



GE Power

Advanced Multi-Tube Mixer Combustion for 65% Efficiency, DE-FE0023965

Michael J. Hughes – Principal Investigator
Combustion Aerothermal Technical Leader
Jonathan D. Berry - Combustion Mechanical Technical Leader

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Agenda

Advanced Multi-Tube Mixer Combustion, Phase II

- Project Schedule & Milestones
- 3100F Integrated System
- Full Scale Test Stand

Advancements in H Class Gas Turbine Combined Cycle

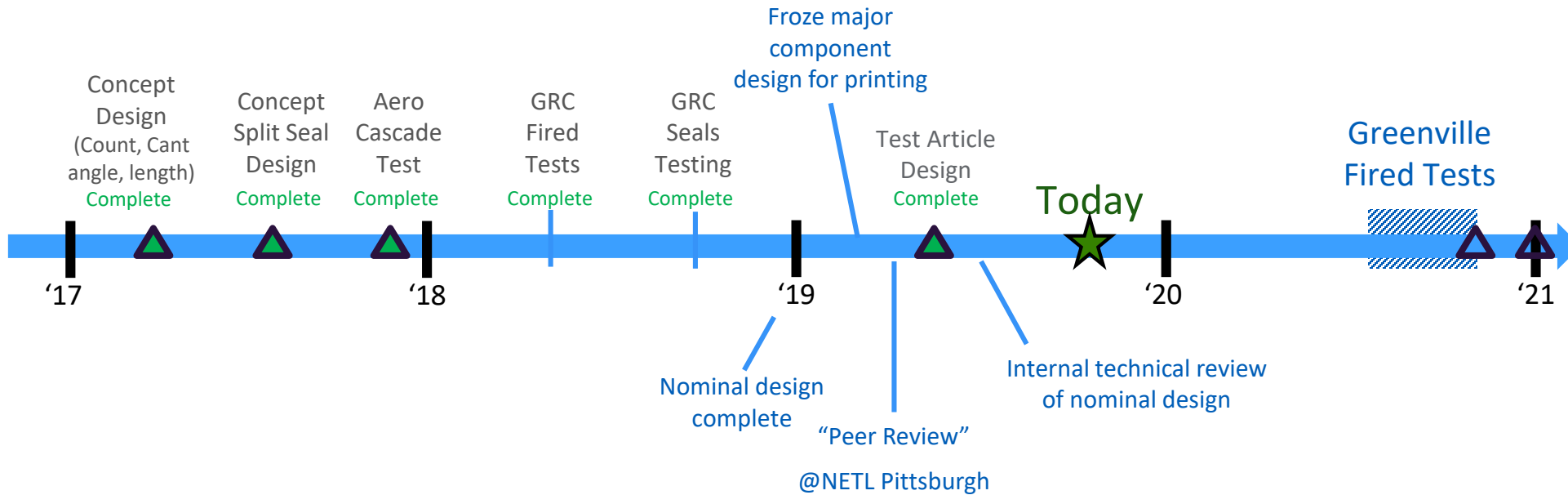
- Making an Impact with the HA Gas Turbine
- New members of the HA product set. Both with DLN2.6e!
9HA.02 through factory testing. 7HA.03 recently announced.

Advanced Multi-Tube Mixer Combustion Phase II

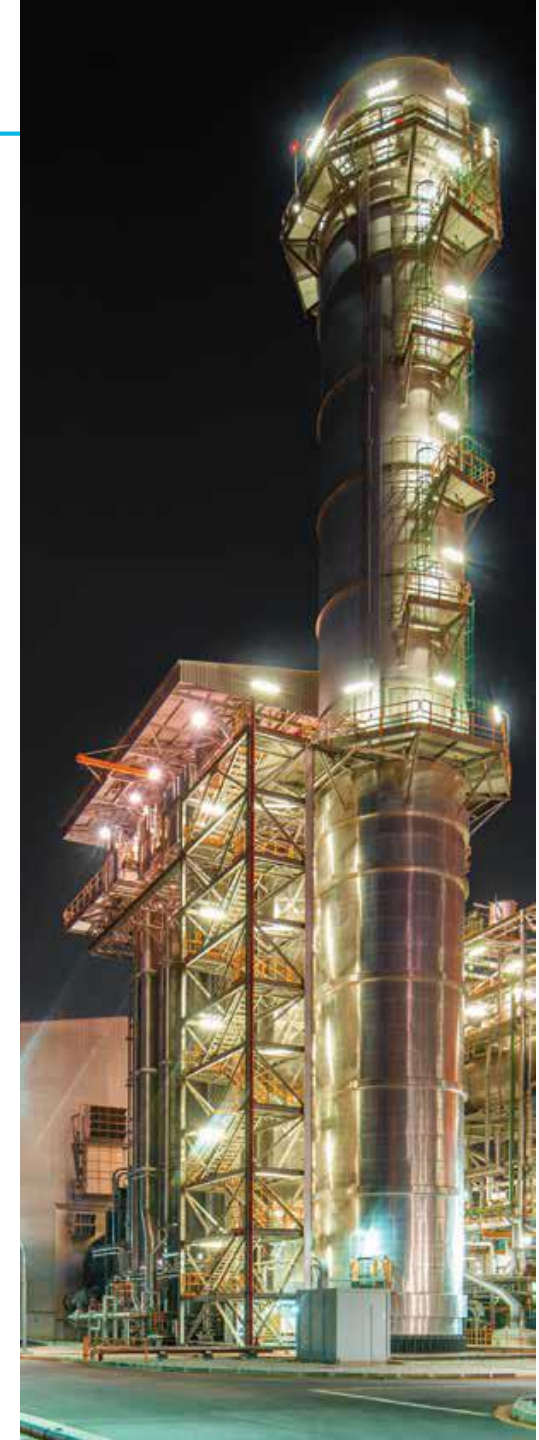
... Integrating the best of DoE technologies ... moving
toward 65% combined-cycle efficiency

Advanced Multi-Tube Mixer Combustion Phase II

The overall objective of this Phase II project is to mature the 3100F Integrated System from the conceptual system conceived under Phase I into a working system demonstrated in a full-scale fired test. That test will be conducted at GE's Greenville Gas Turbine Technology Laboratory (GTTL) and will feature multiple full-scale test articles in a hot cascade arrangement.



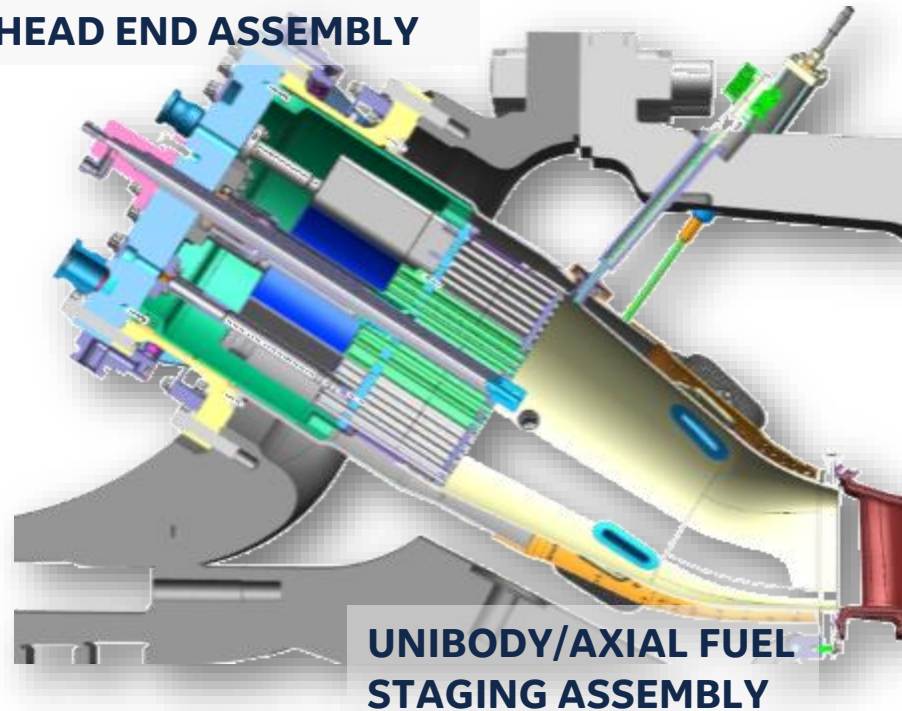
Analytically Drive Design



3100F Integrated System

DLN2.6e (9HA.02, 7HA.03)

**ADVANCED PREMIXER
HEAD END ASSEMBLY**

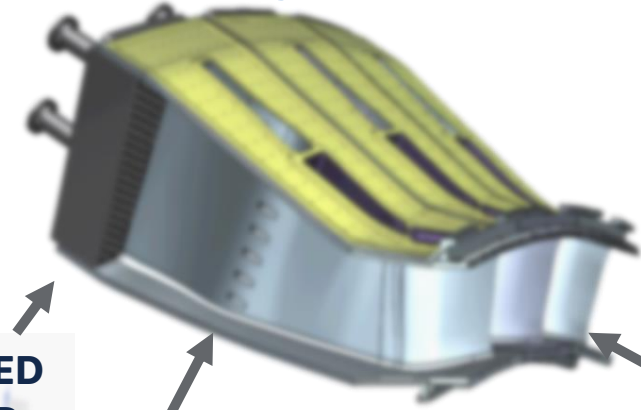


3100F Integrated System

**ADVANCED
PREMIXER**

**AXIAL FUEL
STAGING**

**TURNING
VANES**



- Retains both Advanced Premixer and Axial Fuel Staging.
- Combines Unibody & S1N into one structure
 - ✓ Leakage reduced. Increased Tfire.
 - ✓ Parts removed. Lower Cap Ex.
- These are large parts. How to make test articles?

The 3100F Integrated System is an elegant fusion of the combustor and first stationary turbine vane. It is the first system to fully leverage the design and packaging options that the Micro Mixer and Axial Fuel Staging components allow. In return the system's unique geometry gives the MM & AFS a favorable environment in which to operate.



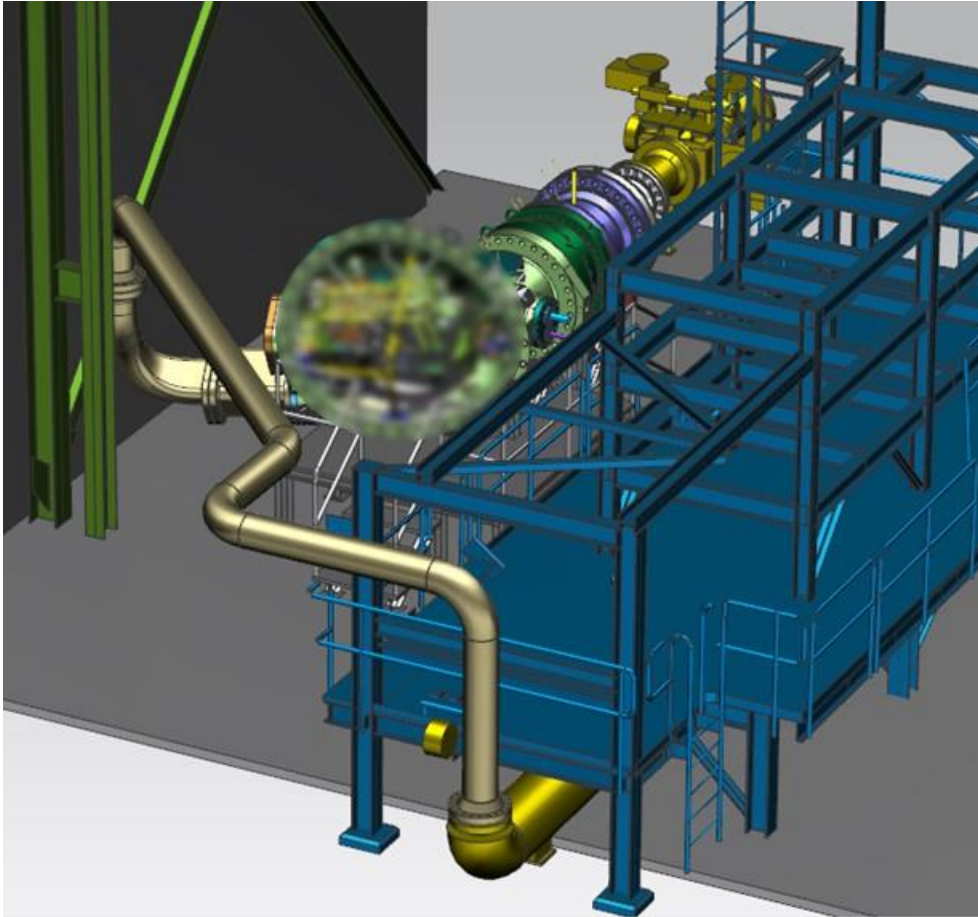
Phase II Program Milestone Status

Milestone	Description	Planned Completion Date	Actual Completion Date	Verification Method	Comments (as of 3/29/2017)
2.1.0.1	Update Project Management Plan	10/21/2016	12/16/2016	PMP file	
2.1.0.2	Kickoff meeting with DOE/NETL	11/30/2016	11/30/2016	Presentation file	
2.2.1.1	Select combustor vane and can count	03/31/2017	04/07/2017	Milestone Memo	GE internal design review 4/3/2017.
2.4.1.1	Complete seals conceptual design	06/30/2017	07/25/2017	Milestone Memo	GE internal design review 7/19/2017
2.5.2.1	Complete first set of trial additive manufacturing with candidate alloys	09/30/2017	09/25/2017	Milestone Memo	Selected HAYNES 282 alloy with Direct Metal Laser Melting process.
2.6.2.1	Complete cold flow cascade rig testing	12/31/2017	12/20/2017	Milestone Memo	Testing complete. Data reduction complete.
2.8.1.1	Complete high temperature EBC testing	06/30/2018	06/26/2018	Milestone Memo	Testing Complete. Data reduction complete.
2.7.1.1	Multi-can, full-scale combustor test article design completed	04/30/2019	04/30/2019	Milestone Memo	Design of GTTL test articles is complete.
2.7.3.1	Complete multi-can rig testing	09/30/2020		Milestone Memo	Test stand and facility design in-process. Test articles manufacturing is in process.
2.10.0.1	Conclusions and documentation	12/31/2020		Final report	



Full Scale Testing of Multiple Ducts

The team has chosen to build a test stand rather than adapt an existing stand. This allows rapid hardware change-outs, access for next generation measurement technologies, and also better ergonomics for the assemblers.



Considerations for testing combustor/turbine combinations:

- The system now has turning. The test stand need to turn.
- Exhaust gas is >3000F at 0.8 Mach.
 - Exhaust duct thermals.
 - Emissions measurement is tricky.
- How can a small number of ducts feel like they're in an engine?
- Running multiple ducts is like running multiple combustors.
- First of a kind test = Lots of instrumentation. 400+ pieces



Phase II Recap

- ✓ The team has completed the nominal design of the 3100F Integrated System
- ✓ Manufacturing trials for the test articles were successful
- ✓ The nominal design was adapted for a full scale test of multiple ducts
- ✓ Test article manufacturing is well underway
- ✓ Design of the test rig is complete. Procurement has begun.





Technology from Previous DoE Programs Moving into GE Gas Turbine Products:

... cleaner, more flexible, more efficient for installed and new gas turbines

The GE team offers our sincere thanks to the Department of Energy NETL team for supporting this effort, as well as numerous previous collaborations. We would not be able to do this work without your generous support.



Thank you!



The HA continues as **the technology leader** in the industry

2 WORLD RECORDS



Proven technology
40+ units installed ...
415,000+
operating hours

Industry-leading
operating flexibility
<30 min start

World's largest,
most efficient
turbine >64% net
combined-cycle efficiency

Fastest growing fleet
100 units ordered ...

Continuing to build
on **\$2B+ HA**
investment

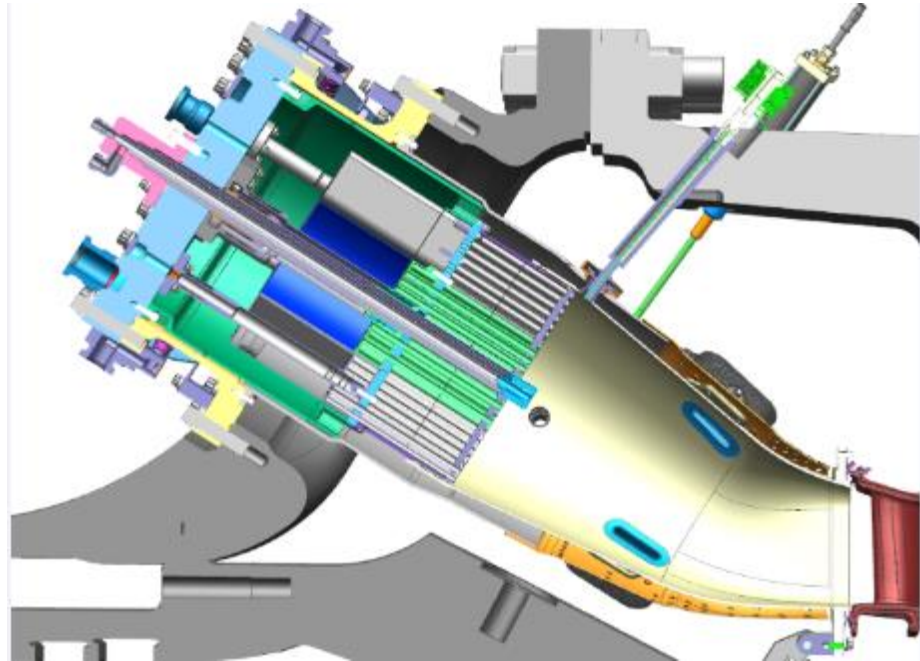




First Production 9HA.02 for Full-Speed, Full-Load Testing & Validation at GE Greenville



DLN 2.6e COMBUSTOR



**ADVANCED PREMIXER
HEAD END ASSEMBLY**

LOW NO_x
IMPROVED OPERABILITY
(DYNAMICS)
FUEL FLEX

**UNIBODY/AXIAL FUEL
STAGING ASSEMBLY**

SHORTER TRANSITION PIECE
LOWER RESIDENCE TIME
AXIAL FUEL STAGING

- LOW NO_x AT LOAD
- LOW CO AT TURNDOWN
- RESPONSE MODE

FIRST SHIPMENTS ON 9HA PLATFORM IN 2018

DLN 2.6e ADVANTAGES

IMPROVED OPERABILITY

LOWER NO_x

FUEL FLEXIBILITY

LOW TURNDOWN

RESPONSE MODE



5 - 9HA.02 Projects in Southeast Asia - 10 Units

Malaysia Track-4A



<https://www.powerengineeringint.com/articles/2018/03/ge-power-services-wins-deal-for-malaysia-1-4-gw-gas-plant.html>

Tambak Lorok



<https://www.power-technology.com/news/newsmarubeni-consortium-to-develop-tambak-lorok-power-plant-in-indonesia-5877955/>

EGAT Bangkokong



<https://asia.nikkei.com/Business/Sumitomo-to-build-largest-Thai-gas-fired-power-plant>

Melaka (MT-4B)



<https://www.thestar.com.my/business/business-news/2017/11/13/malaysias-largest-power-plant-to-begin-ops-in-2021/>

Jawa-1



<http://news.samsungcnt.com/samsung-ct-granted-1760-mw-ccgp-project-indonesia/>

7.6 GW Total ... First Fire in 4Q19 ... First COD in Jul'20



INTRODUCING 7HA.03 ... THE NEXT EVOLUTION OF GE'S INDUSTRY-LEADING HA PLATFORM

BETTER GAS TURBINE PERFORMANCE

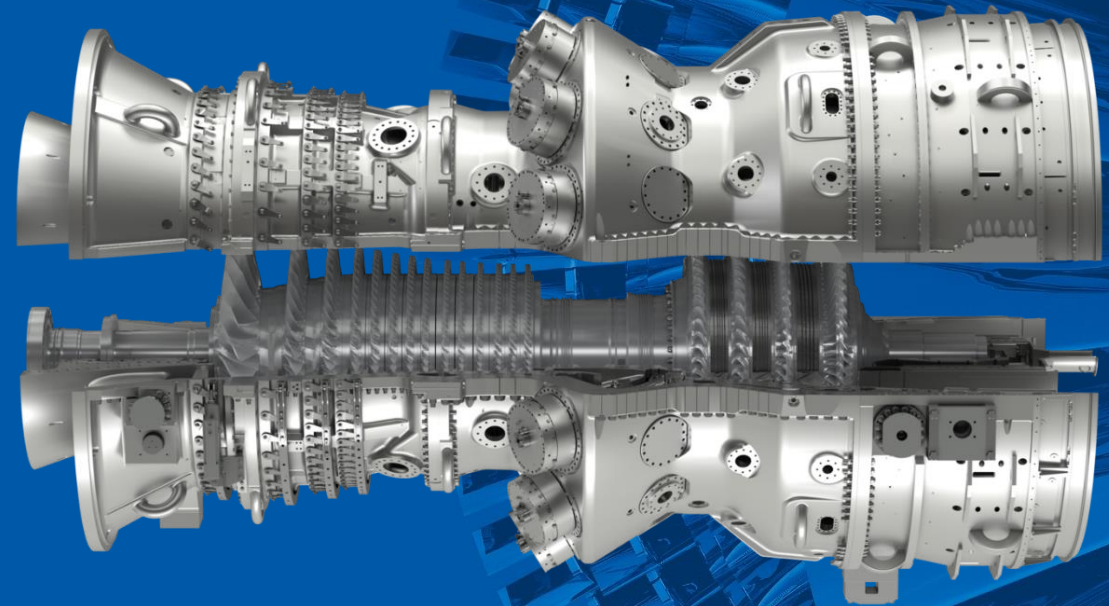
- Highest capacity **60Hz GT ... 430MWs GT; 1282MW** (2x1 CC)
- Unmatched efficiency available at **>64% net CC**
- Lowest \$/kwh conversion of gas to electricity

MOST FLEXIBLE 60 HERTZ GAS TURBINE

- Full GT load in **10 min**, full CC-plant load in **<30 min**
- **75+ MWs** per min ramp rate
- **2X** greater fuel flexibility than the 7HA.02

LOWER CAPITAL COSTS, DECREASED INSTALLATION & COMMISSIONING TIME

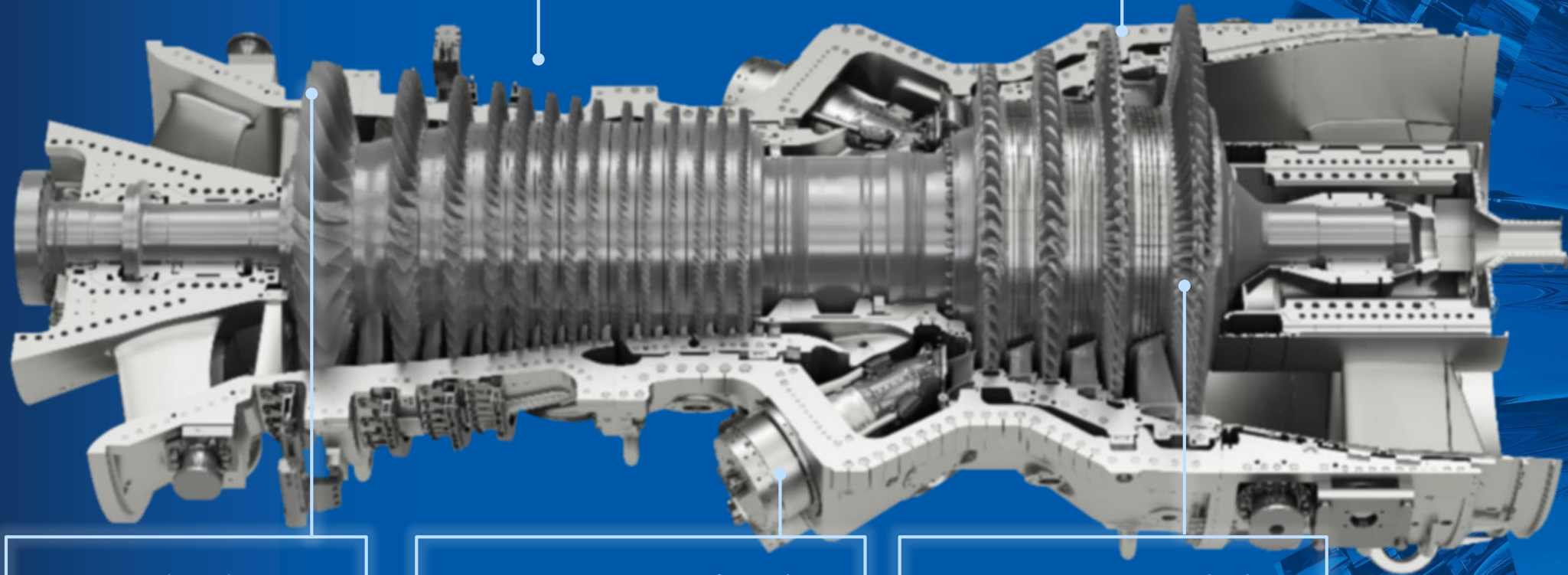
- Largest CC block of power ... lowest installed cost on a \$/kwh basis
- Modularization improvements ... shortens critical path installation cycle by **8 weeks**



PROVEN TECHNOLOGY

14-Stage Compressor

4-Stage Gas Turbine
Without Cooled Cooling Air



Larger Titanium R1
Blade Row (7HA.02)

1st DLN 2.6e Combustion
System on 60 Hz GT (9HA)

Larger Stage 4 Blade
Dual Shrouded (7HA.02)

SIMPLE, RELIABLE ROTOR AND HGP COOLING DESIGN = MORE UPTIME FOR CUSTOMERS



We will never stop innovating ...

Today

Additive
Manufacturing
Cross fleet
solutions

Future

Path to 67%
efficiency
Hybrid
solutions

Industry leading
solutions for best
customer
economics

GREATER EFFICIENCY,
BETTER PERFORMANCE, LOWER O&M COSTS



Summary



Key Takeaways

A decades-long partnership between DoE's NETL and GE Power

... has resulted in technologies that enable cleaner, more flexible, and higher efficiency power generation. Commercial Axial Fuel Staging and Advanced Premixer Pilots originated under this collaboration. These technologies have already had a meaningful impact on E, F, and HA gas turbines.

9HA.02 and 7HA.03, 4th and 5th members of the HA Product Set

... continues the march towards 65%. >64% net efficiency available today. The 9HA.02's DLN2.6e with Advanced Premixer is the latest example of DoE sponsored technologies, matured, and introduced into commercial Gas Turbines.

The 3100F Integrated System

... shows significant performance and cost benefit. Has the potential to change the trajectory of future HA Gas Turbines.



GE POWER

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

