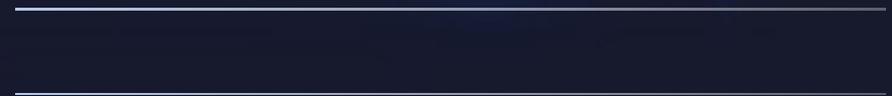




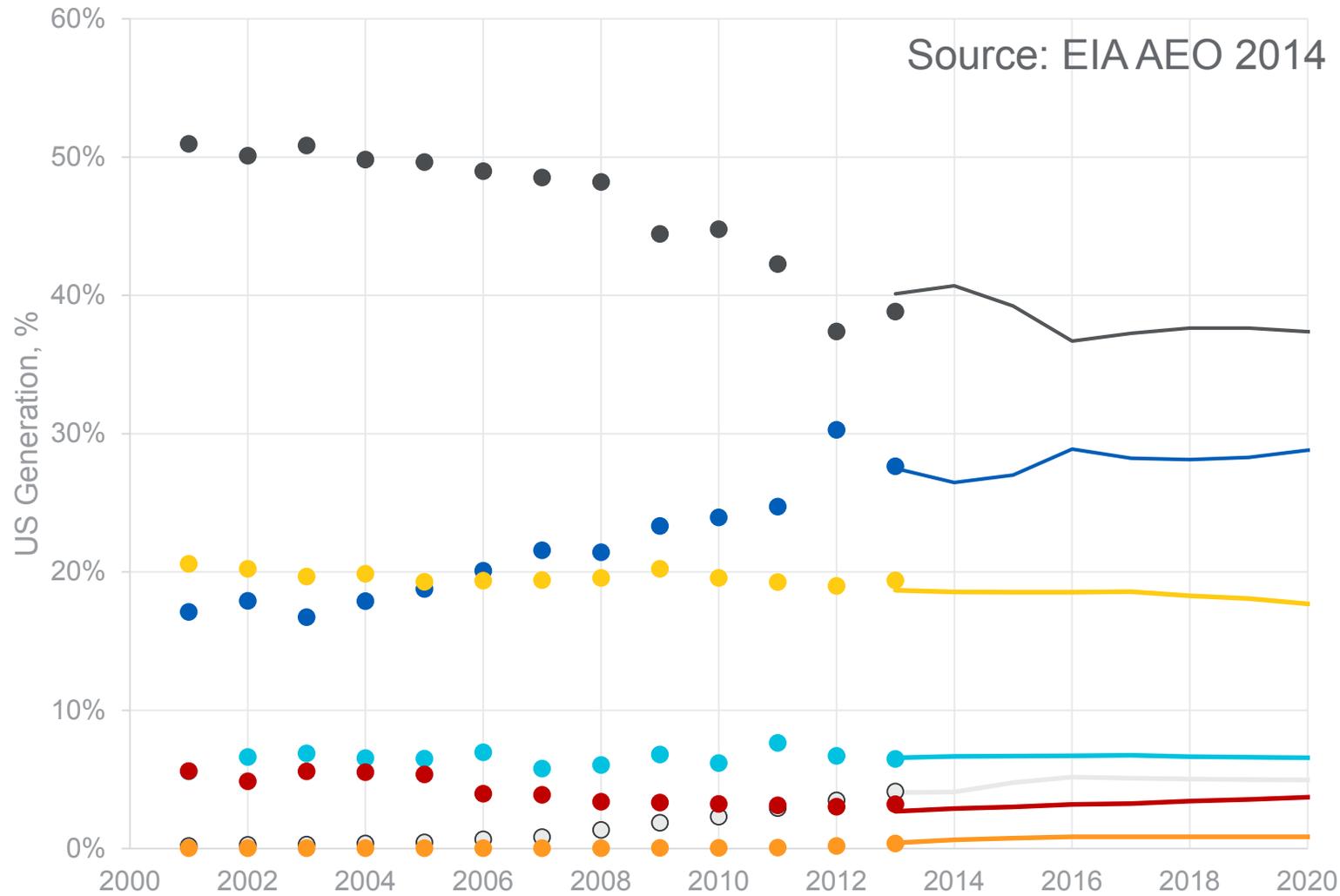
ARPA-e Flexible Carbon Capture Workshop

Gas Turbines Capability & Context

Patrick Riley
GE Research
July 30, 2019



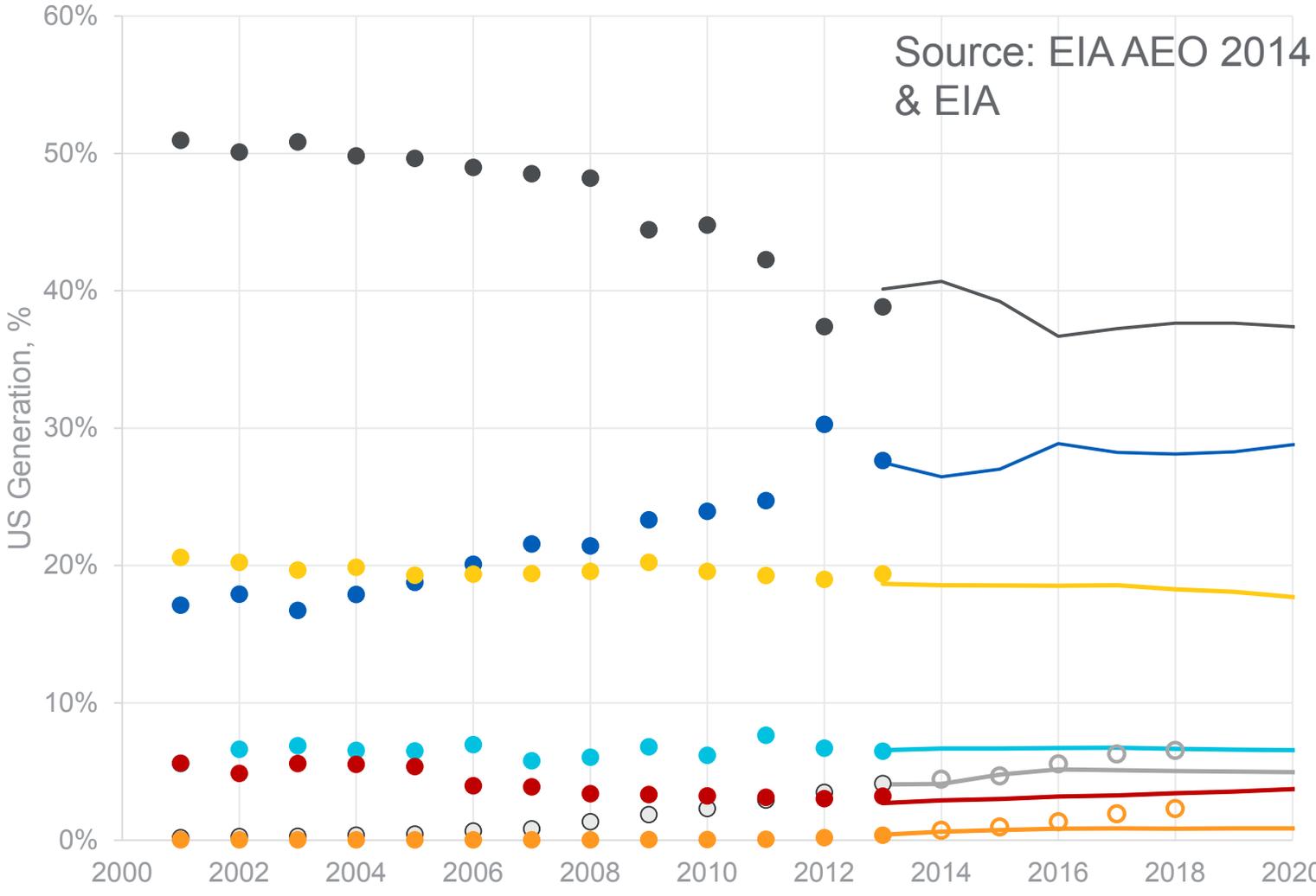
EIA's View Just 5 Years Ago ...



	● 2013	▬ 2018 via 2014 EIA AEO	Δ 2018 vs. 2013
Coal	38.8%	37.6%	-1.2%
Gas	27.6%	28.1%	+0.5%
Nuclear	19.4%	18.3%	-1.1%
Hydro	6.5%	6.7%	+0.2%
Wind	4.1%	5.0%	+0.9%
Solar	0.4%	0.9%	+0.5%
Other	3.2%	3.4%	+0.2%

Role of GT in the Future Consistent with the Past

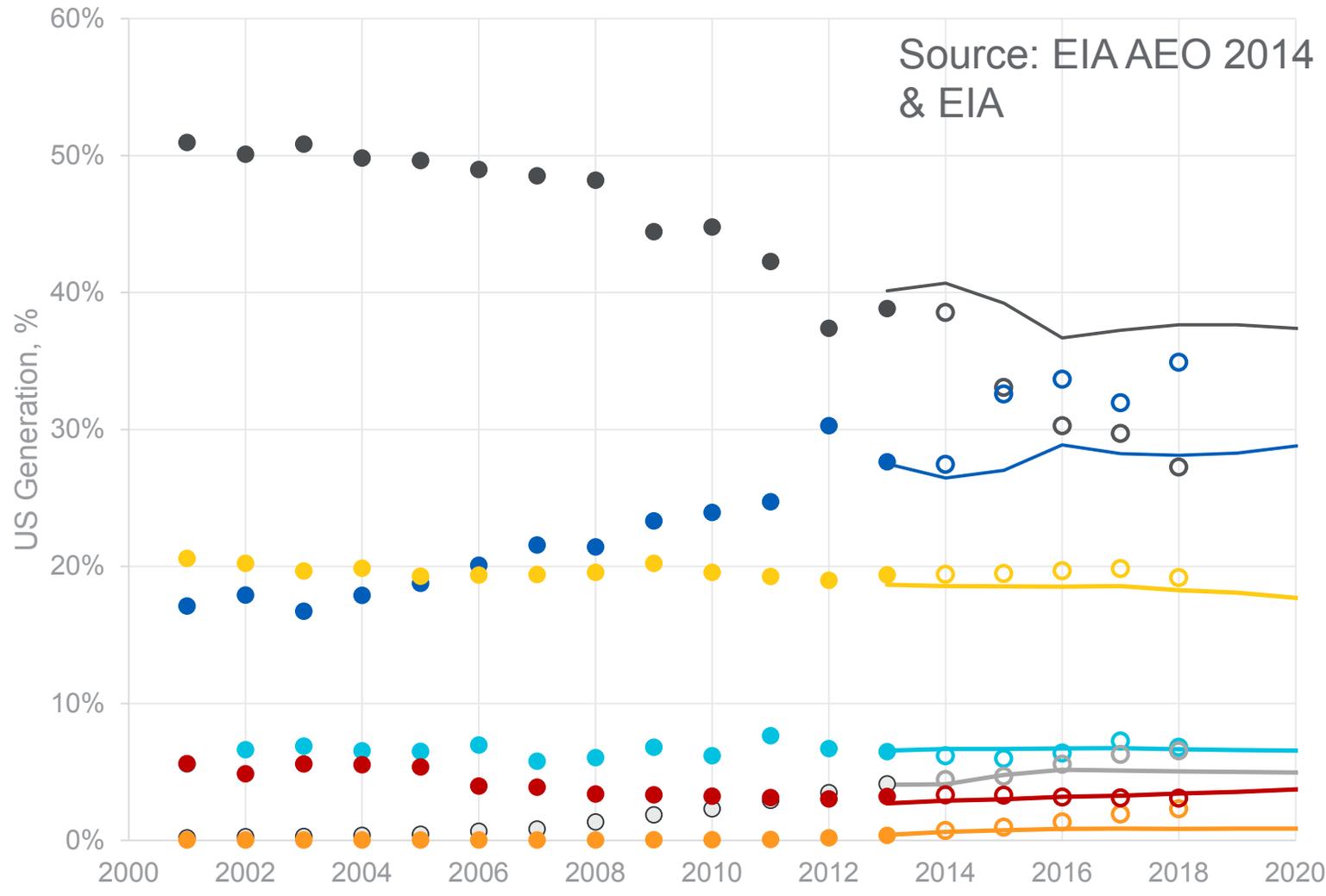
What Actually Happened Part 1 ...



	● 2013	— 2018 via 2014 EIA AEO	○ 2018 Actual	Δ Actual vs. AEO (2018)
Coal	38.8%	37.6%		
Gas	27.6%	28.1%		
Nuclear	19.4%	18.3%		
Hydro	6.5%	6.7%		
Wind	4.1%	5.0%	6.5%	+1.5%
Solar	0.4%	0.9%	2.3%	+1.4%
Other	3.2%	3.4%		

Rise of Renewables ... 3x Faster

What Actually Happened Part 2...



	● 2013	— 2018 via 2014 EIA AEO	○ 2018 Actual	Δ Actual vs. AEO (2018)
Coal	38.8%	37.6%	27.2%	-10.4%
Gas	27.6%	28.1%	34.9%	+6.8%
Nuclear	19.4%	18.3%	19.2%	+0.9%
Hydro	6.5%	6.7%	6.8%	+0.1%
Wind	4.1%	5.0%	6.5%	+1.5%
Solar	0.4%	0.9%	2.3%	+1.4%
Other	3.2%	3.4%	3.1%	-0.3%

Growth of Renewables alongside Continued Growth of Gas

Why GT's were Resilient

Low Cost
gas price, efficiency

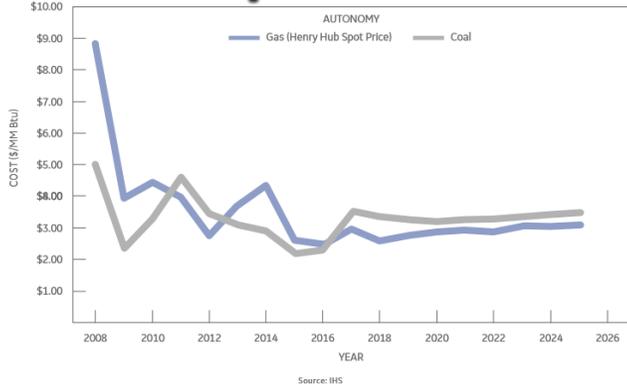
Flexibility

quick starts, fast ramp rates

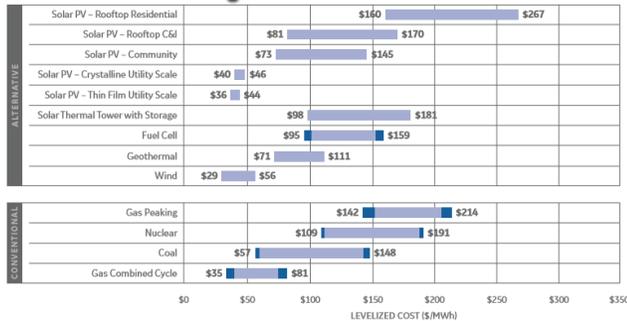
Resource Efficient

CO₂, water, land

Cheap Abundant Fuel



Competitive LCOE



NOTE: Darkened areas in horizontal bars represent low end and high end levelized cost of energy corresponding with +/-25% fuel price fluctuations.
Source: Lazard Levelized Cost of Energy Analysis 12.0



7HA.02

Start time

Less than 30 min

Ramp

60 MW/min

Turndown

<200 MW while maintaining emissions limits

✓ **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



Gas & Renewables Symbiosis

GE Power - gas turbine portfolio

Source: 2019 GE Gas Power Systems catalog

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

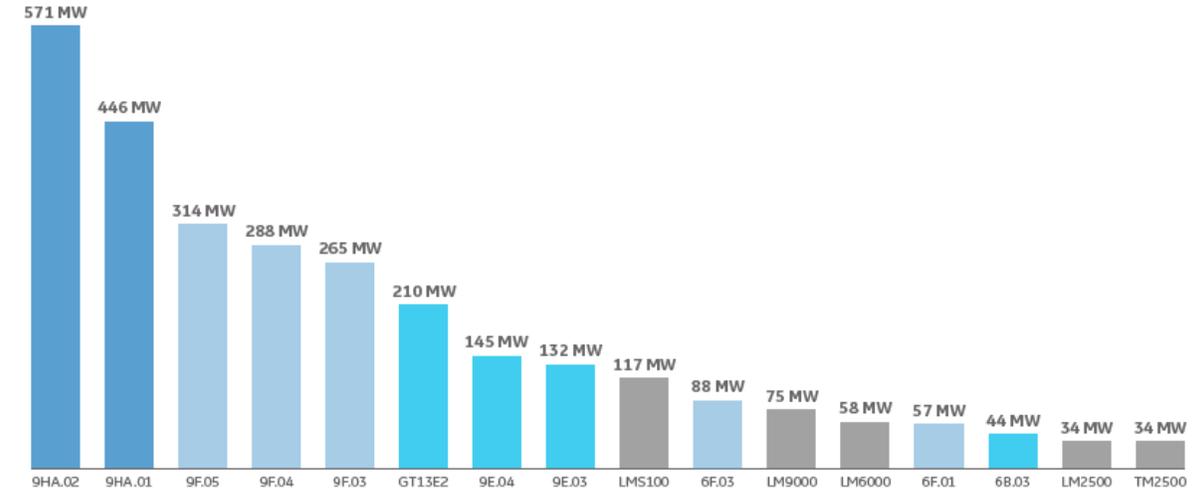
- Rugged and available, even in harsh climates.
- Industry-leading fuel flexibility, burning more than 50 gases and liquids.
- Quick installation for fast-track projects.
- More than 3,700 installed units with more than 217 million combined operating hours.

COMPACT AND PROVEN AERODERIVATIVES

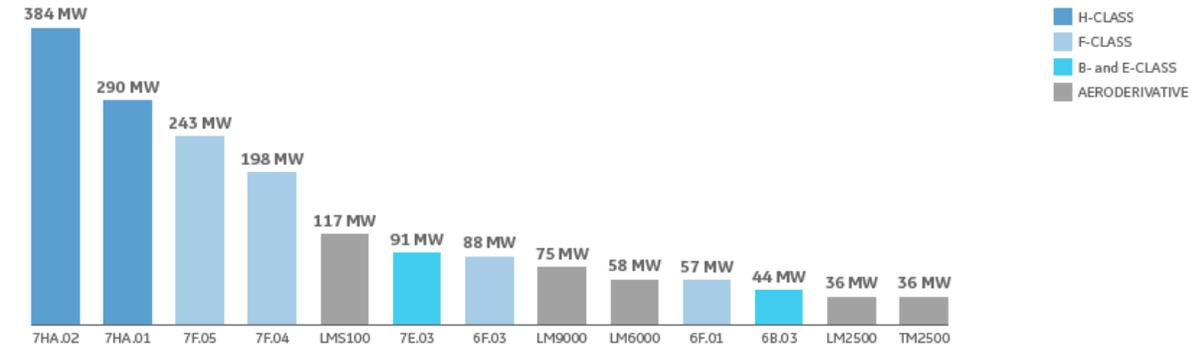
- Flexible and reliable power generation packages with aviation-derived engines.
- More than 100 million operating hours acquired over the last 45 years.
- Up to 44% simple cycle efficiency and 56% combined cycle efficiency with fast startup, high ramp rates, and outstanding cycling capability.



50 HZ PORTFOLIO BY RATING



60 HZ PORTFOLIO BY RATING

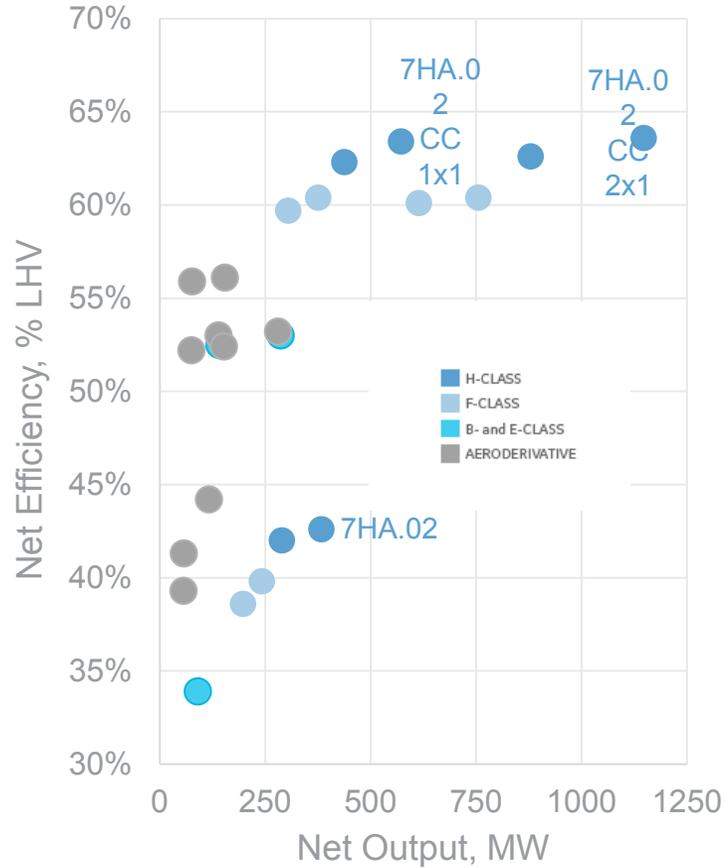


- H-CLASS
- F-CLASS
- B- and E-CLASS
- AERODERIVATIVE

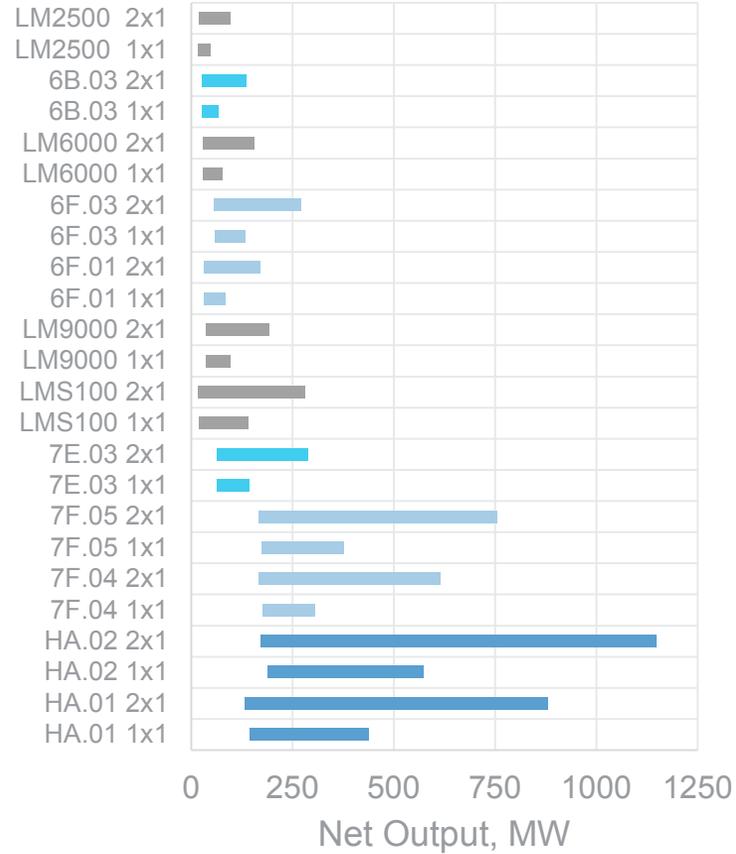
Wide Range of Product Sizes

GE Power - gas turbine portfolio metrics

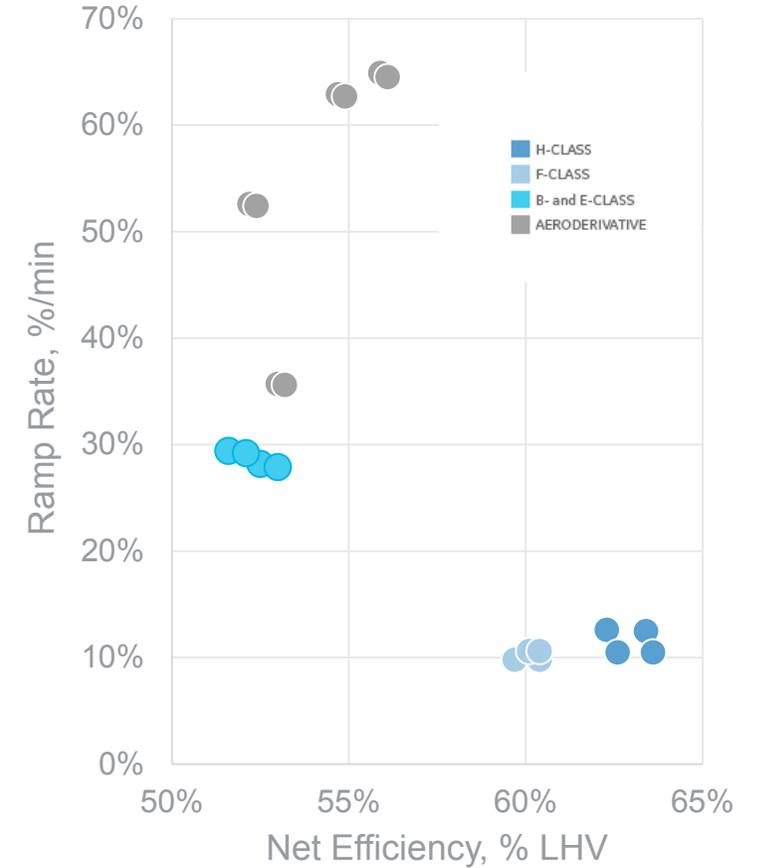
Efficiency



Plant Turndown



Ramp Rate



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

Improving Flexibility & Operating Range

Gas Turbine Fuel Flexibility

GE gas turbine capability with alternative fuels

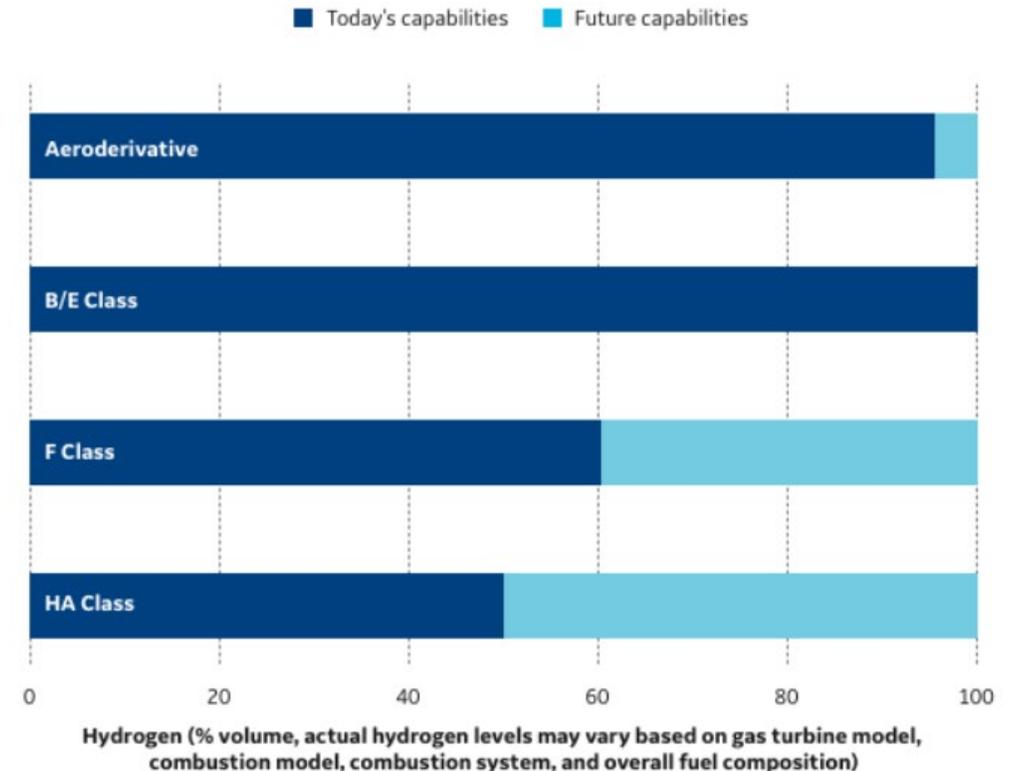
Liquid fuels

- 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

Summary & Discussion Topics

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 η of 55% & faster ramps/starts with hybrid storage

How to Design CCS for Forward-Looking Operating Profile

