



GE Power

# Towards 65% efficiency: GE solution for advanced combined cycle power plant with HA gas turbine

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# GE Power

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# Global electricity trends

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**1.1** billion  
people **lack**  
**access** to  
reliable power

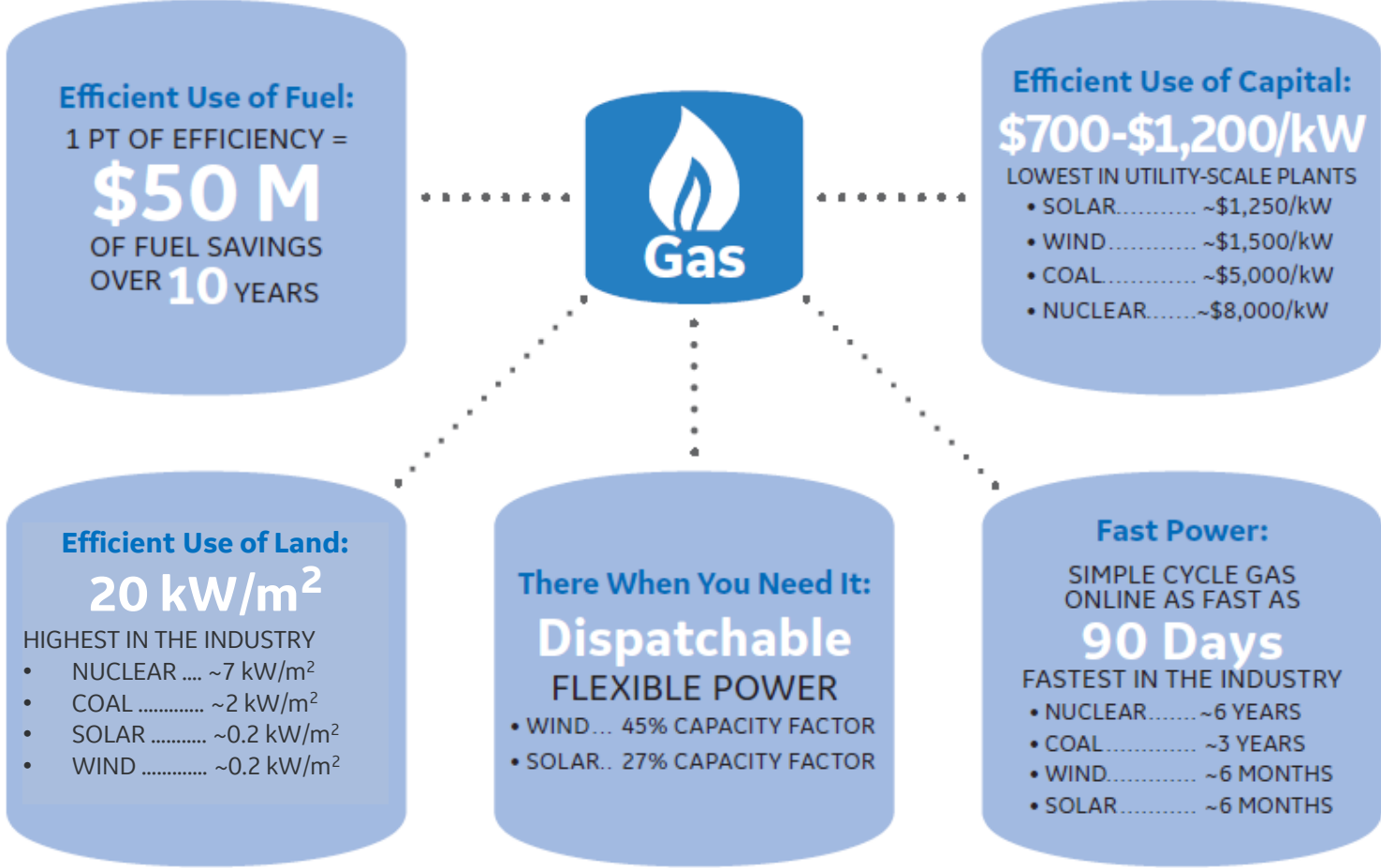
## Landscape Changing

Gas will continue to play a key role,  
more power generated in the U.S.  
**using gas** than from **any other**  
**fuel source** in 2016

**~20%** of  
power added in the  
next decade predicted  
to be **gas power**



# Gas: A natural choice in power generation mix



Source: IEA, IHS, EIA, EPRI, DoE EE&RE, GE Marketing



# Agenda

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- Product Portfolio
- HA Technology Overview
- Plant Solution / Integrated Systems
- Operational Flexibility
- Fleet Status
- Digital



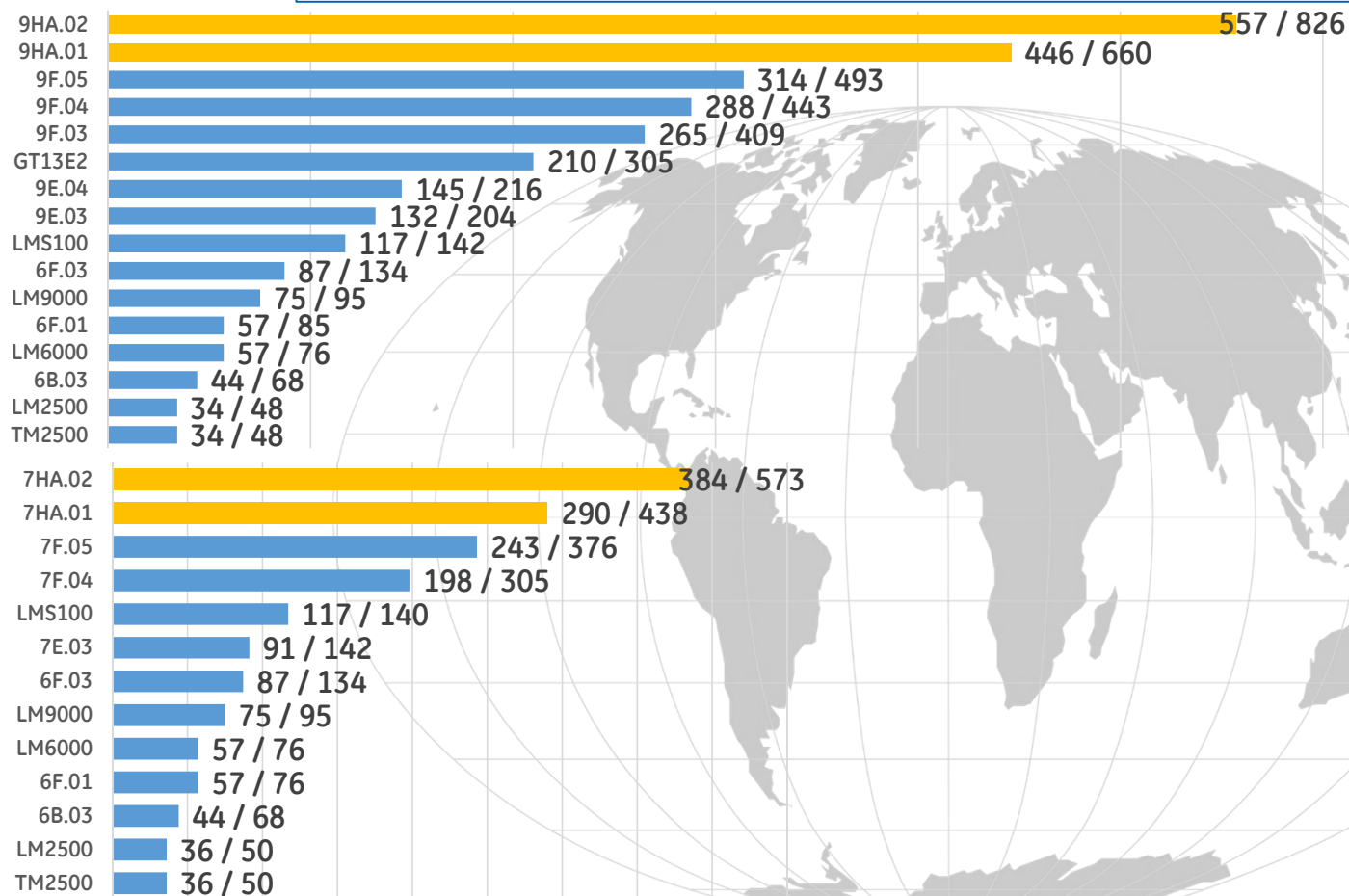
# Product Portfolio





# World's Largest and Most Reliable Gas Turbine Fleet

## Electric Power Output (MW): SC / CC (1x1 Configuration), Net, ISO



+7000 Gas Turbines

+1600 GW

+300M Operating Hours



GE  
Fleet  
(%)

Delta vs.  
Industry  
(% pts)

Reliability 98.0 +0.2

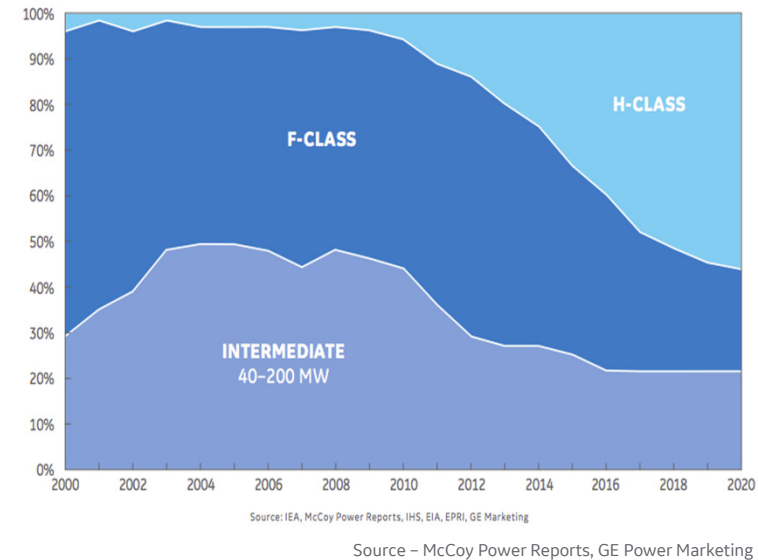
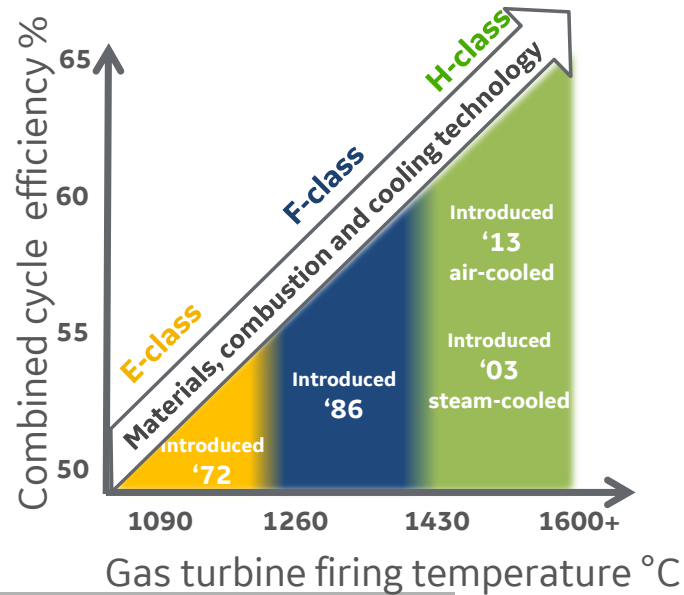
Availability 92.3 +0.7

Start Reliability 97.9 +0.3

Source: ORAP®. All rights to underlying data reserved: SPS®.  
Modified by GE. Rolling 12-month data Jun 2015 – Jul 2016.



# Industry dynamics ... shifting to higher efficiency flexible H-Class



## The H class advantage

- 1 50%+ less cost/kw than all other energy sources  
1 Gas Turbine powers **750,000** homes
- 2 Best power density/land use of all technologies  
1,100mw Combined Cycle Plant requires **17** acres of land
- 3 Operating flexibility & dispatchability offsets renewables variability  
Full Gas Turbine output in less than **10** minutes
- 4 World record efficiencies...  
~1pt. Combined Cycle Advantage investing for **65%** early/mid next decade





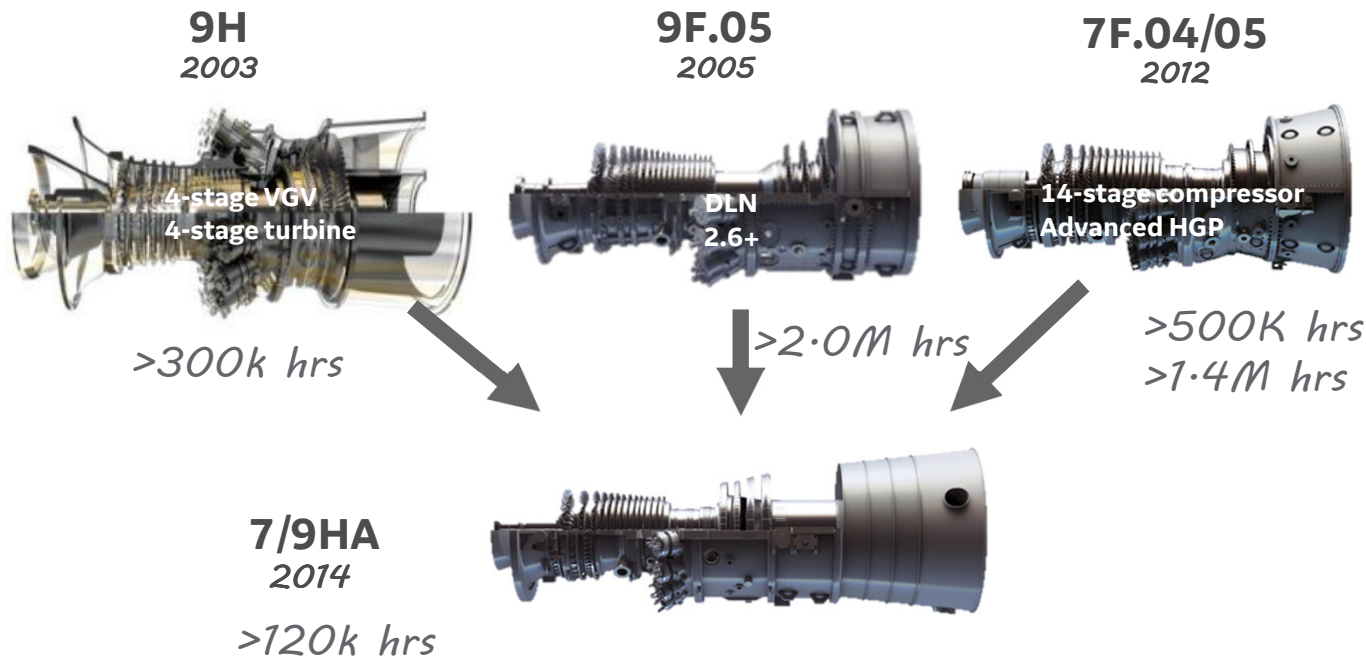
# HA Technology Overview





# HA gas turbine platform evolution

## Three generations of gas turbine technology



Note: Year denotes first operation

### Product Performance

| Product | GT Output (MW) | 1x1 CC Output (MW) | Eff. 1x1 CC (%) |
|---------|----------------|--------------------|-----------------|
| 7HA.01  | 290            | 438                | 62.3            |
| 7HA.02  | 384            | 573                | 63.3            |
| 9HA.01  | 446            | 660                | 63.5            |
| 9HA.02  | 557            | 826                | 64.0            |

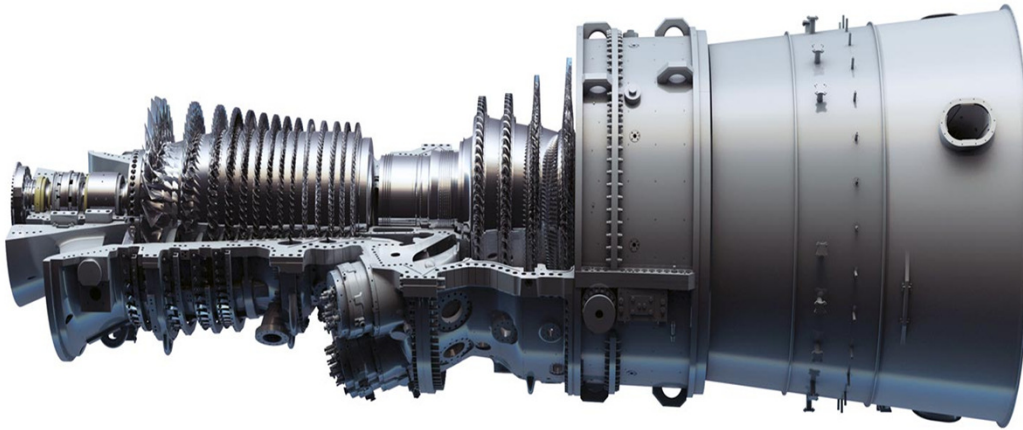
### Fuel & Operational Flexibility

|                    |                              |
|--------------------|------------------------------|
| Fuel               | Rich & Lean NG, #2 dist, ASL |
| Startup Time (Hot) | < 30 minutes                 |
| Turndown           | 25% GT base load             |
| Ramp rate          | 15% GT MW/min                |

Over 15 years of operating experience with H-class technology



# 9HA.02 Industry-Leading Characteristics



**GT Output 557MW**  
**CC Output 826 MW (1x1), 1,658 MW (2x1)**  
**25 ppm Nox @ 15% O<sub>2</sub>**  
**Efficiency 64.0%-64.2%\***

\* Catalog Ratings

✓ **Leading in Performance**  
MW & CC Efficiency

✓ **Leading in operability**  
Turndown & Ramprate

✓ **Simplicity**  
Integrated Cooling & Prime Package

**World's largest, most efficient gas turbine in simple or combined cycle**

\*CC operation, ISO, Net LHV



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# Technology Roadmap – Being delivered on the HA's

## Model & efficiency

HA Today  
**62 → 63%**

IN OPERATION

9HA.02  
**63 → 64%**

BEING MANUFACTURED

Product Growth  
**→ 65%**

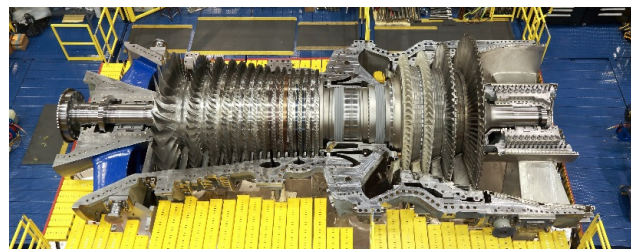
BEING DEVELOPED

## Technologies

14 stage 3D compressor

“Staged” combustion

Titanium S1 comp blade



4-stage turbine

Flowpath sealing

Turbine aero

Micromixer



Micro-channel cooling



Advanced sealing



Cooled LSB



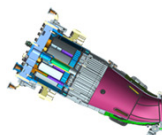
Ultra-Low k TBC



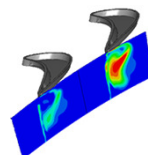
>600C Steam



Advanced Combustion



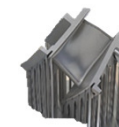
Unsteady aero



Advanced Core/Castings



High-temp additive



High Temp Rotor



Ceramic Matrix Composites



Portfolio of Material, Component and Systems Technologies – Available for new units and upgrades





# Plant Solutions / Integrated Systems





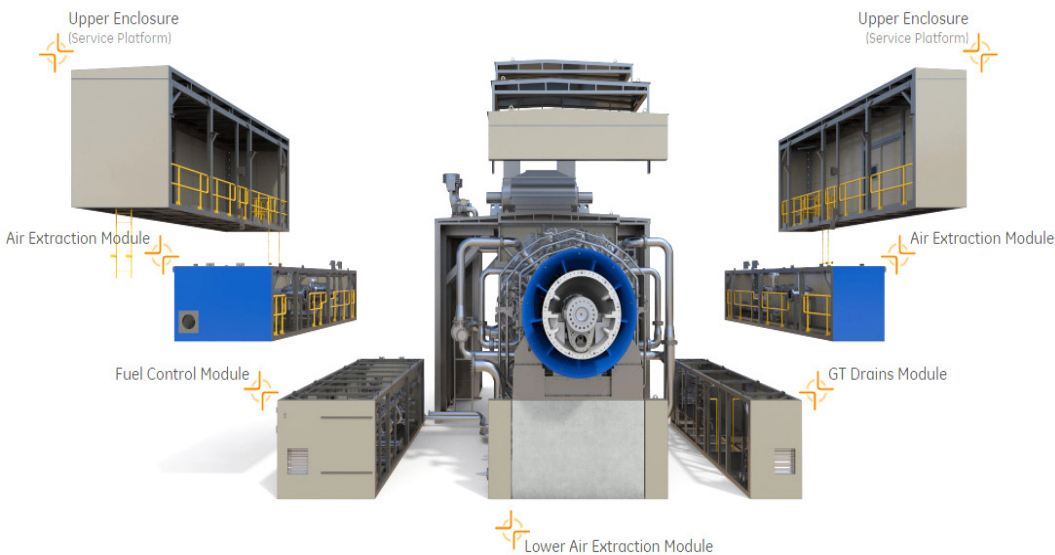
# Faster, De-Risked Construction Schedule

↓ **63%**  
**Field connections**

↓ **55%**  
**Field welds**

↓ **64%**  
**Electrical terminations**

↓ **98%**  
**Field installed valves**



- ✓ Critical path installation cycle shortened **8 weeks**
- ✓ Labor reduced **13,000 hours**
- ✓ Up to **25% faster** installation than F-class

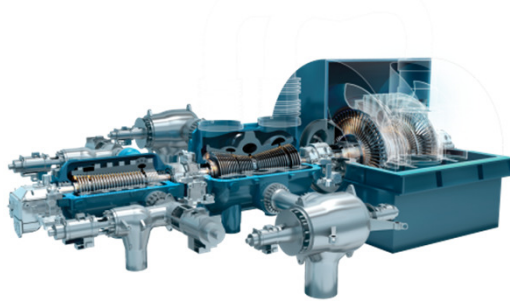
Modular gas turbine approach – Simplifies site construction and unit maintenance



# GE Plant Equipment Portfolio

## Bottoming cycle

Combined cycle steam turbines

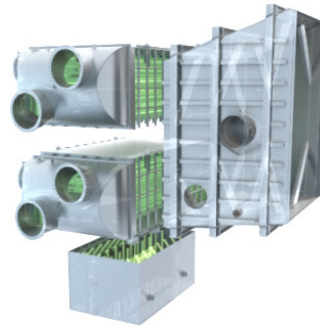


HRSGs

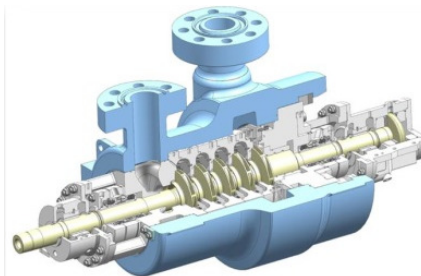


## Mechanical BoP

Condensers

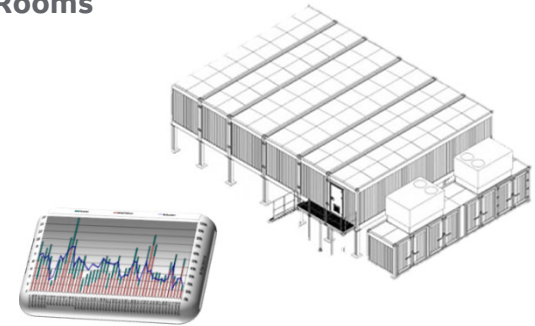


Pumps



## Electrical BoP

E-Rooms



GCB, power transformers ...



The GE store: World leading plant equipment portfolio all out of one hand

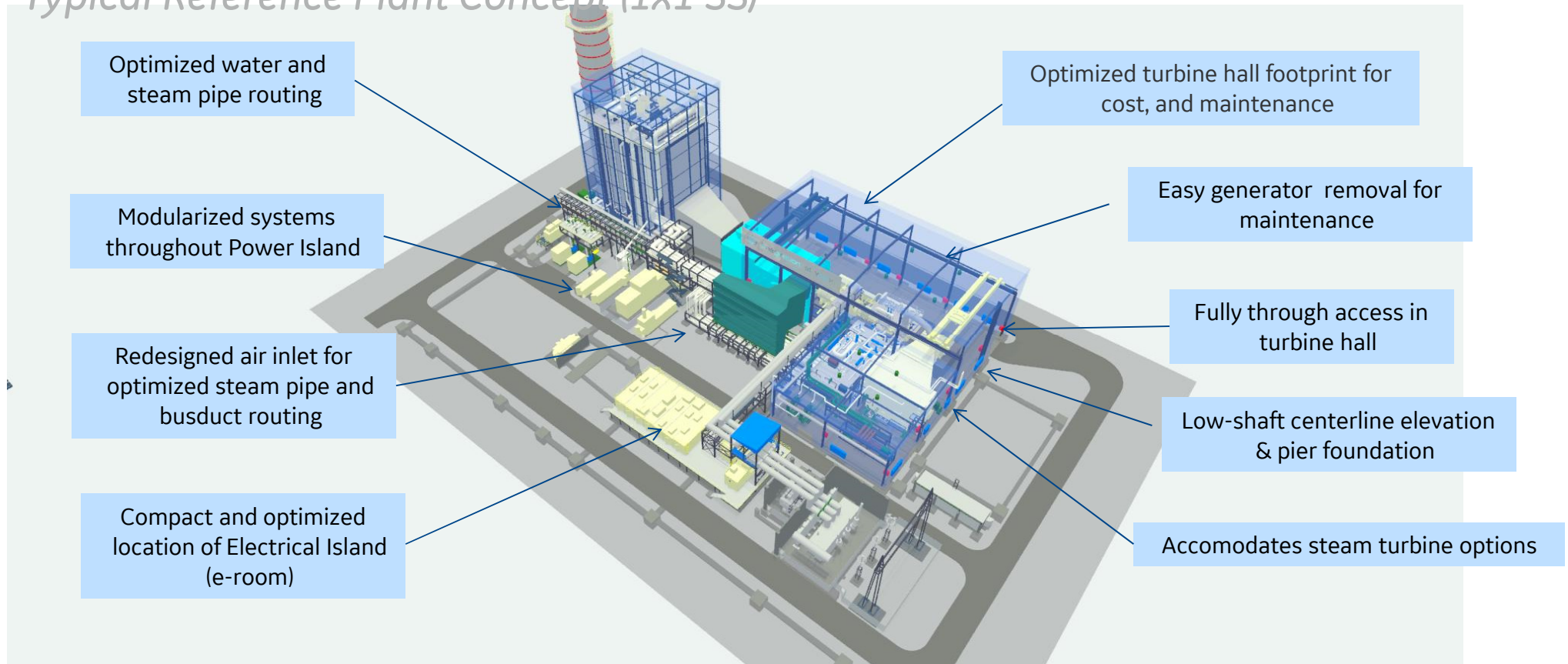
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# Industry Leading Plant Capability

## *Typical Reference Plant Concept (1x1 SS)*



Baseline arrangement optimized for cost, constructability and maintenance



Yes We Do That !

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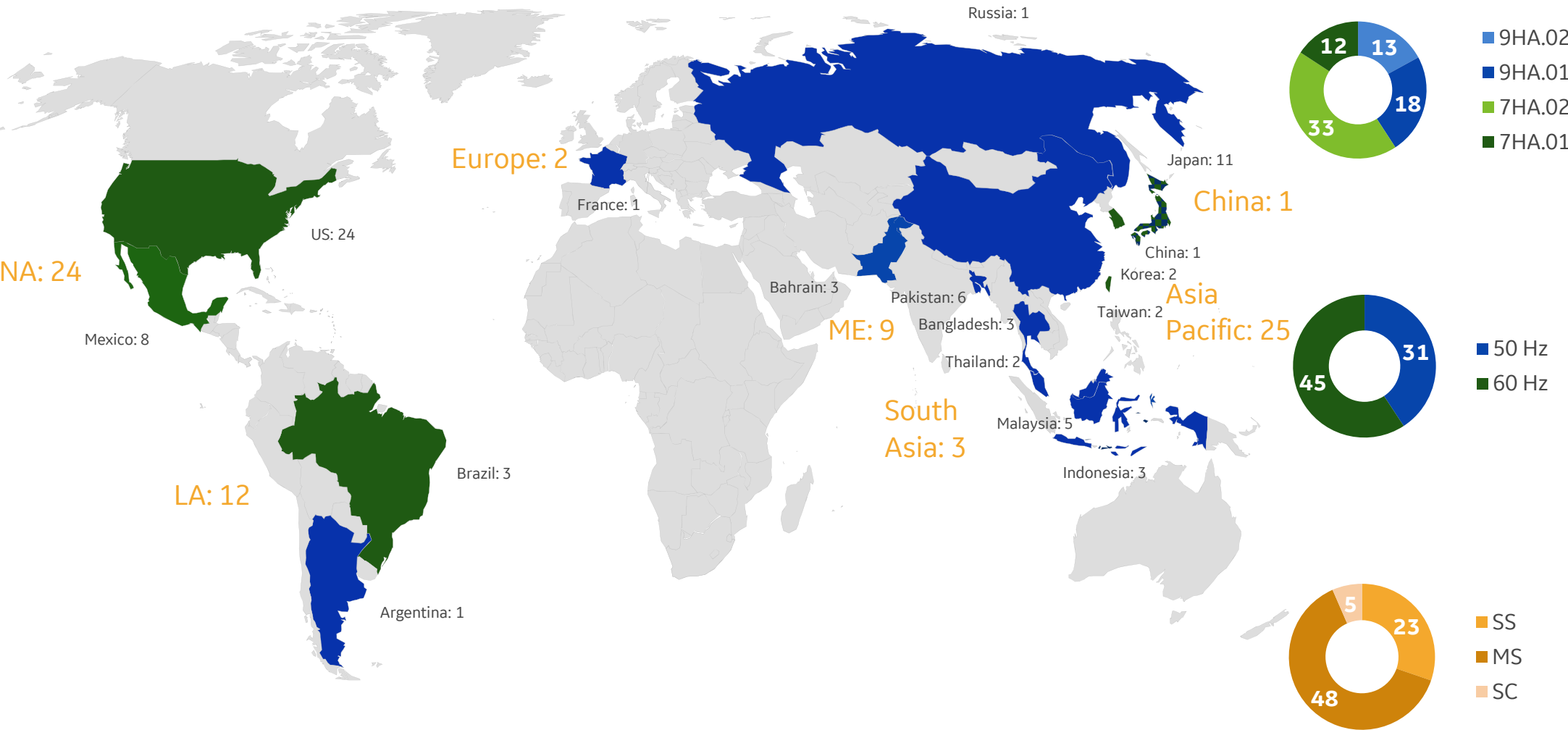
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# HA Fleet Update



# Orders: 76 Units





# HA portfolio market dynamics and fleet update

## Orders and commercial operation

**76** orders

**50** units shipped

**24** COD

**> 120** k/hours operation

**1,541** fired starts

**57** Selections

### COD

**EDF** ... 9HA fleet leader **>13,000** hours

**Exelon** ... **27,379** hours running

**Pakistan** ... All 6 units in service  
with **17,236** hours

**2 base-load 9HA.01's**  
Continuously operating at **11,713** hours

**Chubu Nishi Nagoya**

**> 63 % efficiency**

**7HA.01** ... Continuously operating  
at **14,718** hours

**7HA & 9HA have surpassed 8,000 hr threshold**

### Commissioning

**Multiple 7HA.02's (USA)**

**Alba (3) 1x1 9HA.01** ... Bahrain

**9HA.02** ... 1<sup>st</sup> COD in mid 2020



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# HA Experience growing rapidly

30 GT's operating >120,000 operating hours

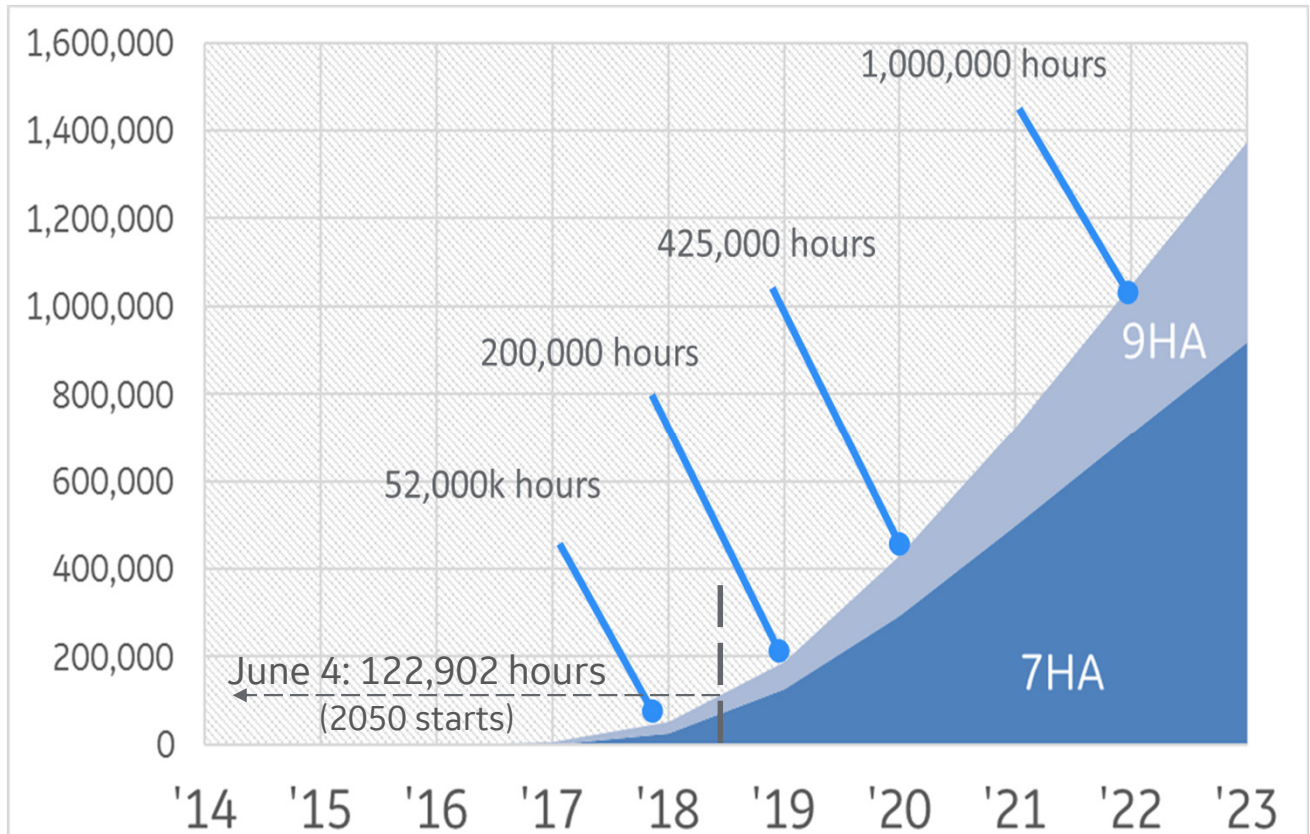
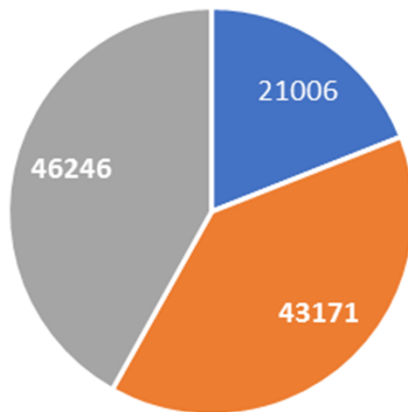
76 units sold

25 customers

15 countries

Operating Hours

■ 7HA.01  
■ 7HA.02  
■ 9HA.01



Fleet hours growing rapidly... accelerating thru 2018





# Operational Flexibility



# Energy mix – the challenge beyond electricity production

Power production as per traditional PPAs strains revenue stream





# Energy mix considerations

Balancing equation of renewables + other generation

## Elements of sustainable grid



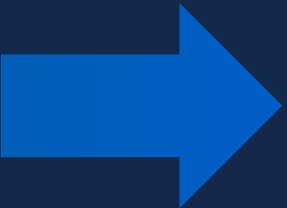
Carbon footprint



Consumer cost



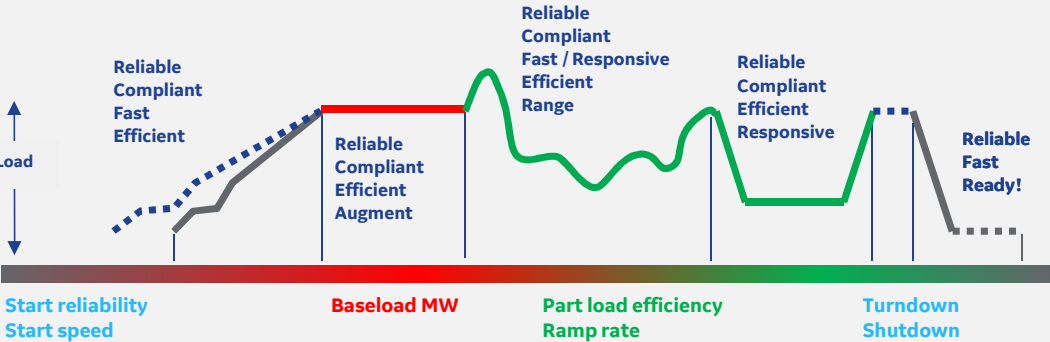
Reliability



## Needs for renewables integration

Respond to transients in renewables “fuel” availability  
Shift inflexible tech (coal, nuclear, hydro) to flexible sources  
Capability to support unseen/uncontrolled distributed gen

## How gas can help ...



Sources: GE Energy Consulting, National Bureau of Economic Research



### Fast & Reliable Start

Fast MWs when renewables ramp down



### Baseload MW & Efficiency

Lowers consumer cost and carbon footprint



### Fast Ramping & Partload Operation

Real-time, efficient response to minute changes



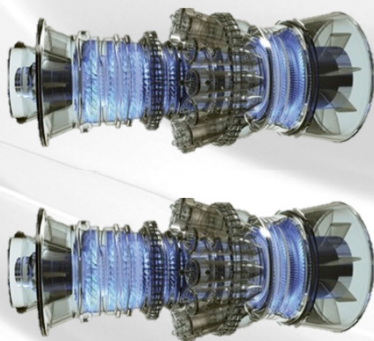
### Low Turndown

Accommodate renewables, maintain reliability



# H-Class driving fuel savings & lower carbon footprint

**F class**  
(2x1 800 MW)  
**54%  
EFFICIENCY**



**VS**

**H class**  
(1x1 800 MW)  
**64%  
EFFICIENCY**



**€30M/year**  
**FUEL SAVINGS**

**15%**  
**CO2 REDUCTION (t/y)**

\* €6/GJ natural gas, 5000 h/y operation, 800MW plant



**Technology Advancing Gas Industry**  
**Reducing CO2 footprint and saving Plant Fuel Costs**

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Digital





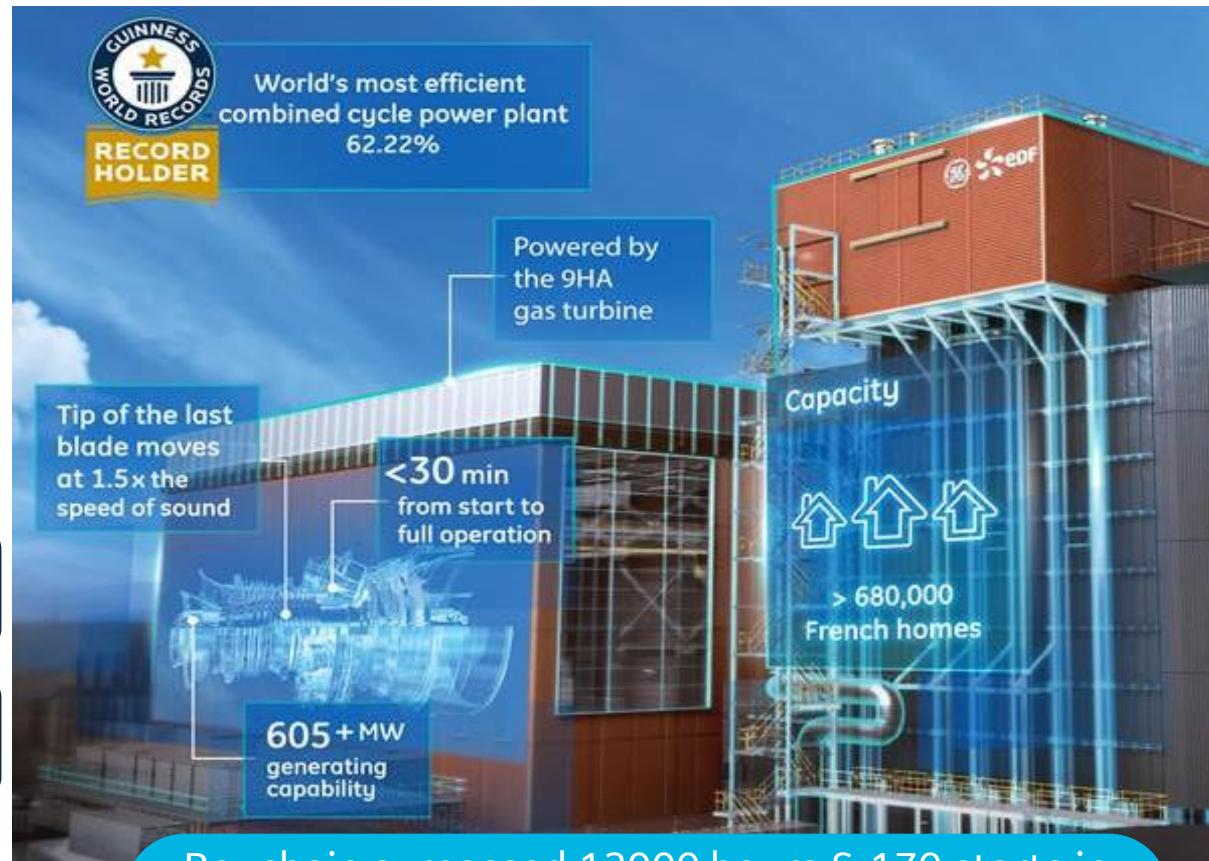
# HA plant record performance achievement

## HA power plant with digital infrastructure (June 2016)

- Foundation Fieldbus \* with smart devices and sensors
- Integrated plant controls
- Unit controls with MBC
- ActivePoint HMI
- Rapid response

Digital applications (Predix\*edge) implementation (November 2016)

Digital solutions (Predix cloud) implementation (June 2017)



Bouchain surpassed 12000 hours & 170 starts in operation



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# Summary

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- 1 Power generation landscape changing
- 2 CCGTs will play a key role in the transition
- 3 Digital and additive manufacturing are enablers
- 4 High efficiency, fuel and operational flexibility
- 5 Continue to invest in core gas turbine and combined cycle technology



An aerial night view of a city, likely New York City, showing a dense grid of skyscrapers and streets. The city is illuminated with various lights, including streetlights, building lights, and traffic lights. The perspective is from a high angle, looking down on the city.

# GE POWER

We'll never be satisfied until the entire world has power.



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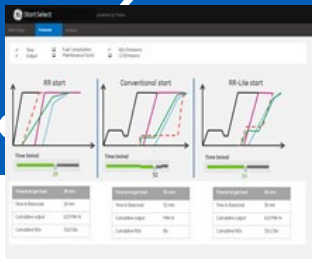
Back-ups



# Example applications

## FLEXIBILITY

Startup path options  
Fast load following

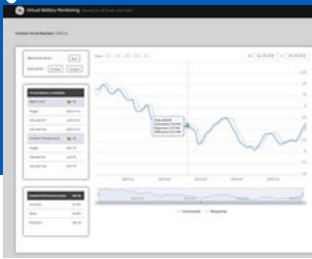


### Start select

- Optimize for
- Start time
  - Fuel burn
  - Emissions
  - Maintenance

### Virtual battery

- Ancillary services payment
- AGC with reduced reserve margin
- Up to 95% performance score



## CAPACITY

Boost output  
manage trades

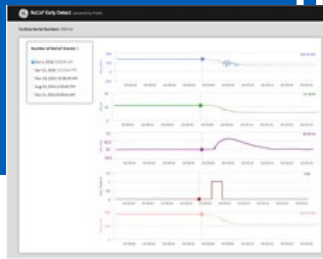


### Dispatch optimizer

- Accumulate energy credits
- Maintain outage interval
- MWh ↑, maximize profitability

## RELIABILITY

Enhanced grid services



### Grid services

- Predict, detect grid disturbance
- Extreme rate of change of frequency event ride-thru

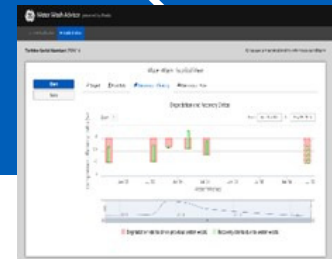
## AVAILABILITY

Performance recovery  
odometers



### GT odometer

- Real-time FFH and FFS analytics
- Project and forecast planned maintenance



### Performance | recovery

- Reduce costs with condition based maintenance
- Increase generation capacity
- Minimize fuel burn

Digital solutions to meet unique customer needs  
Video Digital Power Plant Apps



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# Single Shaft Combined Cycle – Platform for multi-functional value

## ↑ Flexibility with **BATTERY**



### Grid-scale battery energy storage

- ✓ Grid balancing
- ✓ Demand-supply match
- ✓ Energy decoupling
- ✓ Plant re-start support
- ✓ CO<sub>2</sub> footprint reduction

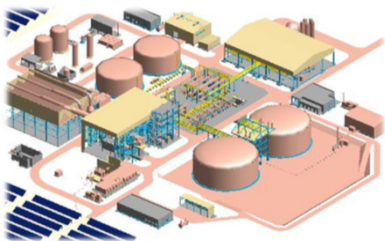
## ↑ Recovery of **WATER**



### Water scarcity relief

- ✓ Retrofittable solution to substitute external water supply
- ✓ Simultaneous reduction of waste water
- ✓ Operating flexibility

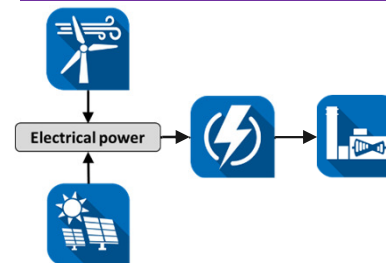
## ↑ Storage with **THERMAL**



### Plant level thermal reservoir

- ✓ Effective store of electricity excess in high temp. heat
- ✓ Fossil fuel reduction
- ✓ No geographical constraint

## ↑ Reducing carbon **EMISSIONS**



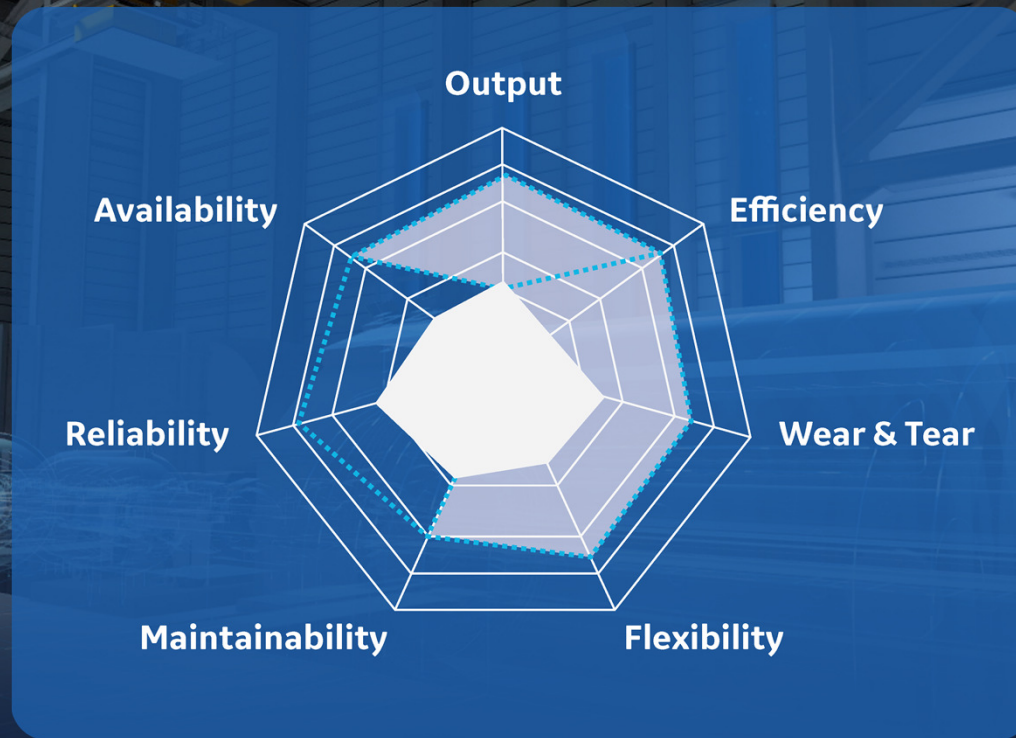
### Green Hydrogen Blends

- ✓ Valorising CO<sub>2</sub>-free hydrogen
- ✓ Natural gas – hydrogen blend flexibility

**DELIVERING MORE VALUE FOR OUR CUSTOMERS**



# Digital – The power of hardware + software



Pushing performance boundaries across the plant

