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

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Dino Pezzella – Senior Sales Manager EU
Global electricity trends

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

**Efficient Use of Fuel:**
1 PT OF EFFICIENCY = $50 M
OF FUEL SAVINGS OVER 10 YEARS

**Efficient Use of Land:**
20 kW/m²
HIGHEST IN THE INDUSTRY
- NUCLEAR .... ~7 kW/m²
- COAL ........... ~2 kW/m²
- SOLAR ........... ~0.2 kW/m²
- WIND ........... ~0.2 kW/m²

**Efficient Use of Capital:**
$700-$1,200/kW
LOWEST IN UTILITY-SCALE PLANTS
- SOLAR.......... ~$1,250/kW
- WIND............ ~$1,500/kW
- COAL............. ~$5,000/kW
- NUCLEAR......... ~$8,000/kW

**Fast Power:**
SIMPLE CYCLE GAS
ONLINE AS FAST AS
90 Days
FASTEST IN THE INDUSTRY
- NUCLEAR...... ~6 YEARS
- COAL.......... ~3 YEARS
- WIND.......... ~6 MONTHS
- SOLAR......... ~6 MONTHS

**There When You Need It:**
Dispatchable
FLEXIBLE POWER
- WIND... 45% CAPACITY FACTOR
- SOLAR... 27% CAPACITY FACTOR

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

• 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

<table>
<thead>
<tr>
<th>Model</th>
<th>SC</th>
<th>CC</th>
<th>Electric Power Output (MW)</th>
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<tbody>
<tr>
<td>9HA.02</td>
<td>446</td>
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<td>557 / 826</td>
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+7000 Gas Turbines
+1600 GW
+300M Operating Hours

| Reliability | 98.0 | +0.2 |
| Availability| 92.3 | +0.7 |
| Start Reliability | 97.9 | +0.3 |

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

**Product Performance**

<table>
<thead>
<tr>
<th>Product</th>
<th>GT Output (MW)</th>
<th>1x1 CC Output (MW)</th>
<th>Eff; 1x1 CC, (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7HA.01</td>
<td>290</td>
<td>438</td>
<td>62.3</td>
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<tr>
<td>7HA.02</td>
<td>384</td>
<td>573</td>
<td>63.3</td>
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<tr>
<td>9HA.01</td>
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<td>63.5</td>
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<td>9HA.02</td>
<td>557</td>
<td>826</td>
<td>64.0</td>
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**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

Note: Year denotes first operation

Over 15 years of operating experience with H-class technology
9HA.02 Industry-Leading Characteristics

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

- **Leading in operability**
  - Turndown & Ramprate

- **Simplicity**
  - Integrated Cooling & Prime Package

GT Output  557MW  
CC Output  826 MW (1x1), 1,658 MW (2x1)  
25 ppm Nox @ 15% O2  
Efficiency  64.0%-64.2%*

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

<table>
<thead>
<tr>
<th>HA Today</th>
<th>HA Today Technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>62 → 63%</td>
<td>14 stage 3D compressor</td>
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<tr>
<td></td>
<td>“Staged” combustion</td>
</tr>
<tr>
<td></td>
<td>Titanium S1 comp blade</td>
</tr>
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<tbody>
<tr>
<td>63 → 64%</td>
<td>4-stage turbine</td>
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<td></td>
<td>Flowpath sealing</td>
</tr>
<tr>
<td></td>
<td>Turbine aero</td>
</tr>
</tbody>
</table>

### Technologies

- 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

- 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)

- Optimized water and steam pipe routing
- Modularized systems throughout Power Island
- Redesigned air inlet for optimized steam pipe and busduct routing
- Compact and optimized location of Electrical Island (e-room)
- Optimized turbine hall footprint for cost, and maintenance
- Easy generator removal for maintenance
- Fully through access in turbine hall
- Low-shaft centerline elevation & pier foundation
- Accomodates steam turbine options

Baseline arrangement optimized for cost, constructability and maintenance
HA Fleet Update
Orders: 76 Units

NA: 24
- US: 24
- Mexico: 8
- Argentina: 1

Europe: 2
- France: 1

LA: 12
- Brazil: 3

ME: 9
- Bahrain: 3
- Pakistan: 6
- Bangladesh: 3

South Asia: 3
- Bangladesh: 3

Asia Pacific: 25
- Japan: 11
- Korea: 2
- Taiwan: 2
- Thailand: 2
- Malaysia: 5
- Indonesia: 3

China: 1
- China: 1

Argentina: 1

Brazil: 3

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Brazil: 3
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

Commissioning
Multiple 7HA.02’s (USA)
Alba (3) 1x1 9HA.01 ... Bahrain
9HA.02 ... 1st COD in mid 2020

7HA & 9HA have surpassed 8,000 hr threshold
HA Experience growing rapidly

30 GT’s operating >120,000 operating hours
76 units sold
25 customers
15 countries

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

CHALLENGES

- Fluctuating Renewables
- Decarbonization
- Grid Limits
- Evolving Market

OPPORTUNITIES

- Power-Water Nexus
- Energy Storage
- Municipal & Industrial Heat
- Systemic Solution

Multi-functional value proposition
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 ...

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

Sources: GE Energy Consulting, National Bureau of Economic Research

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H-Class driving fuel savings & lower carbon footprint

F class
(2x1 800 MW)

54% EFFICIENCY

H class
(1x1 800 MW)

64% EFFICIENCY

VS

€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

* "Trademark of General Electric Company"
Summary

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
GE POWER

We'll never be satisfied until the entire world has power.
Back-ups
Example applications

**FLEXIBILITY**
- Startup path options
- Fast load following

**CAPACITY**
- Boost output
- Manage trades

**RELIABILITY**
- Enhanced grid services

**AVAILABILITY**
- Performance recovery
- Odometers

---

**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

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

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

**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

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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

Grid-scale battery energy storage
- Grid balancing
- Demand-supply match
- Energy decoupling
- Plant re-start support
- CO₂ footprint reduction

Storage with THERMAL

Plant level thermal reservoir
- Effective store of electricity excess in high temp. heat
- Fossil fuel reduction
- No geographical constraint

Recovery of WATER

Water scarcity relief
- Retrofittable solution to substitute external water supply
- Simultaneous reduction of waste water
- Operating flexibility

Reducing carbon EMISSIONS

Green Hydrogen Blends
- Valorising CO₂-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