Electric Sector Coupling: Promise and Pitfalls
• About Us
• Sector Coupling
• Electricity Balancing
• Flexible Loads SWOT Analysis
• Conclusions
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

<table>
<thead>
<tr>
<th>Energy efficiency</th>
<th>Decarbonization of electricity</th>
<th>Electrification of end-uses</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2010</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16.83</td>
<td>741</td>
<td>18%</td>
</tr>
<tr>
<td><strong>2050</strong></td>
<td>4.61</td>
<td>+ 16 pt</td>
</tr>
<tr>
<td>- 73%</td>
<td>- 91%</td>
<td>34%</td>
</tr>
</tbody>
</table>

*Energy intensity of GDP, MJ/$

*Electricity emissions intensity, gCO₂/kWh

*Share of electricity in total final energy, %

## India

<table>
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<tbody>
<tr>
<td><strong>2010</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12.96</td>
<td>771</td>
<td>14%</td>
</tr>
<tr>
<td><strong>2050</strong></td>
<td>3.08</td>
<td>+ 13 pt</td>
</tr>
<tr>
<td>- 76%</td>
<td>- 81%</td>
<td>27%</td>
</tr>
</tbody>
</table>

*Energy Intensity of GDP, MJ/$

*Electricity Emissions Intensity, gCO₂/kWh

*Share of electricity in total final energy, %

## UK

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<tbody>
<tr>
<td><strong>2010</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.87</td>
<td>441</td>
<td>19%</td>
</tr>
<tr>
<td><strong>2050</strong></td>
<td>0.91</td>
<td>+ 22 pt</td>
</tr>
<tr>
<td>- 68%</td>
<td>- 106%</td>
<td>40%</td>
</tr>
</tbody>
</table>

*Energy intensity of GDP, MJ/$

*Electricity emissions intensity, gCO₂/kWh

*Share of electricity in total final energy, %

Source: figures from [Deep Decarbonization Pathways Project country reports](https://www.deepdecarbonization.org/) (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)

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

- **System Inertia & Stability**
- **Interconnection**
- **500 kV**
- **Transmission**
- **12 kV**
- **Distribution**
- **120/240 V**

**Time-Scale of Balancing Challenges (seconds)**

- **AC Cycle**
- **Second**
- **Minute**
- **Hour**
- **Day**
- **Week**
- **Season**
- **Year**

**Spatial Scale of Balancing Challenges (voltage)**

- **Under/Over Voltage**
- **Voltage Flicker & Harmonics**
- **Inadequate Fault Currents**

**Seasonal Energy Imbalance**

- **More Solar Than Load**
- **More Wind Than Load**

**System Inertia & Stability**

- **Regulation & Area Control Error**
- **Minimum Generation Constraints**
- **Increasing Generator Starts**

**Inadequate Generation Ramping**

- **Forecast Errors**
- **Transmissio n Congestion**
- **Backflow (fault detection & Islanding)**

**Under/Over Voltage**

- **Inadequate Generation Constraints**
- **Ramping Regulation & Area Control Error**
- **Area Control Error**

**Disruption to feeder configuration**

- **More Solar Than Load**
- **More Wind Than Load**

**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.
Flexible Load SWOT Analysis
Flexible Load SWOT Analysis

STRENGTHS

WEAKNESSES

OPPORTUNITIES

THREATS
## Flexible Loads (End-Use Loads) SWOT Analysis

<table>
<thead>
<tr>
<th>Strengths</th>
<th>Weaknesses</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Flexibility without large new infrastructure needs</td>
<td>- Requires customer participation</td>
</tr>
<tr>
<td>- Flexible end-use load offers potential to avoid infrastructure not substitute for it</td>
<td>- Reliability as a resource will require further study as it grows</td>
</tr>
<tr>
<td>- Flexible end-use loads have existing thermal or chemical storage mediums or demand for the end-use services themselves are flexible</td>
<td>- Very similar to DR generally, but with a different type of customer and potentially without longer-term contractual relationships</td>
</tr>
<tr>
<td>- End-use loads have a variety of unique operational constraints</td>
<td>- Limited duration: Can’t heat up water in April for use in June</td>
</tr>
<tr>
<td></td>
<td>- Sit behind distribution infrastructure, limiting their flexibility to respond to system generation conditions</td>
</tr>
<tr>
<td></td>
<td>- Downside risk of flexible operation is considerable</td>
</tr>
<tr>
<td></td>
<td>- The first time someone runs out of hot water in the shower may be the last time their load is flexible</td>
</tr>
<tr>
<td>- Distributed generation</td>
<td>- Cheap batteries reduce the incentive to pursue demand-side flexibility</td>
</tr>
<tr>
<td>- Electrification</td>
<td>- Rate design principles and processes</td>
</tr>
<tr>
<td></td>
<td>- Difficulty establishing price signal for fixed assets</td>
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<td>- Electric fuel production</td>
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**Notes:**

- Distributed generation
- Electrification
- Rate design principles and processes
- Difficulty establishing price signal for fixed assets
- Electric fuel production
### Flexible Loads (Electric Fuels) SWOT Analysis

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<tr>
<td>- Can achieve some colocation benefits with renewables</td>
<td>- Needs exogenous demand for products or supporting policy changes</td>
</tr>
<tr>
<td>- 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)</td>
<td>- High penetrations of renewables are required before they can operate at reasonable capacity factors if they’re just soaking up overgeneration</td>
</tr>
<tr>
<td>- High operating to capital cost ratio</td>
<td>- Low roundtrip efficiency</td>
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</tbody>
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<td>- High-hydro renewable systems that already have some seasonal imbalance</td>
<td>- Cheap batteries reduce near-term opportunities for balancing and may out-compete demand for fuels (i.e. hydrogen)</td>
</tr>
<tr>
<td>- Economy-wide carbon targets</td>
<td>- Cheap biofuels</td>
</tr>
<tr>
<td>- 100% renewable goals</td>
<td></td>
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</table>
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