Electric Sector Coupling: Promise and Pitfalls

EVOLVED ENERGY RESEARCH

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About Evolved Energy Research

- Energy consulting firm focused on addressing key energy sector challenges posed by climate change
- Lead developers of EnergyPATHWAYS, a bottom-up energy system model used to explore the near-term implications of long-term deep decarbonization
- We advise clients on issues of policy implementation and target-setting, R&D strategy, technology competitiveness and impact investing

Sector Coupling Opportunities

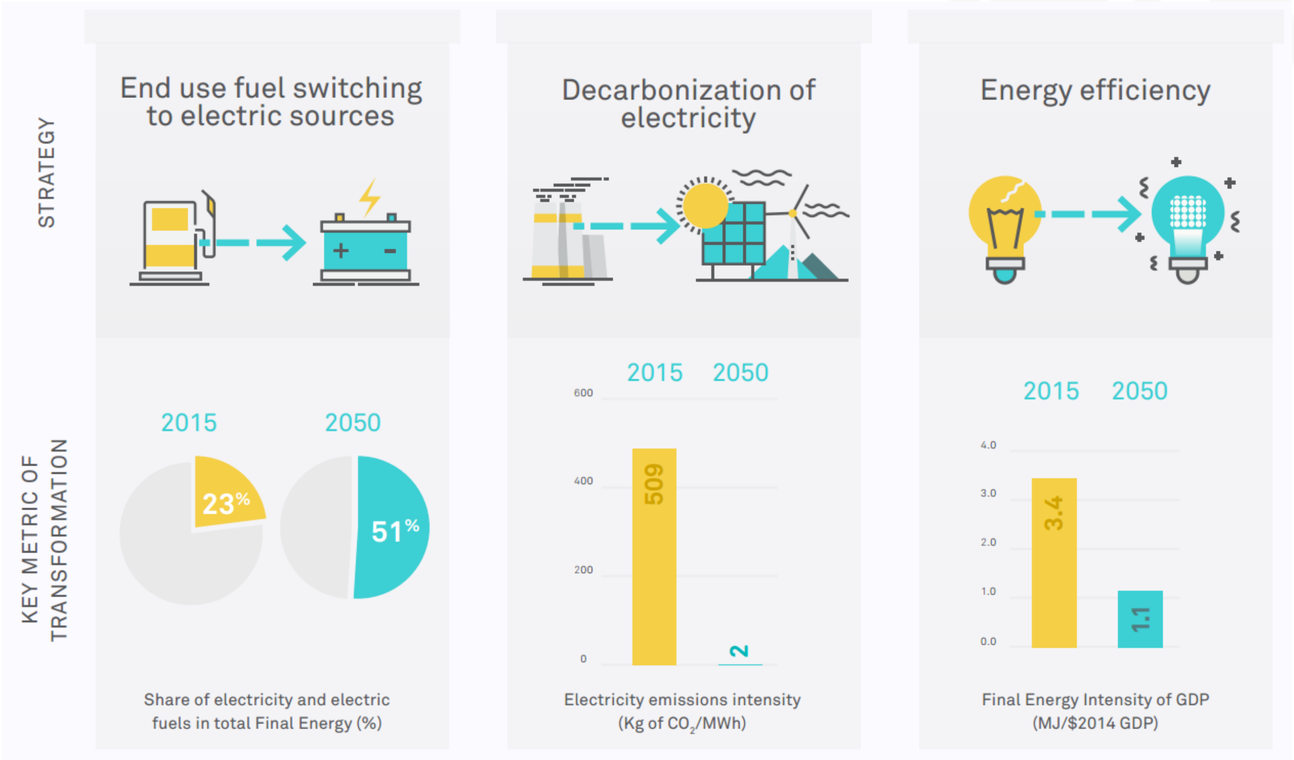
- Development of renewable generation is often taking place in the context of broader energy system decarbonization efforts
- Those efforts have revealed the importance of **electrification of energy end-uses,** one of the three-pillars of decarbonization including **decarbonizing the grid** and **increasing efficiency of energy use**

Three Pillars in Practice

United States

2050 U.S. Benchmarks

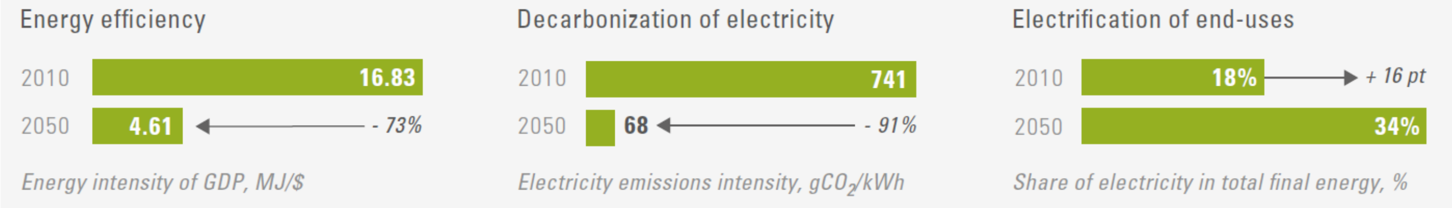
- 2x increase in the share of energy from electricity or electrically derived fuels
- ~99% decrease in the emissions intensity of electricity generation
- 3x drop in energy use per unit GDP



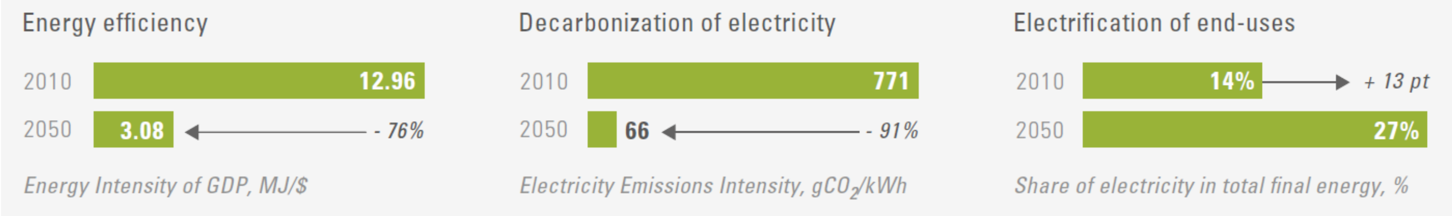
Three Pillars in Practice

China, India and United Kingdom

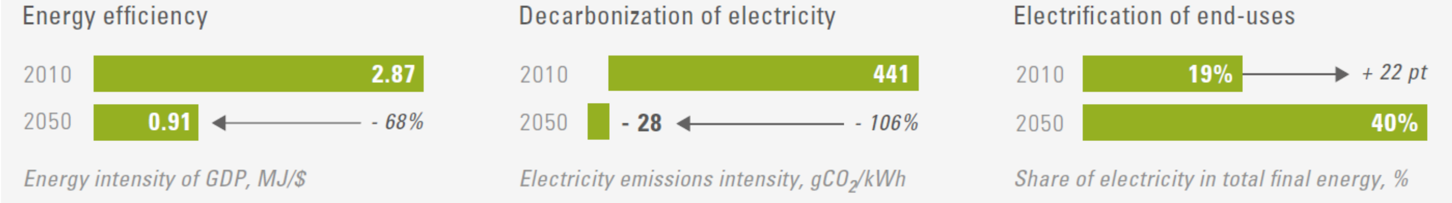
China



India

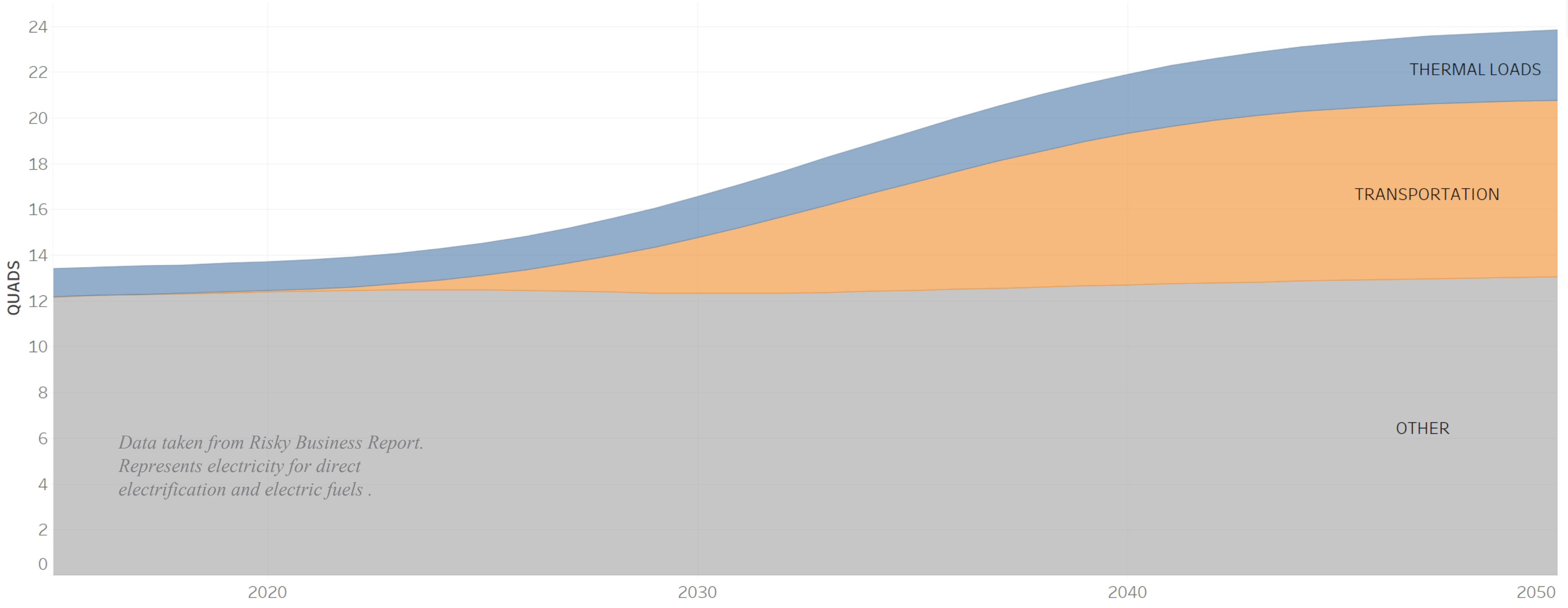


UK



Source: figures from Deep Decarbonization Pathways Project country reports (2015)

Electrification Loads



Data taken from Risky Business Report. Represents electricity for direct electrification and electric fuels .

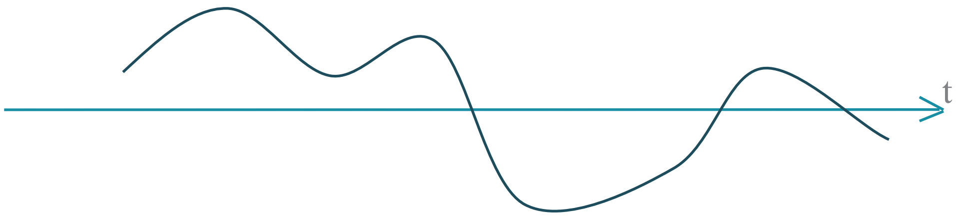
Expanding Potential of Flexible Loads

- Flexible load is defined as load that responds to supply-side signals, not just to demand-side requirements
  - Ex. An EV owner arrives home. He'd like to have his battery full, but he's willing to delay that charging if he is charged less for it at a later hour
- Load growth in electrification scenario comes from sectors that are prime candidates to operate flexibly:
  - Thermal Loads: loads that have a thermal storage medium (i.e. water heater) that can operate within a range and allow for flexible operation without service degradation
  - Transportation Loads: loads that require battery storage which can allow for flexible charging and state of charge management without degrading service
- Electric fuel production (electrolysis; power-to-gas; power-to-liquids) are other types of potential load that can operate flexibly due to their high operating/capital cost ratio

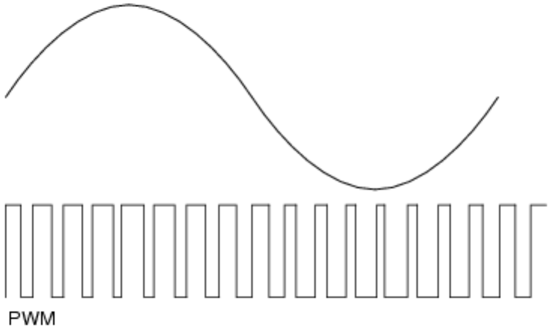
Electricity Balancing

Electricity balancing has two components

1. Ensuring electricity supply matches demand through time



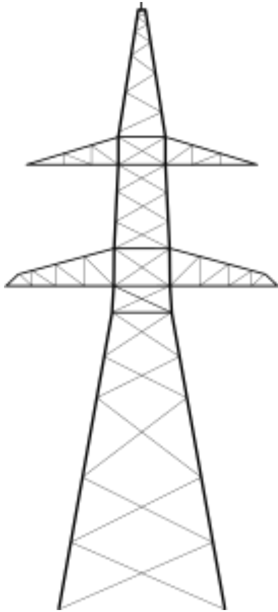
2. Ensuring power quality (voltage, frequency, reactive power)

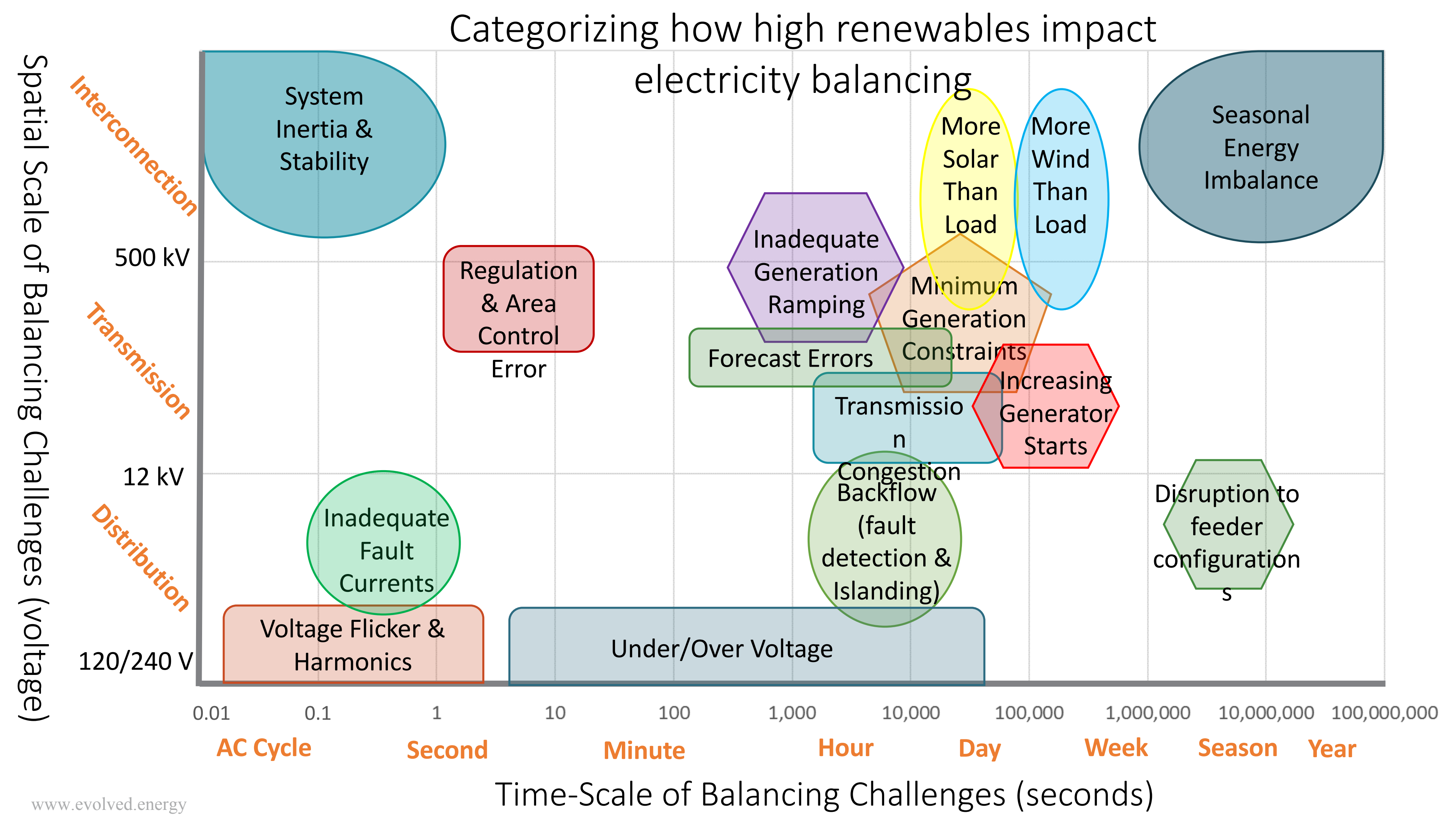


https://www.allaboutcircuits.com/textbook/alternating-current/chpt-13/synchronous-motors/

How do renewables present unique challenges for balancing?

- Renewables have certain characteristics that make them difficult to manage in the context of today's electricity system
  - **Variability** – output is not controllable and can change rapidly
  - **Uncertainty** – future output can be difficult to predict
  - **New locations** – deployment in locations not anticipated when the grid was built
  - **Inverters vs. synchronous motors** – technical character of inverters are different

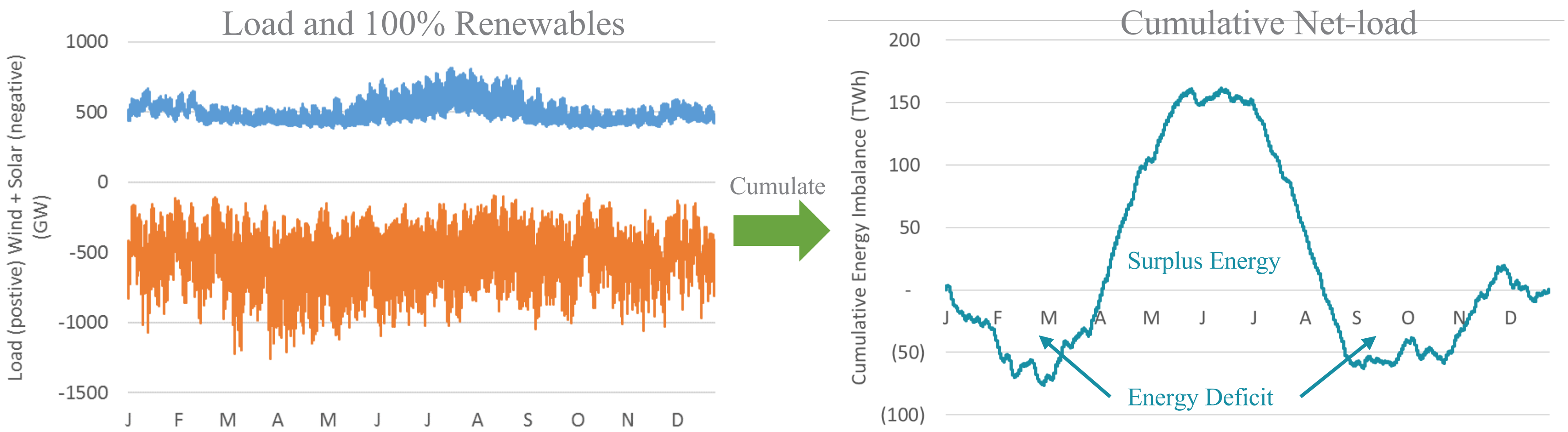




Categorizing how high renewables impact electricity balancing
Spatial Scale of Balancing Challenges (voltage)
Interconnection
Transmission
Distribution
500 kV
12 kV
120/240 V
System Inertia & Stability
Regulation & Area Control Error
Inadequate Generation Ramping
More Solar Than Load
More Wind Than Load
Seasonal Energy Imbalance
Minimum Generation Constraints
Forecast Errors
Transmission Congestion
Increasing Generator Starts
Backflow (fault detection & Islanding)
Disruption to feeder configurations
Inadequate Fault Currents
Voltage Flicker & Harmonics
Under/Over Voltage
0.01
0.1
1
10
100
1,000
10,000
100,000
1,000,000
10,000,000
100,000,000
AC Cycle
Second
Minute
Hour
Day
Week
Season
Year
Time-Scale of Balancing Challenges (seconds)
www.evolved.energy

Seasonal energy imbalance

- Increasing the penetration of wind & solar beyond ~75% in temperate climates results in seasonal energy imbalances that become the dominate challenge for achieving deep decarbonization in electricity



U.S. Eastern Interconnect 2015 Load with simulated 40% Solar & 60% Onshore Wind by Energy

Flexible Load SWOT Analysis

Flexible Load SWOT Analysis

STRENGTHS	**WEAKNESSES**
OPPORTUNITIES	**THREATS**

Flexible Loads (End-Use Loads) SWOT Analysis

• Flexibility without large new infrastructure needs
• Flexible end-use load offers potential to avoid infrastructure not substitute for it
• Flexible end-use loads have existing thermal or chemical storage mediums or demand for the end-use services themselves are flexible
	• Requires customer participation
	• Reliability as a resource will require further study as it grows
	  • Very similar to DR generally, but with a different type of customer and potentially without longer-term contractual relationships
	• End-use loads have a variety of unique operational constraints
	  • Limited duration: Can’t heat up water in April for use in June
	  • Sit behind distribution infrastructure, limiting their flexibility to respond to system generation conditions
	• Downside risk of flexible operation is considerable
	  • The first time someone runs out of hot water in the shower may be the last time their load is flexible

• Distributed generation • Electrification	• Cheap batteries reduce the incentive to pursue demand-side flexibility • Rate design principles and processes • Difficulty establishing price signal for fixed assets • Electric fuel production

Flexible Loads (Electric Fuels) SWOT Analysis

- Can achieve some colocation benefits with renewables
- Can provide long-duration storage in two ways, by chemically storing energy or by changing the blending of a product (e.g. blending into the gas pipeline)
- High operating to capital cost ratio

- Needs exogenous demand for products or supporting policy changes
- High penetrations of renewables are required before they can operate at reasonable capacity factors if they're just soaking up overgeneration
- Low roundtrip efficiency

- High-hydro renewable systems that already have some seasonal imbalance
- Economy-wide carbon targets
- 100% renewable goals

- Cheap batteries reduce near-term opportunities for balancing and may out-compete demand for fuels (i.e. hydrogen)
- Cheap biofuels

Conclusions

Conclusions

- Renewable integration opportunities depend entirely on a system context
  - Renewable prices
  - Alternative balancing resource costs
  - Economy emissions targets
- Eventual role of flexible loads will be determined in a portfolio context
- Barriers to eventual deployment are economic, technical, and regulatory, but the opportunities are large