Committees on Energy Resources & the Environment and Electricity

100 % Clean Energy: What Comes Next for Markets and the Grid?

NARUC Summer Policy Summit

100% Clean Energy: What comes next for markets and the grid?

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GridLAB

What does 100% Clean Energy mean?

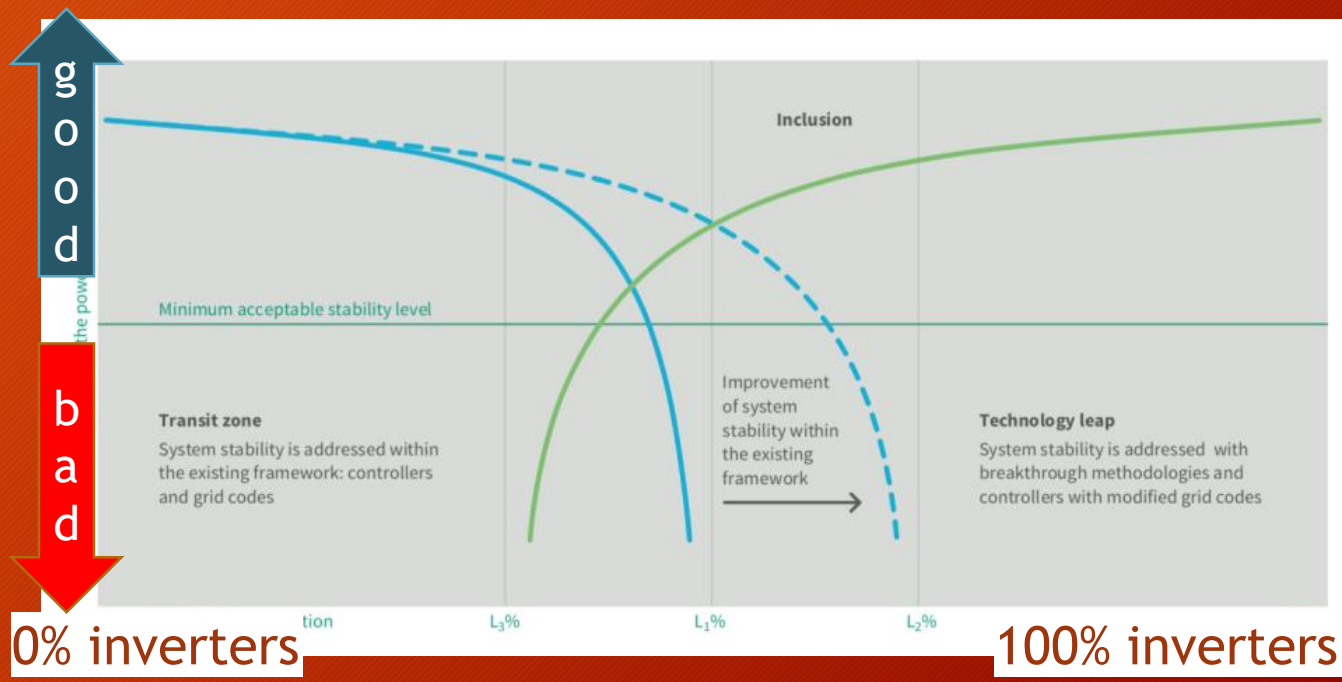
- Iceland runs on 100% hydro and geothermal
- A large state in the west might run on hydro, wind, solar PV, solar thermal, geothermal and biomass
- A utility in the Midwest might run on nuclear, wind, solar PV, coal + CCS
- An island might run on wind, solar PV and batteries

The main challenges are ***variable*** energy resources (VER), ***inverter-based*** resources (IBR), and ***low/zero marginal cost*** resources

100% Clean Energy is possible with today's technology/know-how.
The question is: Can we do this smarter, cheaper, and by 2050?

Short-term reliability: stability

- What we know
  - Wind and solar need to provide reliability services and performance should be rewarded
  - Synchronous condensers can help with stability but also introduce other challenges
- Challenges
  - Even before you get to 100%, in pockets of high penetrations of IBR, stability can suffer
  - Weak grids; power transfer limitations
- Opportunities
  - Grid-forming inverters are a potential solution but are not a silver bullet
  - Power electronics can be programmed to do all kinds of things – what do we want them to do?

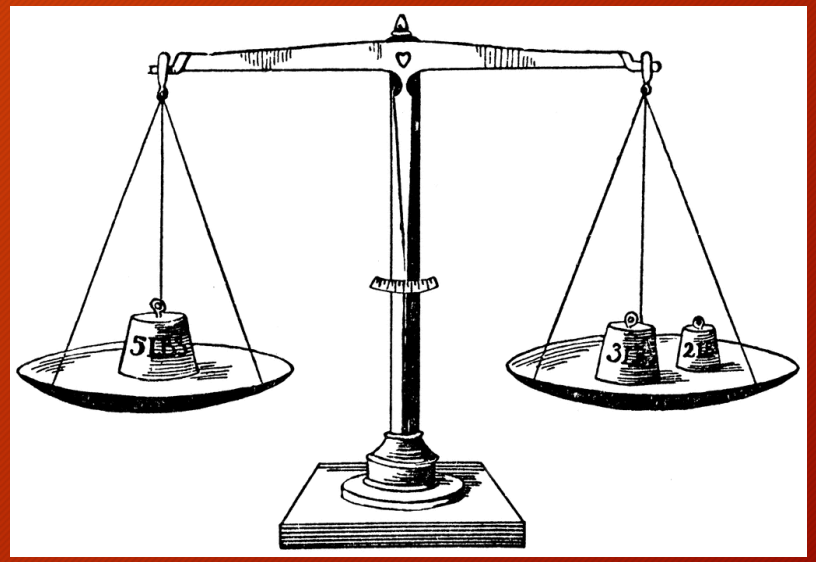


Source: MIGRATE, 2016

Today we are on the blue line and working towards the dashed blue curve. We don't know what the green curve looks like or how to get there.

Medium-term reliability: system balancing

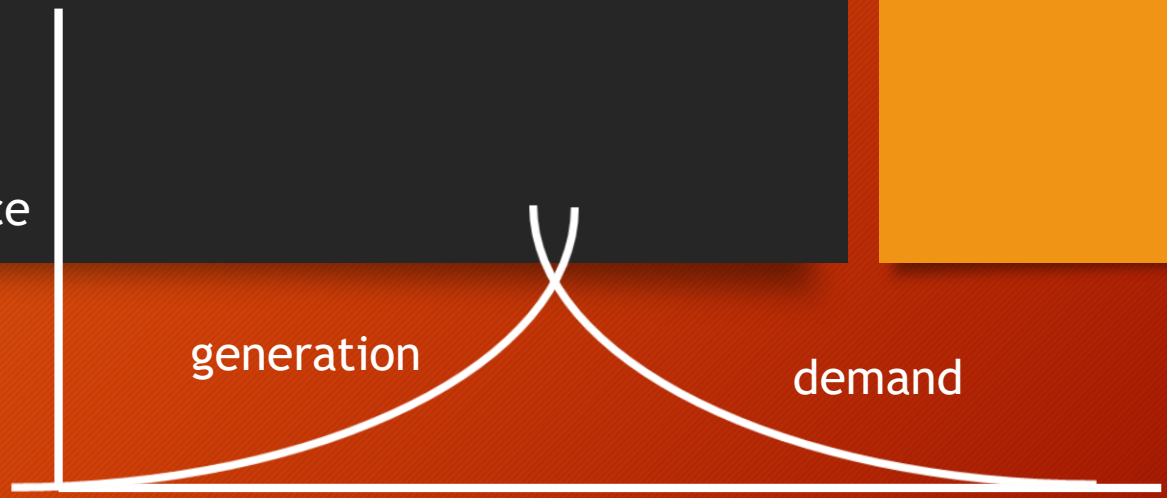
- What we know
  - Many mitigation options including: larger regions with faster trading, storage, demand-side flexibility, increased flexibility of non-VER, dispatch of and ancillary services from VER, improved forecasting
- Challenges
  - How we view curtailment
  - Impact from these tools eventually saturates
  - RPS goals may be challenged by increased electrification
- Opportunities
  - Rapidly falling price of batteries
  - Electrification of transportation, heating, industrial sectors AND optimization of interactions between these energy systems
  - Controllable load and price-responsive demand
  - Commercialization of advanced dispatchable technology (CCS, hydrogen-fueled generators, advanced nuclear)

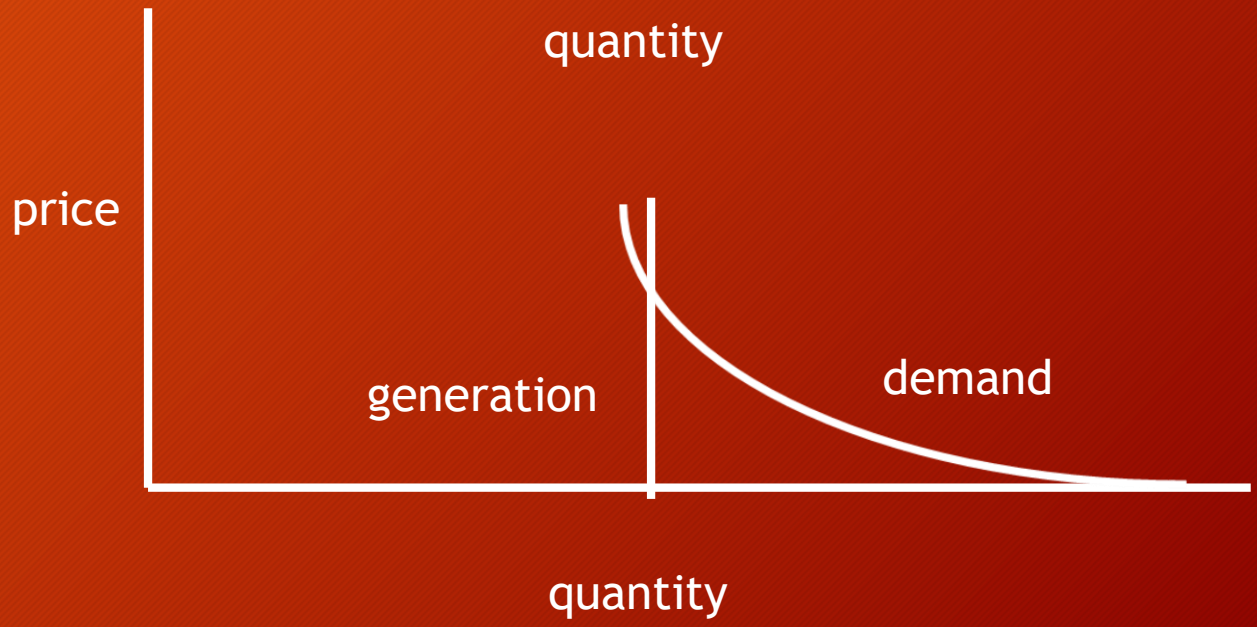


We know how to manage the variability. But the impacts from existing tools are saturating.

Long-term reliability: Resource adequacy

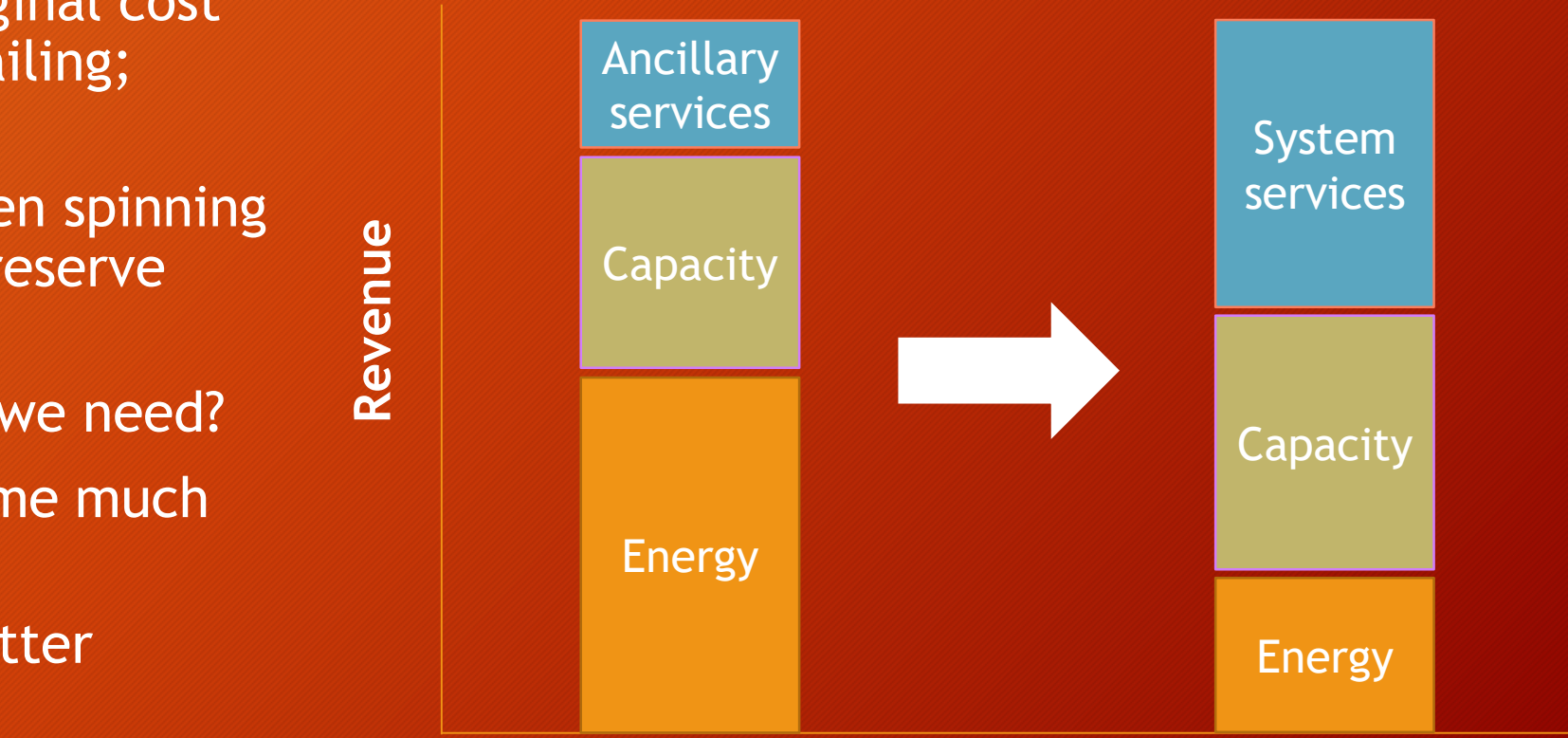
- What we know
  - Four-hour batteries alone may not be sufficient; may need storage portfolio
- Challenges
  - Seasonal mismatch of supply and demand may result in high costs to reach 100% goal
  - Multiple calm, cloudy days or multiple cold, calm days after a snowstorm
  - Meeting 1 day in 10 years LOLE with high VER penetrations
- Opportunities
  - Power-to-X for seasonal storage
  - Price-responsive load; does the metric 1 day in 10 years continue to exist?
  - Advanced firm technology (CCS, hydrogen-fueled generators, advanced nuclear)





We don’t know how to run markets with 100% clean energy…or what the transition looks like

- Many hours with zero marginal cost energy; Balancing by curtailing; Occasional price spikes
- How quickly do energy, then spinning reserves, then regulating reserve prices go to zero?
- What system services will we need?
- Do capacity markets become much more important?
- Is a regulated market a better framework for 100%?
- Forecasting will be essential to position storage resources



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