Maintaining Reliability Throughout the Energy Transition

100% Renewables? Not So Fast

Wind, Solar, Hydro and Batteries

- If we cannot control dispatch we do not have a reliable solution
  - Cannot control cloud coverage, droughts, or windspeed
- Batteries do not generate energy; they store excess for later consumption

- Energy markets have to be in equilibrium in real-time
  - What is Area Control Area?
  - What is Effective Load Carrying Capabilty

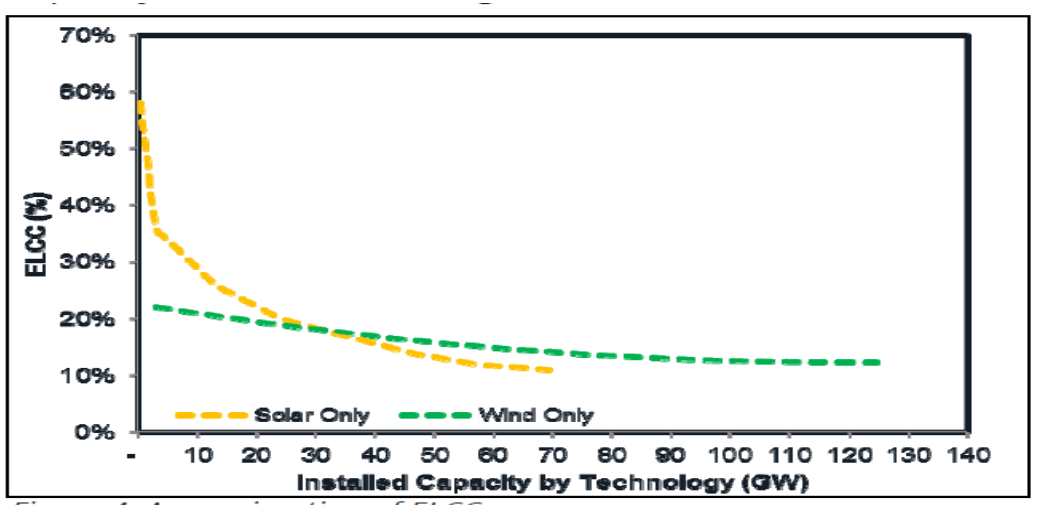
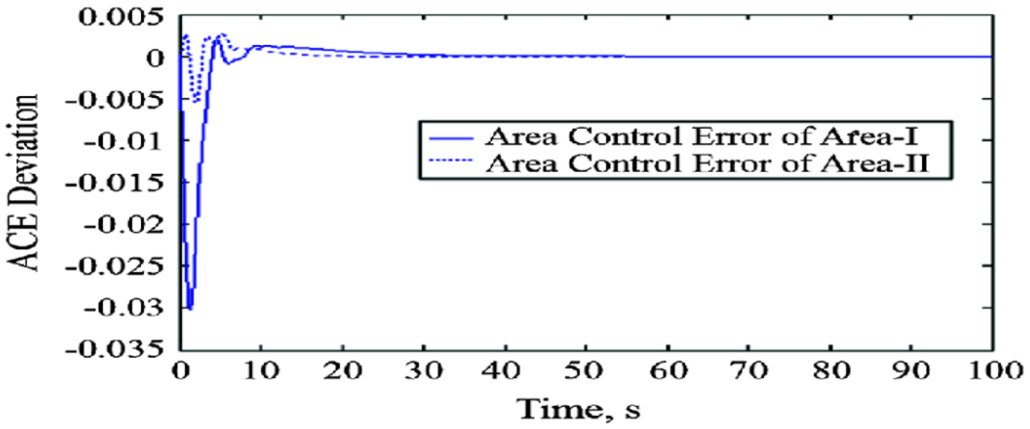
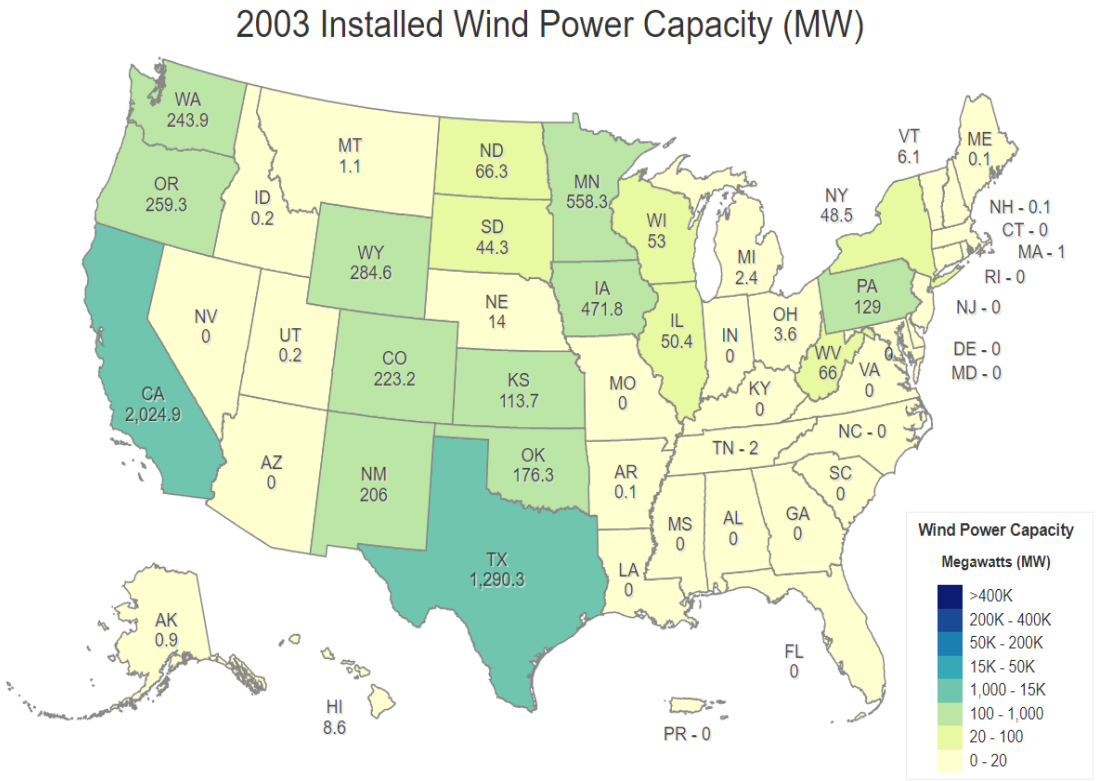


Figure 4: Approximation of ELCC

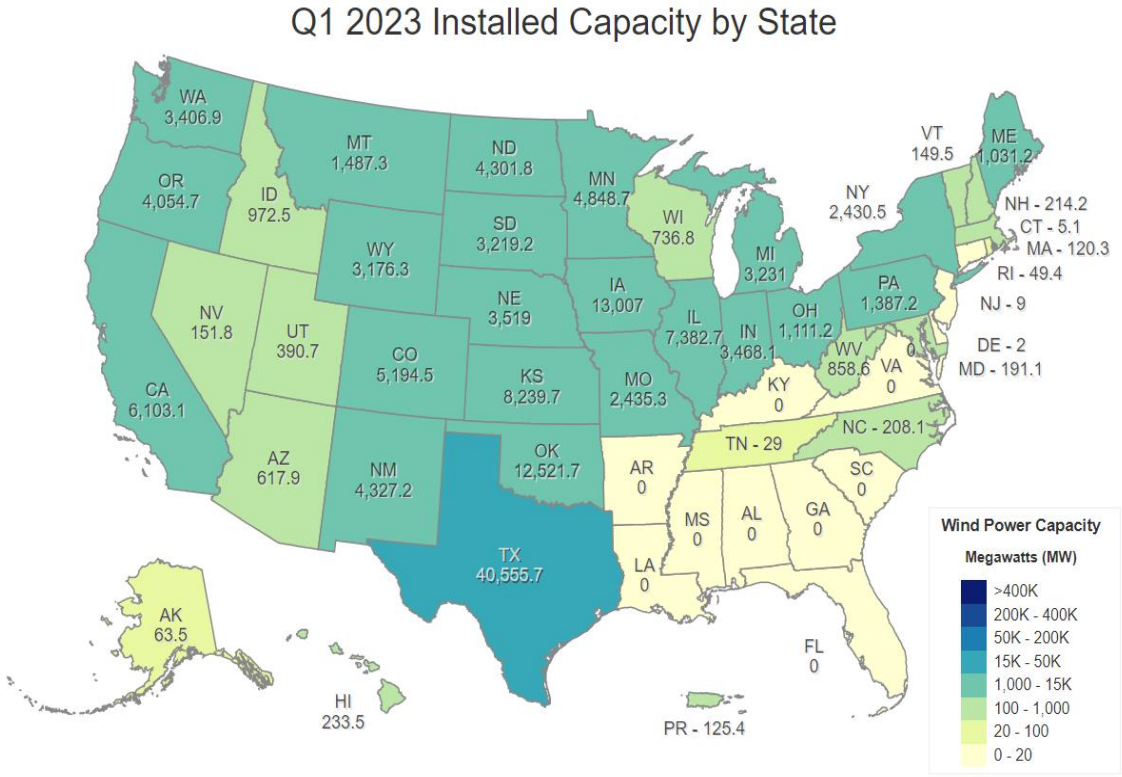


Weather is a Major Primary Mover



Total Installed Wind Capacity: 6,350 MW

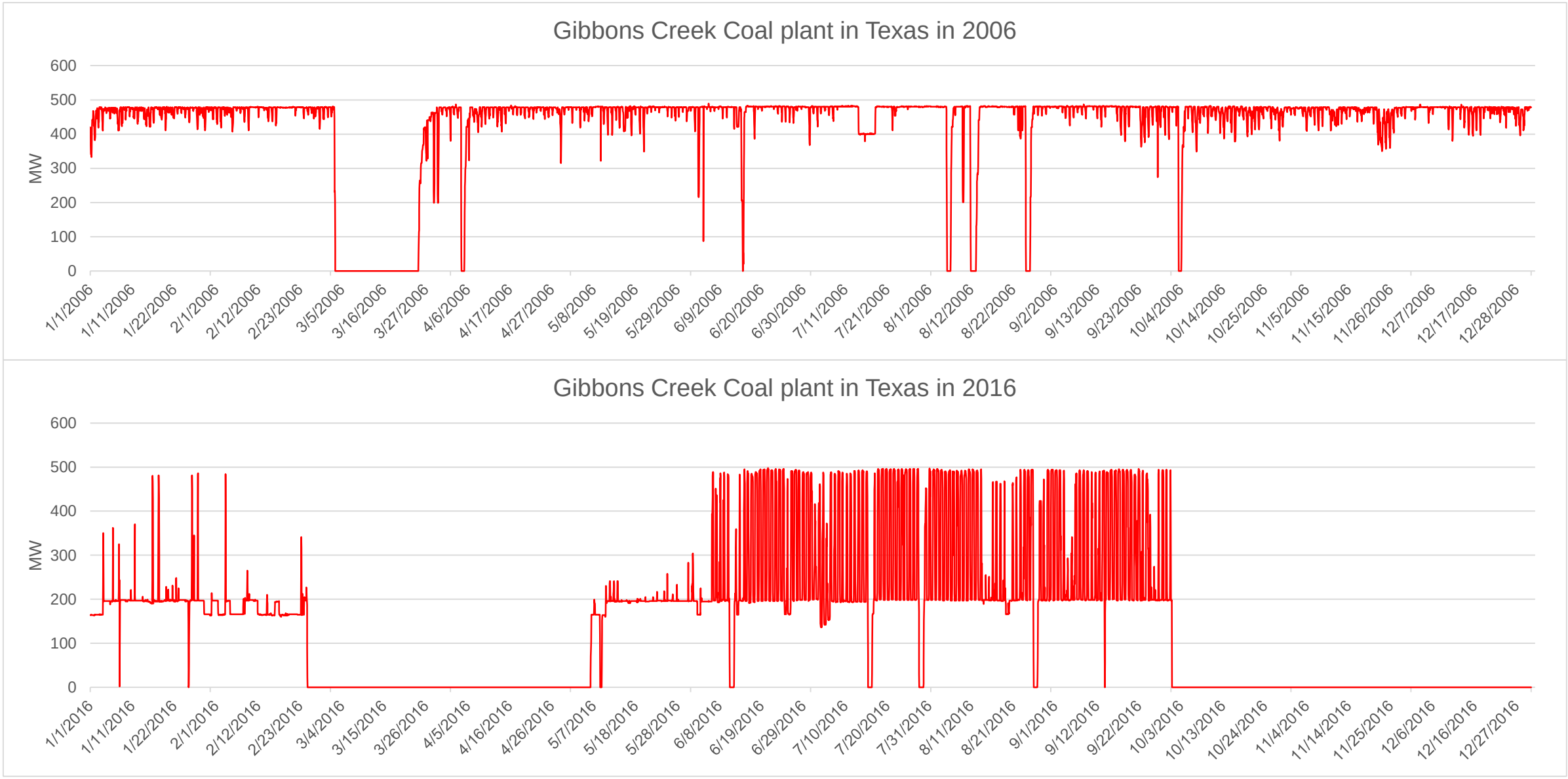
Source: Global Energy Concepts (DNV-GEC) database



Total Installed Wind Capacity: 145,569 MW

Source: American Clean Power Association

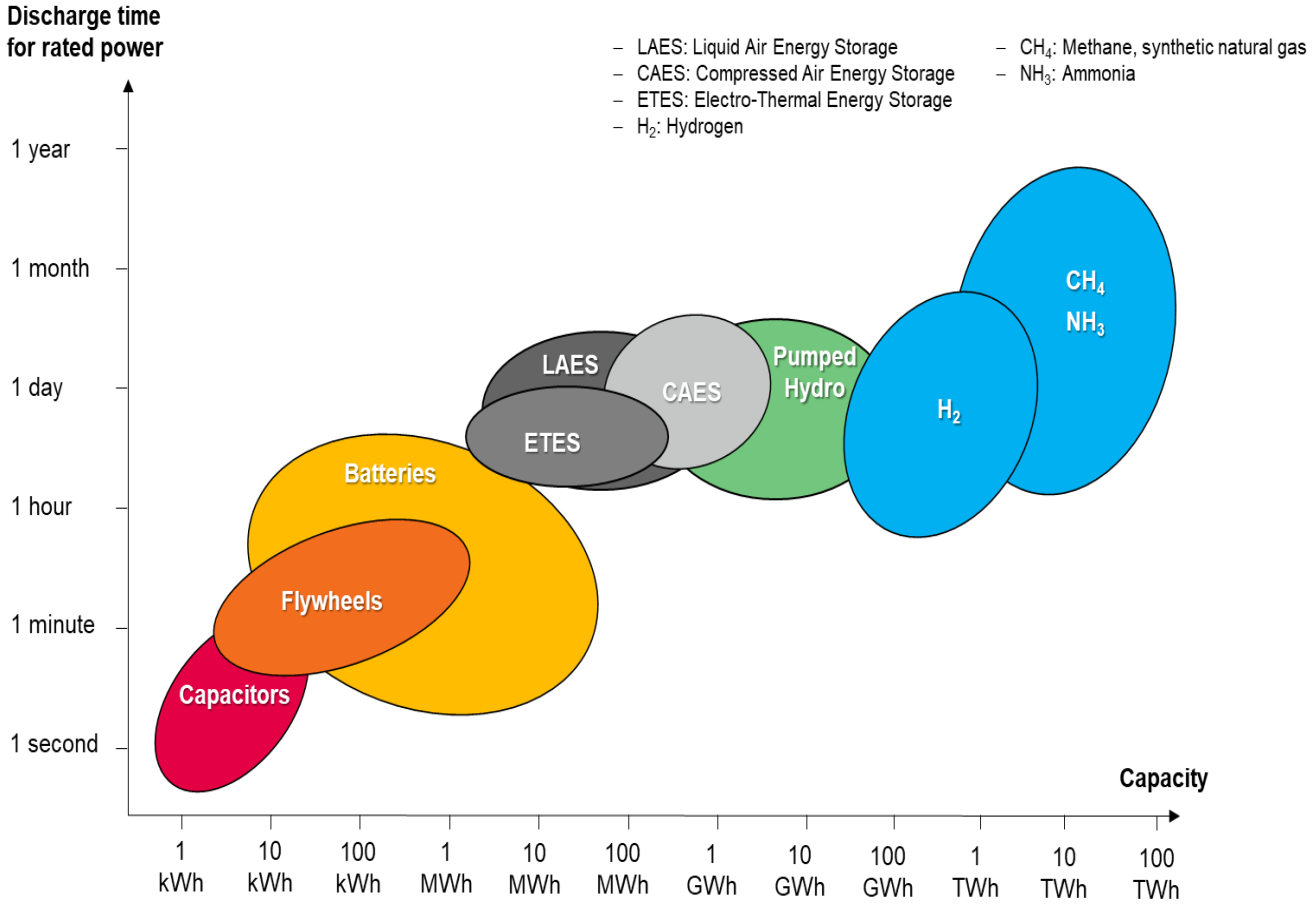
Impact of High Renewable Penetration on Legacy Assets



Energy Storage at a Glance

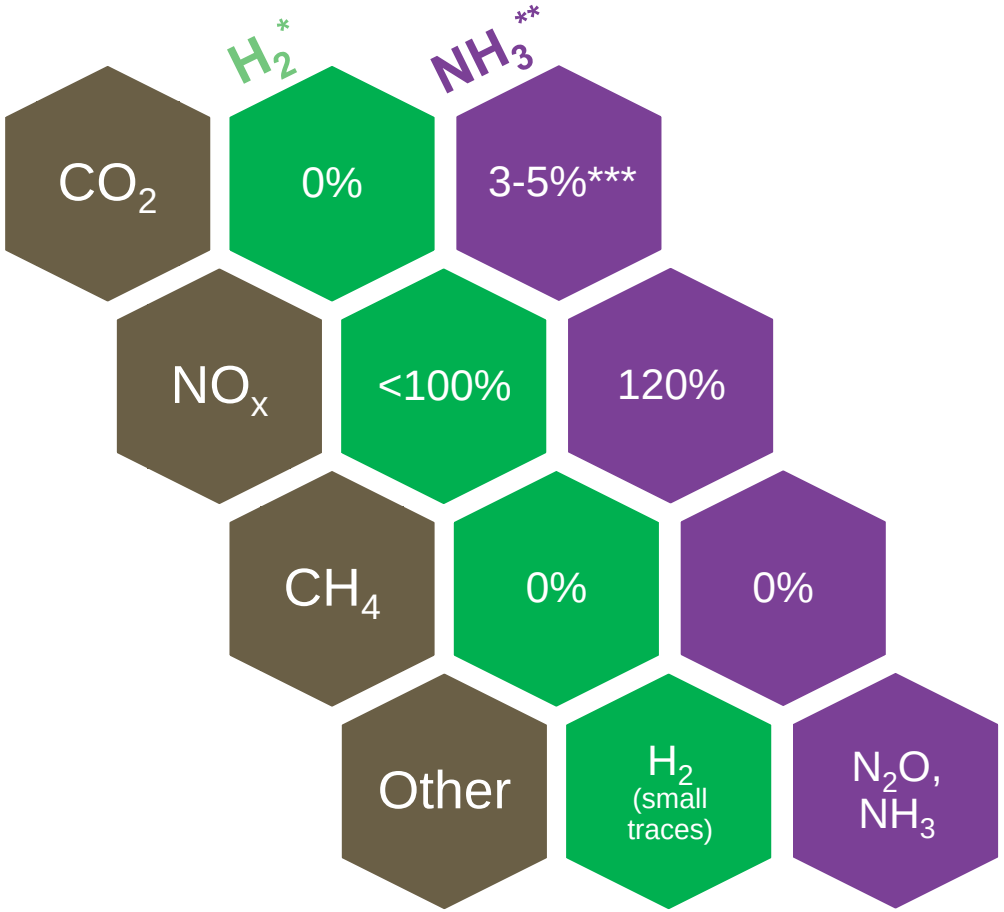
- The power systems are facing fundamentally new challenges due to the increase of renewables
- Storage systems can provide multiple services for the energy system
- Storage creating value along the entire value chain of the power system
- MAN ES supporting its customers with multiple

Image from Matt Smith/Keystone Crossroads

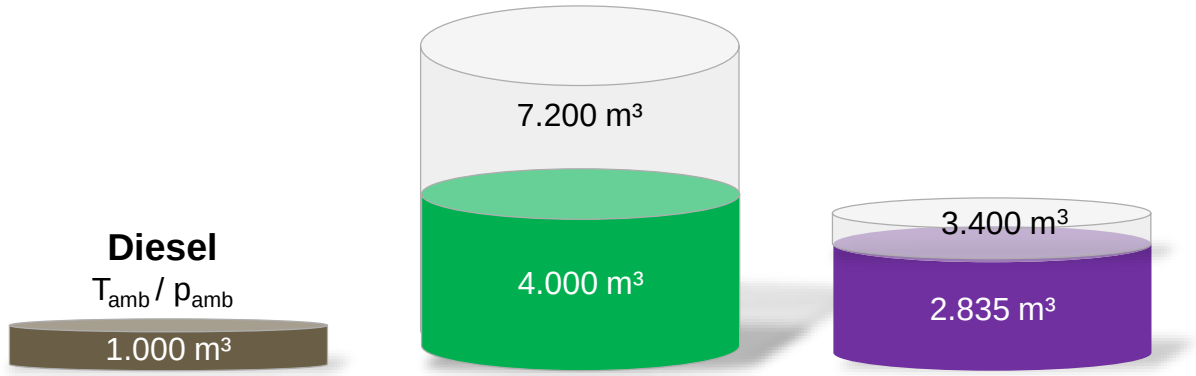


Power Generation with Future Fuels

NH_3/H_2 qualities as fuel for 49/60



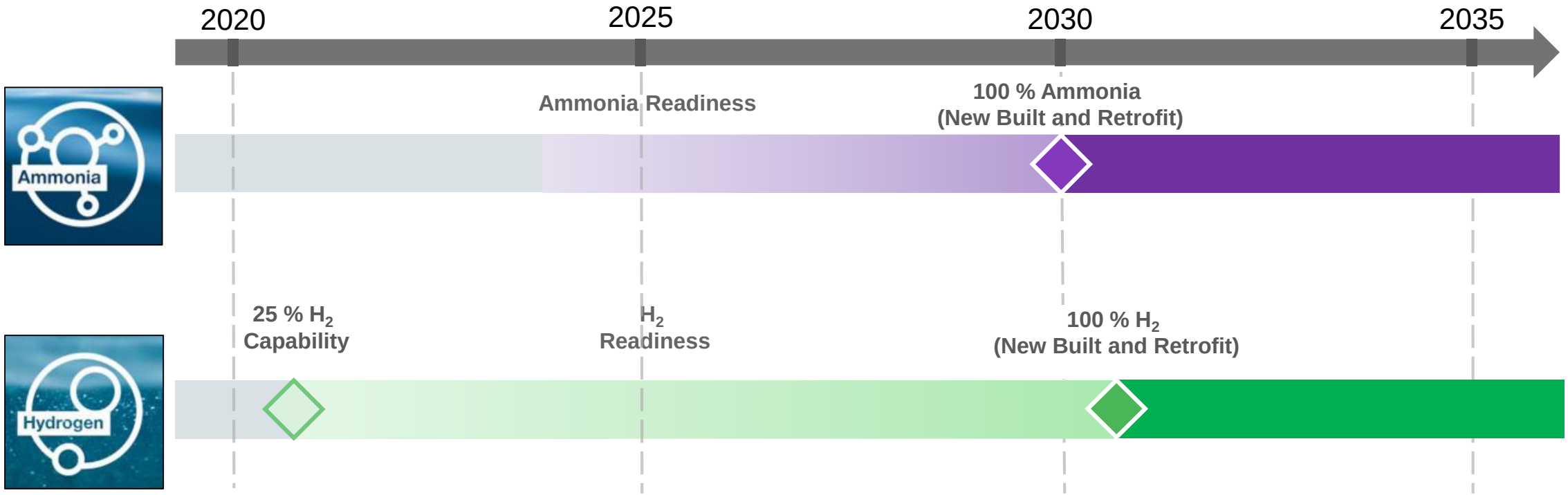
	H_2	NH_3
Engine power output (R&D)	90-100%	90-100%
Storage	-253°C / 6 bar Room T. / 350-700 bar	-33°C / 6 bar
Equivalent cryogenic tank volume	7.2 x Diesel 2.6 x LNG	3.4 x Diesel 1.2 x LNG
Hazard potential	Highly flammable	Toxic



* Emissions in comparison to conventional gas engine (=100%).| ** Emissions in comparison to conventional DF engine operated with diesel (=100%) | *** If fossil fuel is used as pilot oil

Future Fuels Engine Development

49/60 NH_3/H_2 New build + Retrofit Roadmap = future proof for any carbon-free standard



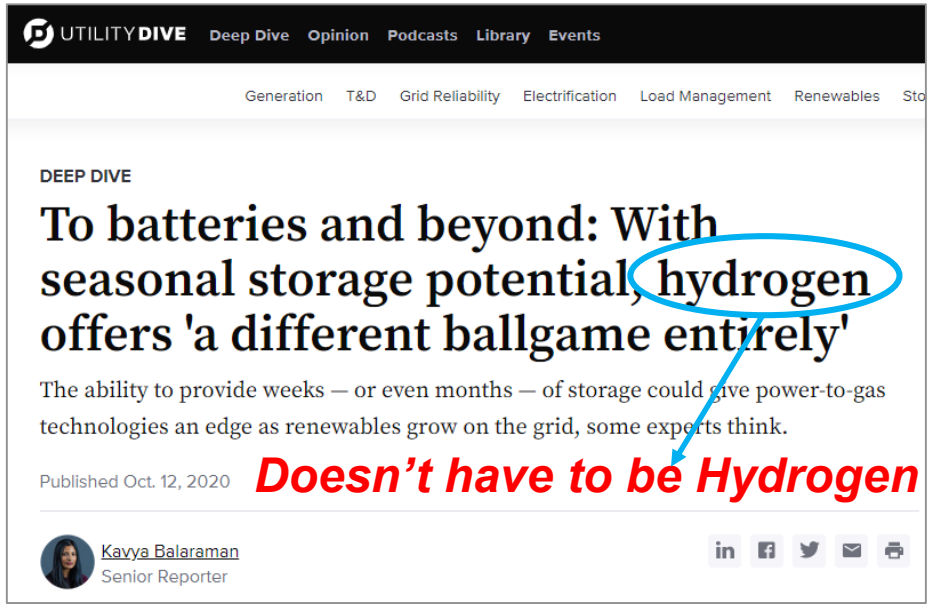
49/60 Family is ready for Future Fuels! The 49/60 engine family is the MAN designated platform for the later application of H_2 and NH_3. Solutions for new-built and retrofit for engines sold with future fuel readiness will be available from 2030/2031.

Ammonia's role in the Energy Transition

…and re-framing the Recip Power Plant

Ammonia as a Long Duration Energy Storage

- Increased renewables require operational flexibility & **firm** Long Duration Energy Storage **(LDES)** to ensure system reliability
- LDES in the form Carbon Neutral/Zero fuels provides reliability in transition to decarbonization
- Compared to other LDES options like Compressed Air Energy Storage, Ammonia is more cost effective
- Economics of Ammonia as a fuel could become more attractive under IRA



Reciprocating Internal Combustion Engine with 25% Hydrogen Firing Capability - As renewable penetration increases, RICE units like the ones used at NOPS will likely see increased deployment across North America. RICE units can meet increased demand for reliability, place dispatchable power online rapidly, and be started/stopped frequently in response to changing load conditions. RICE units can ramp up to full load in less than 5 minutes and operate at about 33% of nominal rating without compromising heat rate. On the other hand, CTs generally ramp at a slightly slower rate (10 – 15 minutes) and while they can turn down to approximately 40% of their rated output, heat rate is compromised.

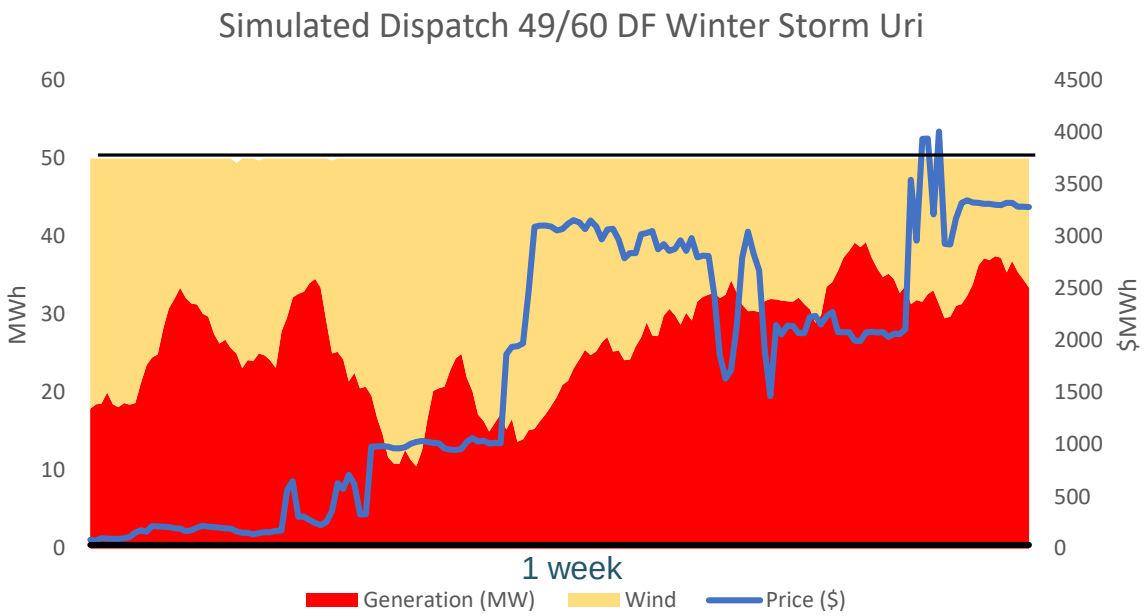
Current RICE OEMs have claimed that existing models are able to accommodate blends of hydrogen up to 25%.[16] As is the case for CT and AERO CT OEMs, RICE technology developers are working on technology advancements and identifying necessary plant modifications which would be required to increase the hydrogen blend capability above 25%. RICE OEMs are also working to develop models compatible with other potential low-carbon fuels such as ammonia, which is anticipated to provide another renewable fuel choice in addition to pure hydrogen.

"RICE OEMs are also working to develop models compatible with other potential low-carbon fuels such as ammonia, which is anticipated to provide another renewable fuel choice in addition to pure hydrogen."

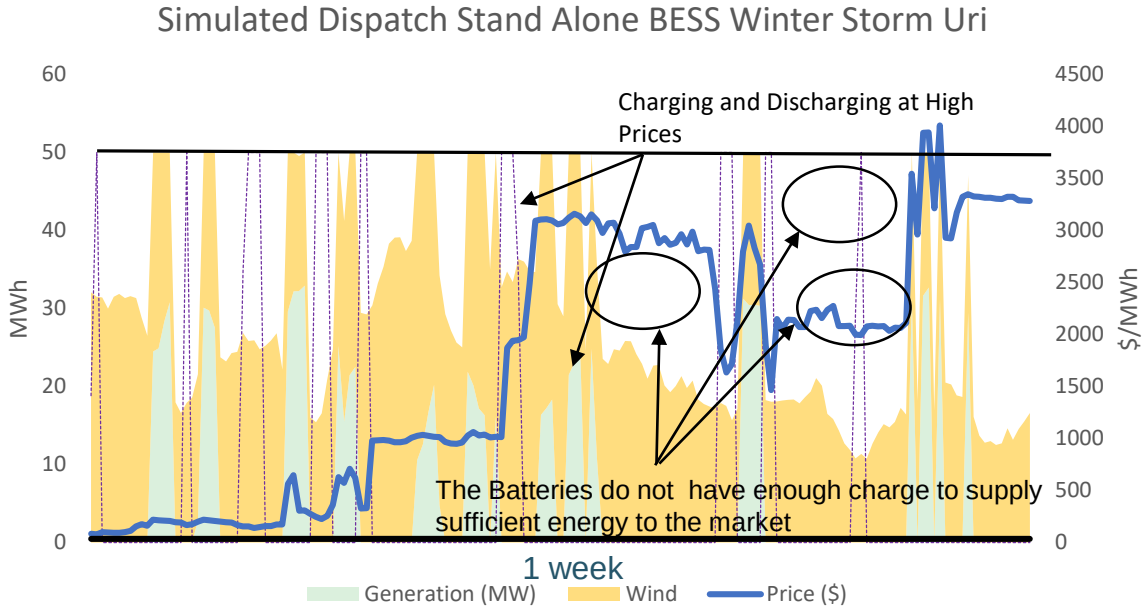
Studying the Value of Flexibility and Dispatchabilty: Winter Storm Uri

Both Engines and Batteries are very flexible but what about during critical peaking events? Fuel flexibility and **independent** dispatchability are critical during super peaking events

99% POI Utilization



58%POI Utilization



In this period of high demand the engines are able to respond to market demand and balance the wind assets simultaneously

MAN Energy Solutions
Future in the making

Thank you very much!

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