice Electricity Markets



Flexible loads can best monetize their resource flexibility in (1) competitive wholesale markets and (2) competitive retail markets where they are free to choose their energy supplier and earn revenue from providing Ancillary Services

How should P2X be evaluated with respect to Resource Adequacy?

- **Conventional resource adequacy methodology is ill equipped to account for contribution of P2X to peak demand or annual energy consumption (see price responsiveness)**
  - Conventional RA methodology finds equilibrium based on exogeneous demand inputs and cost of generation (fuel prices, CAPEX, etc)
  - Feedback loop between demand for P2X, new generation, and clearing price for electricity
- **Forecasted reserves drive market design decisions, especially in capacity markets, but also in energy-only markets**
  - How much capacity is procured in a forward capacity market?
  - How does P2X affect ELCC?
  - How should ERCOT's ORDC or PCM be implemented/modified to ensure sufficient revenue in the market to cover CONE?
  - How much revenue should come from energy vs. capacity-type payments?
  - ISOs should seek to model P2X loads on the basis of production cost modeling to the extent possible



Sources: IRENA 2019, DNV 2022

Conclusions

- Power-to-X has the potential to challenge power systems in terms of physical reliability and electricity market design
- Challenges notwithstanding, more flexible P2X loads can be part of the solution to integrating more intermittent renewables into the grid
- Many of these challenges will be difficult to manage without considering new methodologies for forecasting resource adequacy, transmission planning, cost recovery, and more