GE Power

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

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Agenda

Advanced Multi-Tube Mixer Combustion, Phase II

- 2 years into a 4 year project…
- Mid-program feedback tests complete.
- Analytical optimization of the “Engine” design is complete.
- No show-stoppers. Anticipated benefits are holding up.
- Initiated design of full scale Greenville test stand and test articles.

Advancements in H Class Gas Turbine Combined Cycle

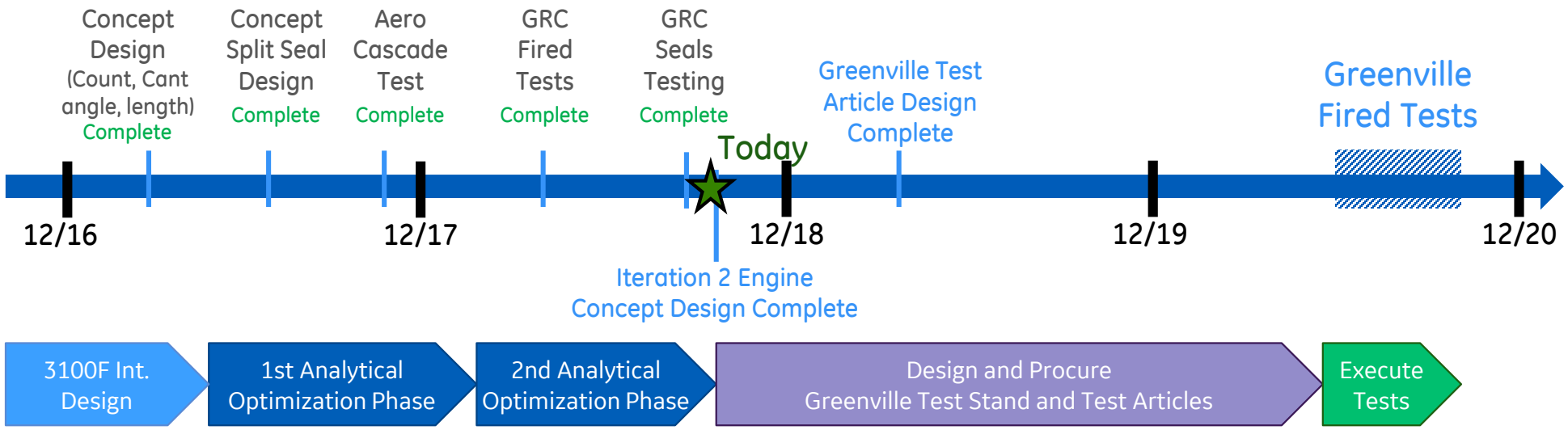
- Making an Impact with the HA Gas Turbine
- 4th member of the HA product set: 9HA with DLN2.6e Combustion System

Advanced Multi-Tube Mixer Combustion Phase II

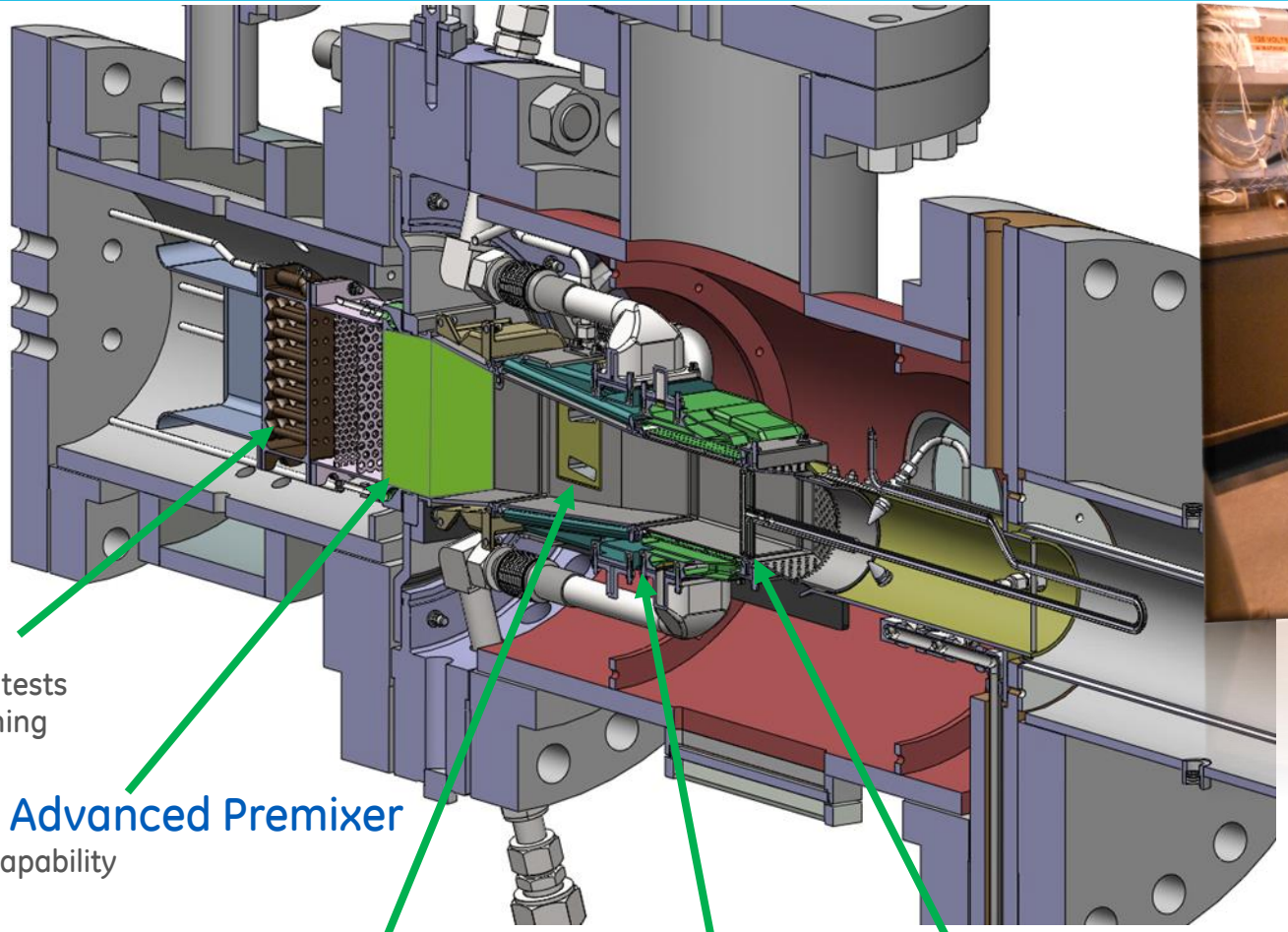
… Integrating the best of DoE technologies … moving toward 65% combined-cycle efficiency

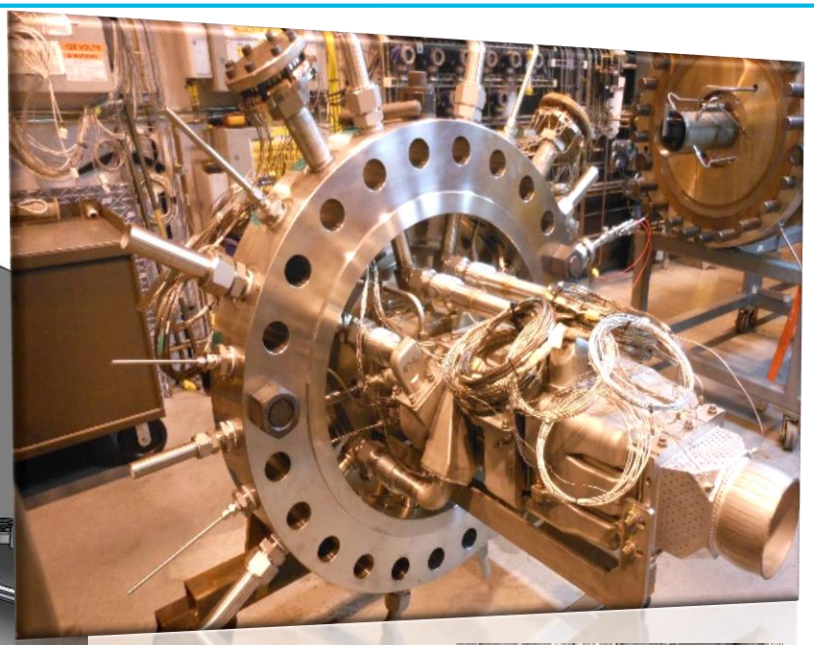
Advanced Multi-Tube Mixer Combustion Phase II

The 3100F Integrated System is the first to be designed around both the Advanced Premixer and Axial Fuel Staging. These building blocks allow system configurations that differ from the traditional can-annular systems found in today's engines. Tight integration with the turbine 1st stage vane reduces cooling flow and cost.



Single-Duct Fired Non-Turning Test at GRC





Pre-Premixer
For perfectly premixed tests
and inlet flow conditioning

Compact Flames Advanced Premixer
with perfectly premixed capability
1-pc DMLM construction

Converging Liner Duct
Relevant dimensions achieved

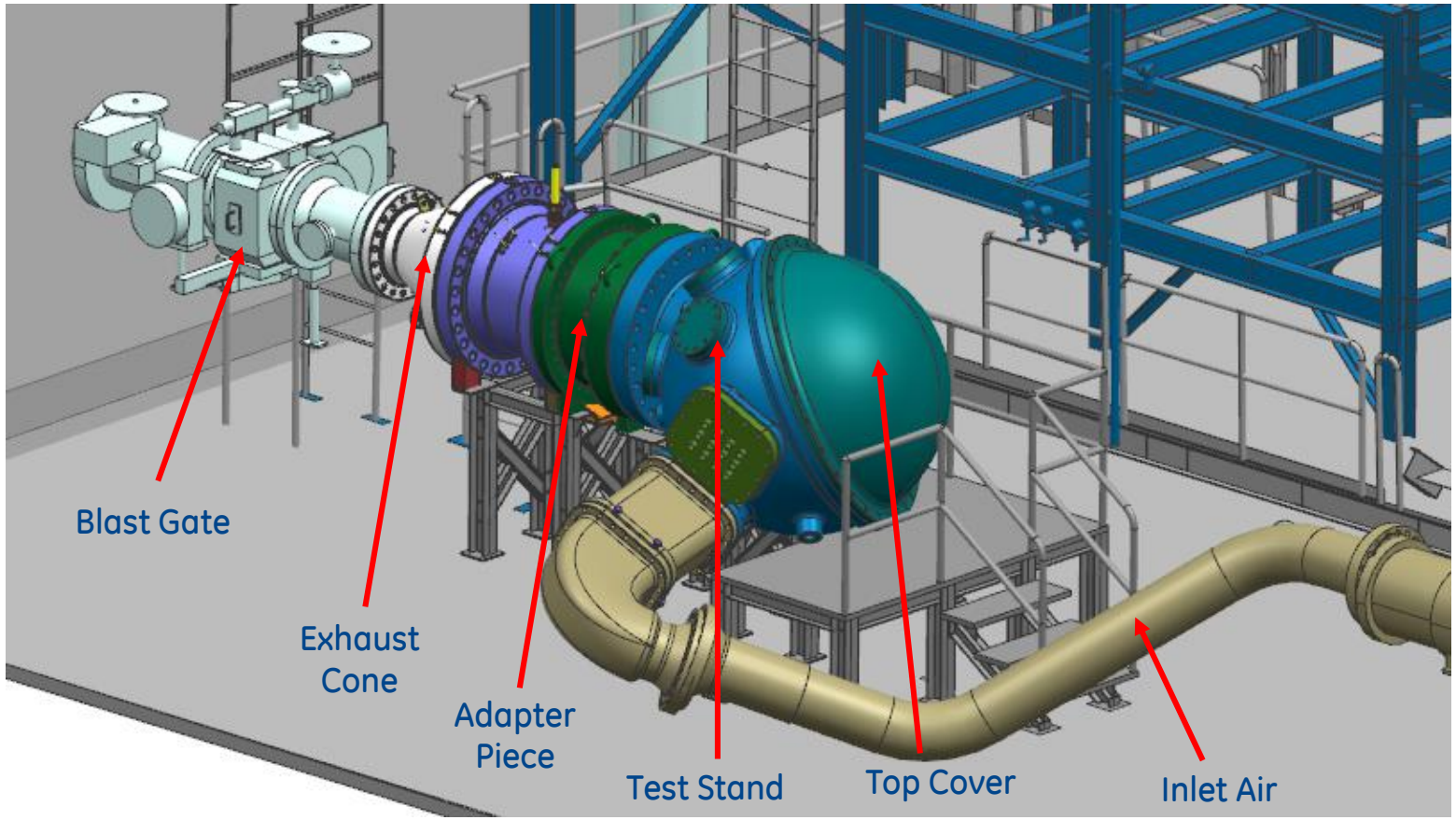
NG-AFS Injectors
Angled. 4x.
Variable AFS air split
Perfectly PM capability
DMLM construction

Cooling Jackets
Low cross flow design
DMLM construction

Axial & Radial Traverse
DMLM multi-element emissions probe
Variable residence time

Full Scale Test Stand

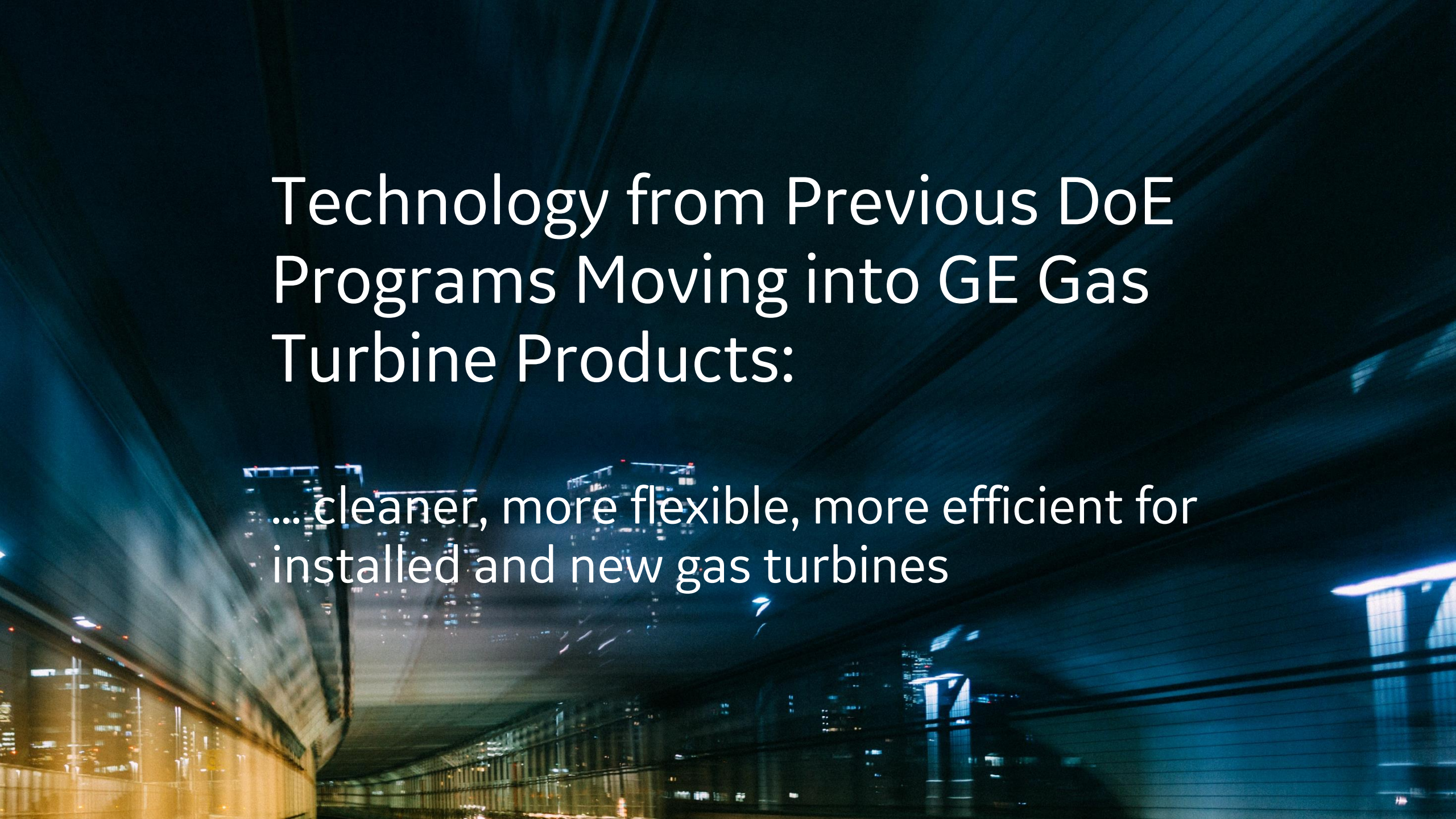
The team has chosen to build a test stand rather than adapt an existing stand. This allows rapid hardware change-outs, access for next generation measurement technologies, and also better ergonomics for the assemblers. The rig is sized to accommodate a number of scenarios that may unfold should this technology make it into a product.



Phase II Recent Accomplishments

Mid-program feedback tests

- ✓**Aerodynamic testing is complete**
- ✓**Fired testing at GE Global Research is complete**
  - Single-duct non-turning test. Brand new rig designed, built, and tested.
  - Incorporates Compact Flames Advanced Premixer, Next-Gen AFS, and advanced cooling concepts.
- ✓**Partial and full scale seal testing is complete**
  - New geometry, new seals, new issues, new learning, new solutions.
- ✓**Alloy and printing processes down-selected for Greenville hardware**
  - Slice the system up. Print in multiple pieces. Join the pieces.
- ✓ **Greenville full scale rig design is nearing completion**
- ✓ **“Engine” design is nearing completion. Adaptation for Greenvillefull scale multiple duct test is underway.**



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

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

MAKING AN IMPACT WITH THE HA GAS TURBINE

HA FLEET

83 Orders

50 GW

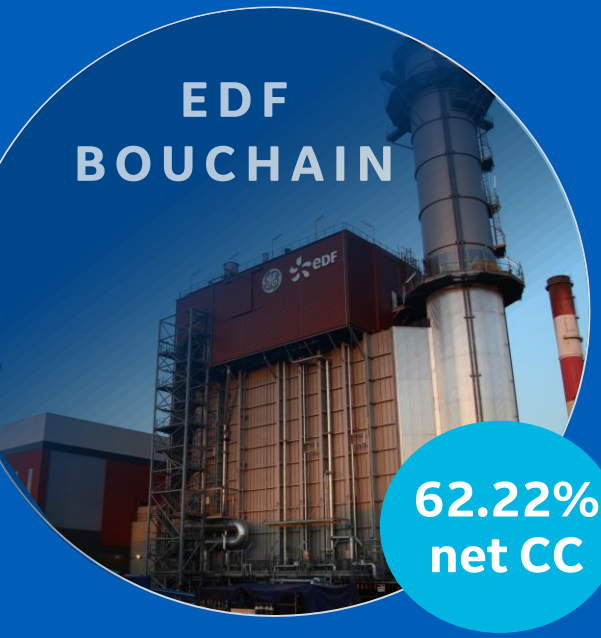
30 COD

195K Hours

2 World Records

THE HA CONTINUES AS **THE TECHNOLOGY LEADER** IN THE INDUSTRY

2 WORLD RECORDS

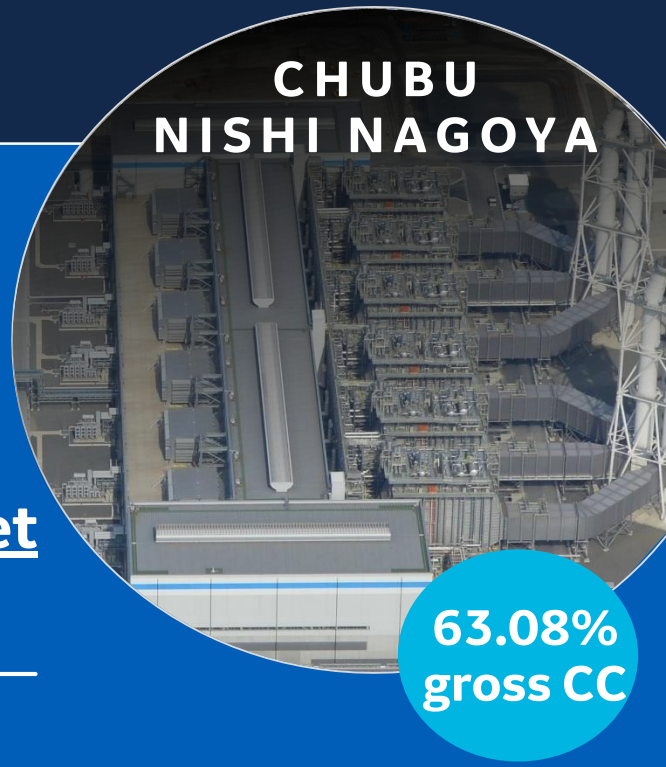


Proven technology
30+ units installed …
Test stand & field validated

Industry-leading
operating flexibility
<30 min start

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

Fastest growing fleet
80+ units ordered …
>50% new orders*

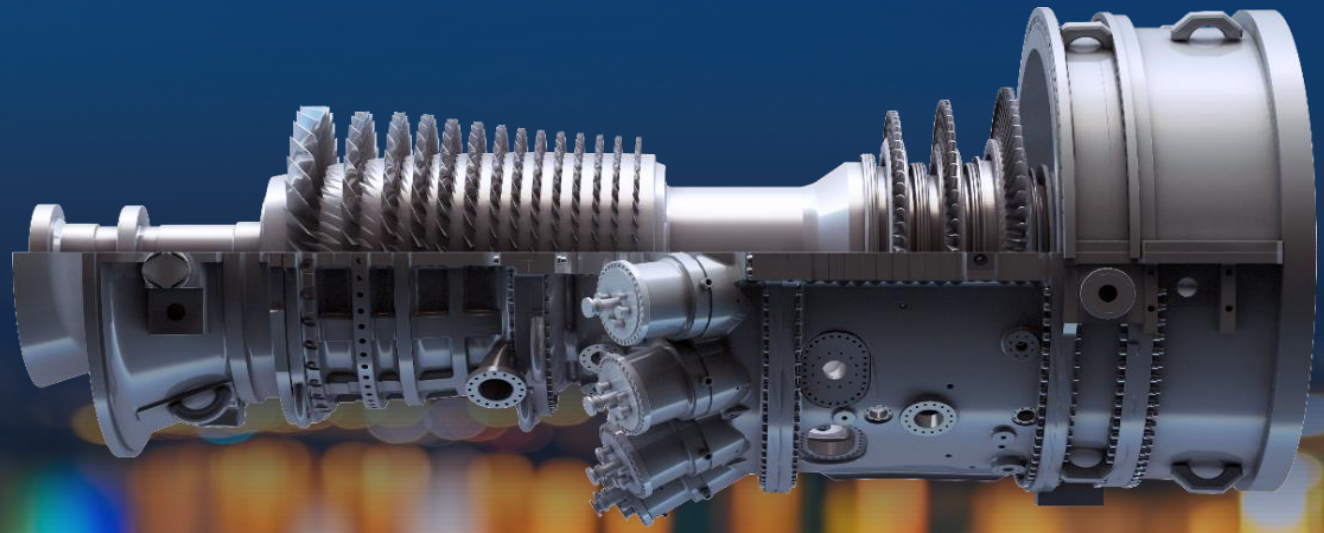


Continuing to build on **$2B+ HA** investment

* '17 +1Q18 actual, 2Q-4Q18 estimate, McCoy, GE marketing

HA GAS TURBINE … BUILT ON PROVEN TECHNOLOGY

9HA.02



>550 MW GT
>800 MW CC
>64% CC NET

14-stage Advanced COMPRESSOR

- ✓ Introduced on 7F.05
- ✓ 600k+ hrs of experience
- ✓ 80+ units in operation
- ✓ Fully validated in full-load test stand

DLN2.6e COMBUSTOR

- ✓ Evolution of DLN2.6+
- ✓ Unibody / Axial Fuel Staging / Advanced Premixer
- ✓ 10+ year development w/ > 1,000 hours of lab testing
- ✓ Higher efficiency, deeper turndown, wider fuel flex

4-stage POWER TURBINE

- ✓ Originally introduced on steam cooled H in early 2000s
- ✓ Advanced cooling and sealing
- ✓ Simplified air cooled with no steam or cold cooling air

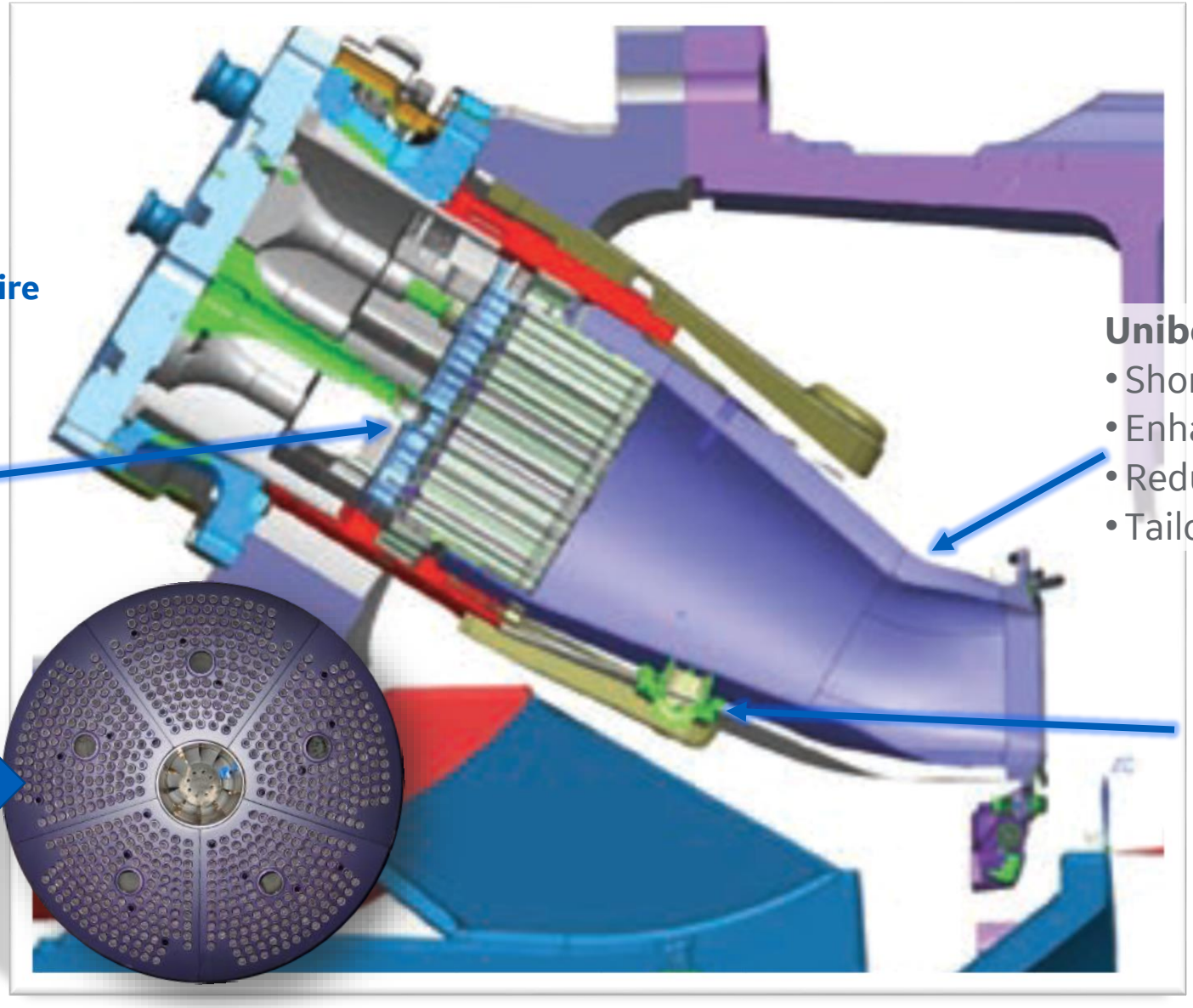
Leading in Performance
MW & CC Efficiency

Leading in Operability
Turndown & Ramp Rate

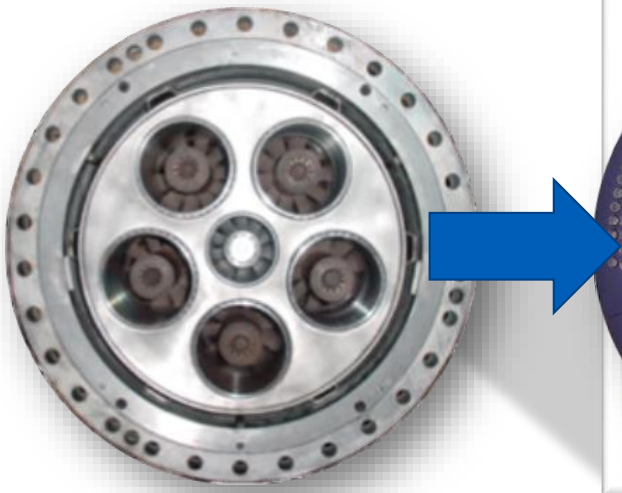
Simplicity
Integrated Cooling & Simplified packaging

DLN2.6e Combustion System

- ✓ **Faster installation**
- ✓ **Improved cooling**
- ✓ **Lower turndown**
- ✓ **Low NO_X at high T_{Fire}**



Advanced Premixer
- Low NO_X at high T_{Fire}
- Fuel Flex – LNG and MWI

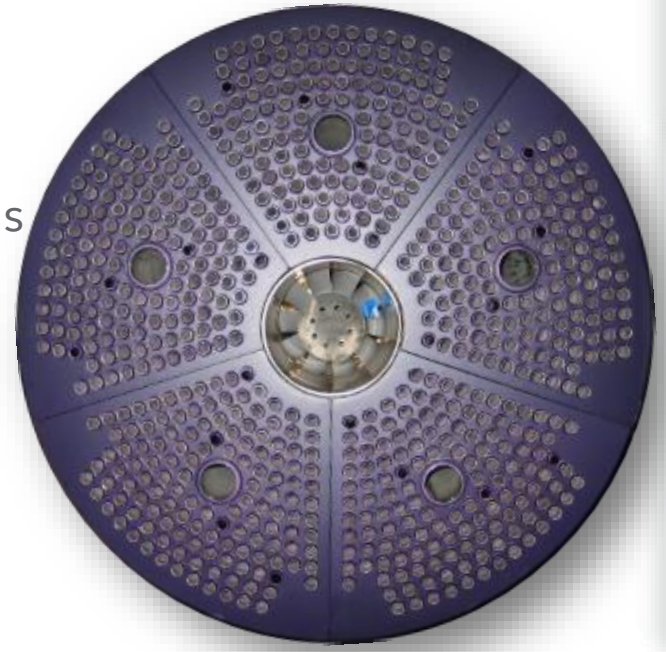


Unibody extended TP
- Shorter Length
- Enhanced shape
- Reduced residence time
- Tailored cooling

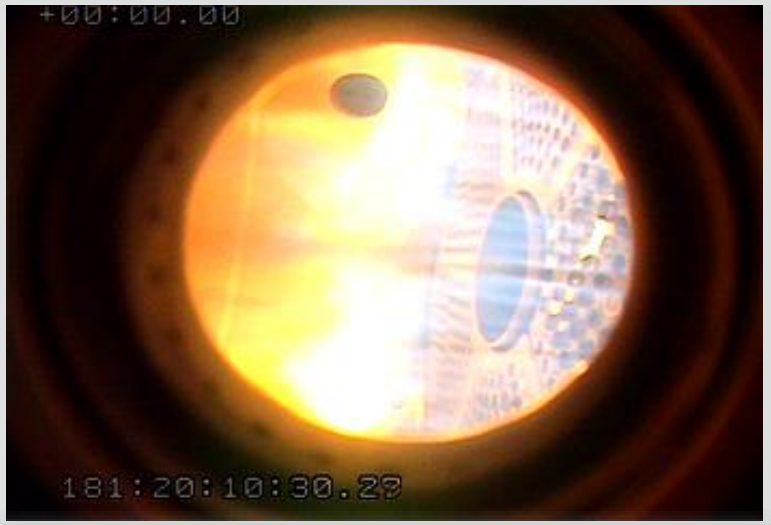
Axial Fuel Staging
- Low NO_X at high T_{Fire}
- Improved Turndown

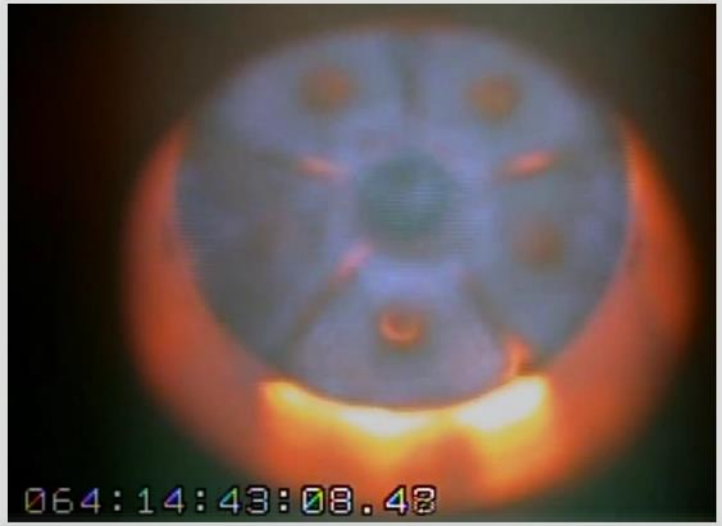
Advanced Premixer… The Early Years

High Hydrogen Premixer, ca. 2005



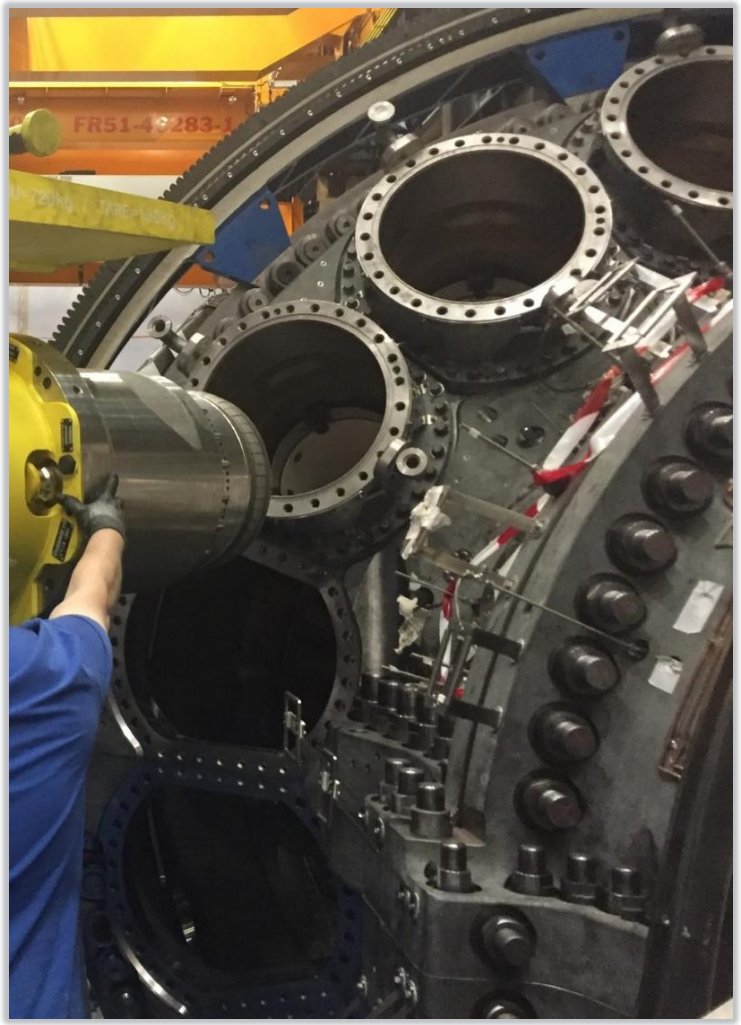
Natural Gas Advanced Premixer

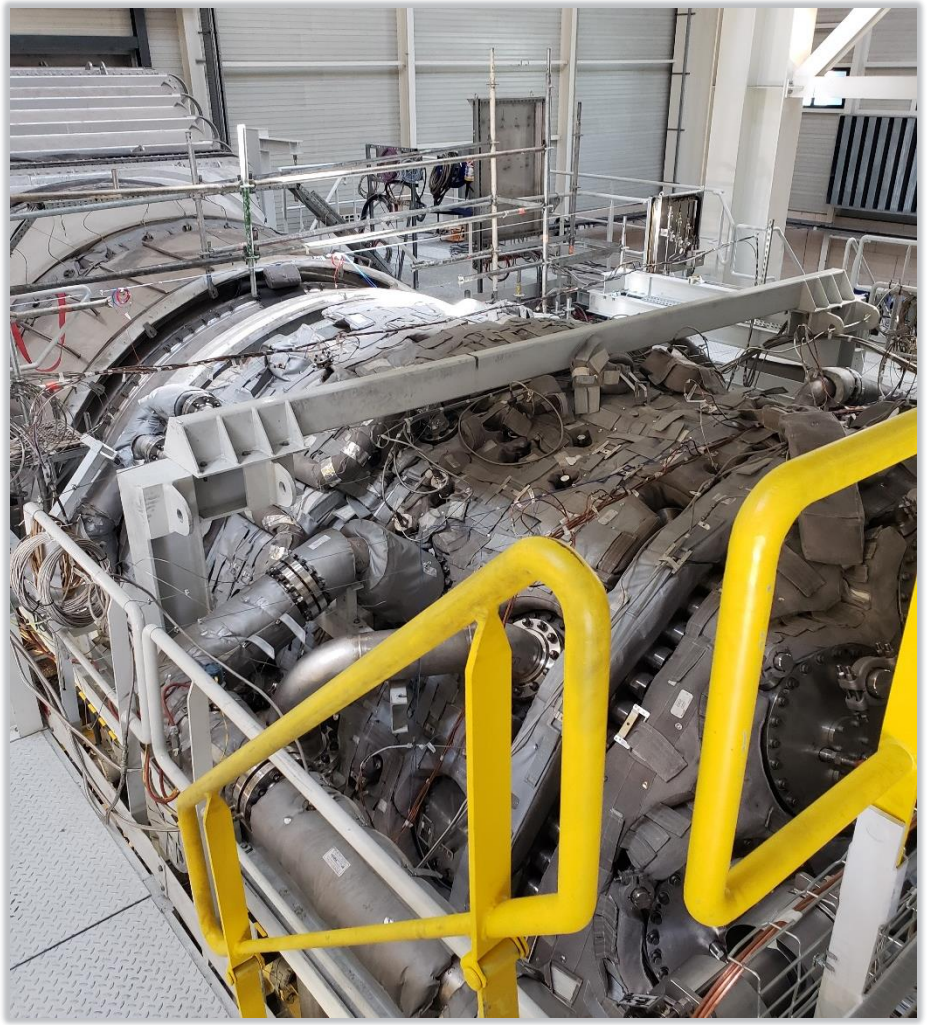




10+ year development w/ > 1,000 hours of lab testing

Advanced Premixer… Introduction on 9HA



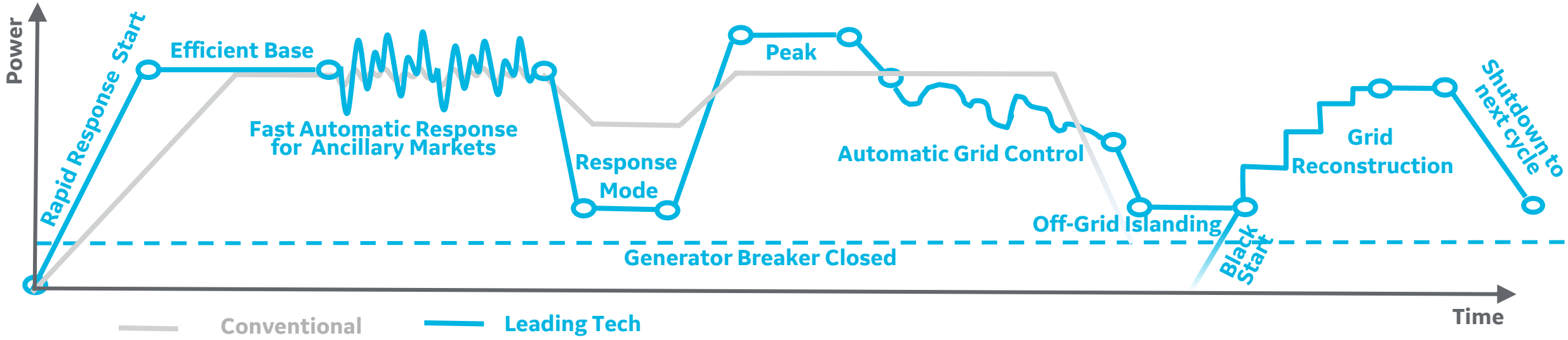


Flexibility Across the Mission Profile

Agility
MOVE THE ASSET QUICKLY

Robustness
SURVIVE EXTERNAL DISTURBANCES

Capacity
BOOST OUTPUT MANAGE TRADES



Fast Ramping & Partload Operation
Real-time, efficient response to minute changes

Low Turndown
Accommodate renewables, maintain reliability

Fast & Reliable Start
Fast MWs when renewables ramp down

Baseload MW & Efficiency
Lowers consumer cost and carbon footprint

When power on demand is more valuable than ever

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, 4th member 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.

3100F Integrated System

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