ARPA-e Flexible Carbon Capture Workshop
Gas Turbines Capability & Context

Patrick Riley
GE Research
July 30, 2019
EIA’s View Just 5 Years Ago …

Role of GT in the Future Consistent with the Past

![Graph showing US Generation, % over years from 2000 to 2020, with data points for Coal, Gas, Nuclear, Hydro, Wind, Solar, and Other.](source: EIA AEO 2014)

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>2013</th>
<th>2018</th>
<th>Δ 2018 vs. 2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>38.8%</td>
<td>37.6%</td>
<td>-1.2%</td>
</tr>
<tr>
<td>Gas</td>
<td>27.6%</td>
<td>28.1%</td>
<td>+0.5%</td>
</tr>
<tr>
<td>Nuclear</td>
<td>19.4%</td>
<td>18.3%</td>
<td>-1.1%</td>
</tr>
<tr>
<td>Hydro</td>
<td>6.5%</td>
<td>6.7%</td>
<td>+0.2%</td>
</tr>
<tr>
<td>Wind</td>
<td>4.1%</td>
<td>5.0%</td>
<td>+0.9%</td>
</tr>
<tr>
<td>Solar</td>
<td>0.4%</td>
<td>0.9%</td>
<td>+0.5%</td>
</tr>
<tr>
<td>Other</td>
<td>3.2%</td>
<td>3.4%</td>
<td>+0.2%</td>
</tr>
</tbody>
</table>

© 2019, General Electric Company. All Rights Reserved.
What Actually Happened Part 1 …

Source: EIA AEO 2014 & EIA

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>38.8%</td>
<td>37.6%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas</td>
<td>27.6%</td>
<td>28.1%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nuclear</td>
<td>19.4%</td>
<td>18.3%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydro</td>
<td>6.5%</td>
<td>6.7%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wind</td>
<td>4.1%</td>
<td>5.0%</td>
<td>6.5%</td>
<td>+1.5%</td>
</tr>
<tr>
<td>Solar</td>
<td>0.4%</td>
<td>0.9%</td>
<td>2.3%</td>
<td>+1.4%</td>
</tr>
<tr>
<td>Other</td>
<td>3.2%</td>
<td>3.4%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Rise of Renewables … 3x Faster
What Actually Happened Part 2…

Growth of Renewables alongside Continued Growth of Gas

Source: EIA AEO 2014 & EIA

<table>
<thead>
<tr>
<th>Source: EIA AEO 2014 &amp; EIA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
</tr>
<tr>
<td>Gas</td>
</tr>
<tr>
<td>Nuclear</td>
</tr>
<tr>
<td>Hydro</td>
</tr>
<tr>
<td>Wind</td>
</tr>
<tr>
<td>Solar</td>
</tr>
<tr>
<td>Other</td>
</tr>
</tbody>
</table>

© 2019, General Electric Company. All Rights
Gas & Renewables Symbiosis

Why GT’s were Resilient

Low Cost
gas price, efficiency

- Flexibility
  quick starts, fast ramp rates

- Resource Efficient
  CO₂, water, land

- Reduced CO₂ intensity …
  ~50% CO₂ intensity of coal

- Less water usage …
  4x less water per MWh than coal

- Most land efficient power generation source …
  50-100x less space per MWh compared to renewables and battery storage system

Cheap Abundant Fuel

- Start time
  Less than 30 min

- Ramp
  60 MW/min

- Turndown
  <200 MW while maintaining emissions limits

© 2019, General Electric Company. All Rights
GE Power - gas turbine portfolio

Source: 2019 GE Gas Power Systems catalog

Wide Range of Product Sizes

HIGH EFFICIENCY H-CLASS
• Most cost-effective conversion of fuel to electricity in the industry.
• Includes the world's largest high efficiency turbine.
• Holds the world record for powering the most efficient combined cycle power plant at 63.08% efficiency.
• Over 300,000 operating hours across 36 gas turbines.

INDUSTRY-LEADING F-CLASS
• Introduced F-class technology 30 years ago.
• World's largest fleet, with more than 1,300 installed units and 70 million operating hours.
• Highest reliability in its class, providing customers more days of operation per year.

RELIABLE B- AND E-CLASS
• Rugged and available, even in harsh climates.
• Industry-leading fuel flexibility, burning more than 50 gases and liquids.
• Quick installation for fast-track projects.
• More than 3,700 installed units with more than 217 million combined operating hours.

COMPACT AND PROVEN AERODERIVATIVES
• Flexible and reliable power generation packages with aviation-derived engines.
• More than 100 million operating hours acquired over the last 45 years.
• Up to 44% simple cycle efficiency and 56% combined cycle efficiency with fast startup, high ramp rates, and outstanding cycling capability.
Newest Turbines Bigger, More Efficient, More Flexible
Gas Turbine Hybrids

- 50 MW+ of greenhouse gas free contingency reserve
- 50 MW+ of flexible capacity
- 50 MW+ of peaking energy
- 25 MW of high quality regulation
- Zero Fuel use and emissions between dispatch events while supporting ancillary services

- Faster startup
- Improved flexibility
- Black start capability w/o diesel genset
- Enhanced grid frequency regulation
- Additional peak capacity during periods of high energy demand/pricing
Gas Turbine Fuel Flexibility

GE gas turbine capability with alternative fuels

Liquid fuels
- Diesel
- Marine gasoil
- Biodiesel
- Light cycle oil
- Naphtha
- Condensate
- Ethanol / Methanol
- Kerosene / Jet fuel
- Butane
- Gasoline
- Dimethyl ether (DME)
- Crude oils
- Heavy fuel oil (HFO)

Gaseous fuels
- Natural gas / LNG
- H2 blends
- Ethane
- Liquid Petroleum Gas (LPG)
- Flare gas and associated gas
- Coal bed methane
- Lean methane
- Refinery/process off gas
- Landfill gas/biogas blends
- High hydrogen
- Synthesis gas
- Steel mill gases
- Sour gas

Broad hydrogen capability across the entire gas turbine portfolio

GE has the largest installed fleet of gas turbines for alternative fuel applications
Variable renewables will continue to grow in generation share
forecasts may disagree on rate, but all agree on wind & solar continuing to grow share in US &
globally

Gas turbines uniquely positioned to work symbiotically with renewables
low cost, flexible, cleaner, provides ensured capacity

Gas turbine key customer metrics extend past efficiency
flexibility, off-design efficiency, start-up time

GT’s highly flexible … Aeroderivatives can ramp up to 65%/min of their full load
with CC $\eta$ of 55% & faster ramps/starts with hybrid storage