Advanced Gas Turbines:
Ensuring U.S. Strategic and Economic Competitiveness in a Critical Sector of the U.S. Advanced Manufacturing Industry

American Society of Mechanical Engineers &
Consortium for Advanced Production and Engineering of Gas Turbines and Rotating Machinery

October 18, 2017

Agenda

- Introduction & Objectives
  - Mike Aller, Consortium for Advanced Production and Engineering of Gas Turbines and Rotating Machinery (CAPE)
- Turbine Fundamentals & U.S. Gas Turbine Industry Overview
  - Dr. Tim Lieuwen, PhD, Georgia Tech & ASME
- U.S. Turbine Manufacturing: Opportunities & Challenges
  - Aviation Gas Turbine Engines – Dr. Tom Prete, PhD, Pratt & Whitney
  - Turbines for Power Generation – Guy Deleonardo, GE Power & Gas Turbine Association
  - Industrial Applications for Gas Turbines – Dr. Doug Rawlins, PhD, Solar Turbines
- R&D Investments and Workforce Training Opportunities
  - Dr. Karen Thole, PhD, Penn State
- Questions & Answers

Why are Advanced Gas Turbines Important?

- **“Apex Technology” at the convergence of aviation, aerospace & power generation**

- **Critical to U.S. Economic Security**
  - **Primary type of Aviation Propulsion**
  - **Job Creation**
  - **Manufacturing & Exports**

- **Critical to U.S. National Security**
  - **<u>Affordable & Effective Mission Capability – Air, Land, Sea & Space</u>**
  - **Maximize Resources for Operational Needs: Reduce Installation Energy Costs**

- **Critical to U.S. Energy Security & Clean Energy Goals**
  - **Largest Share of Electric Power Generation**
  - **US Natural Gas sourced from and supporting production in North America**
  - **Significant Role as Backstop for Renewable Generation Sources**

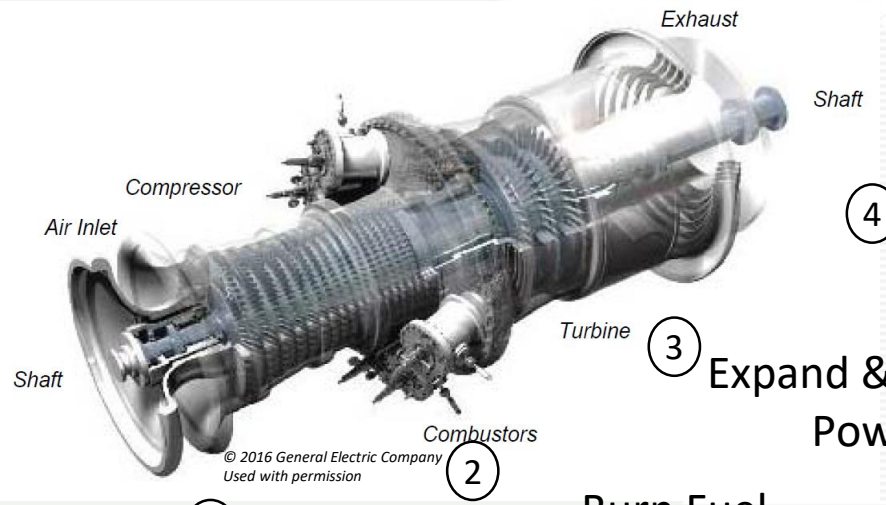
Advanced Gas Turbines: Strategic Dual-Use Technology

GAS TURBINE MANUFACTURING IN THE UNITED STATES

TIM LIEUWEN, PH.D., P.E.
EXECUTIVE DIRECTOR,
STRATEGIC ENERGY INSTITUTE

CREATING THE NEXT®

Gas Turbine 101: High Technology Machine
…Fuel to Electricity or Thrust



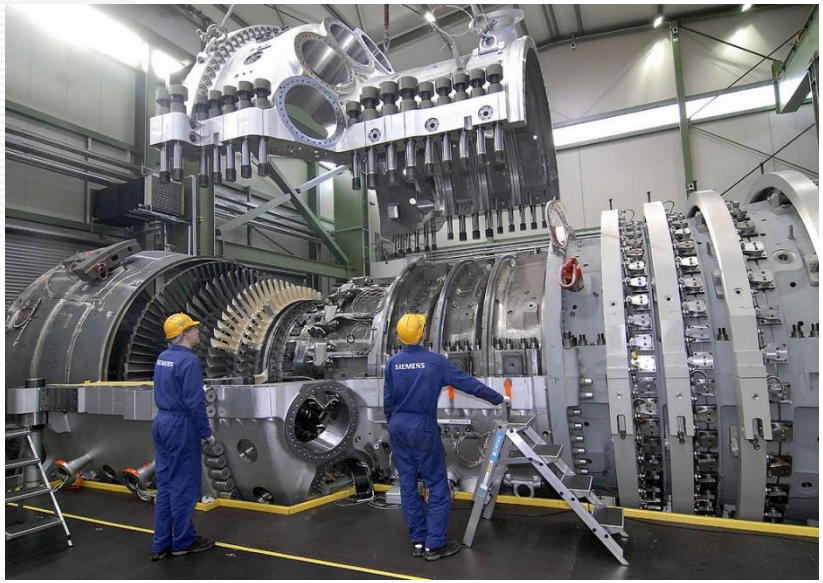
1 Compress Air

2 Burn Fuel

3 Expand & Extract Power

4 Exhaust Energy for more Power

5 To Generator to produce electricity



Industries

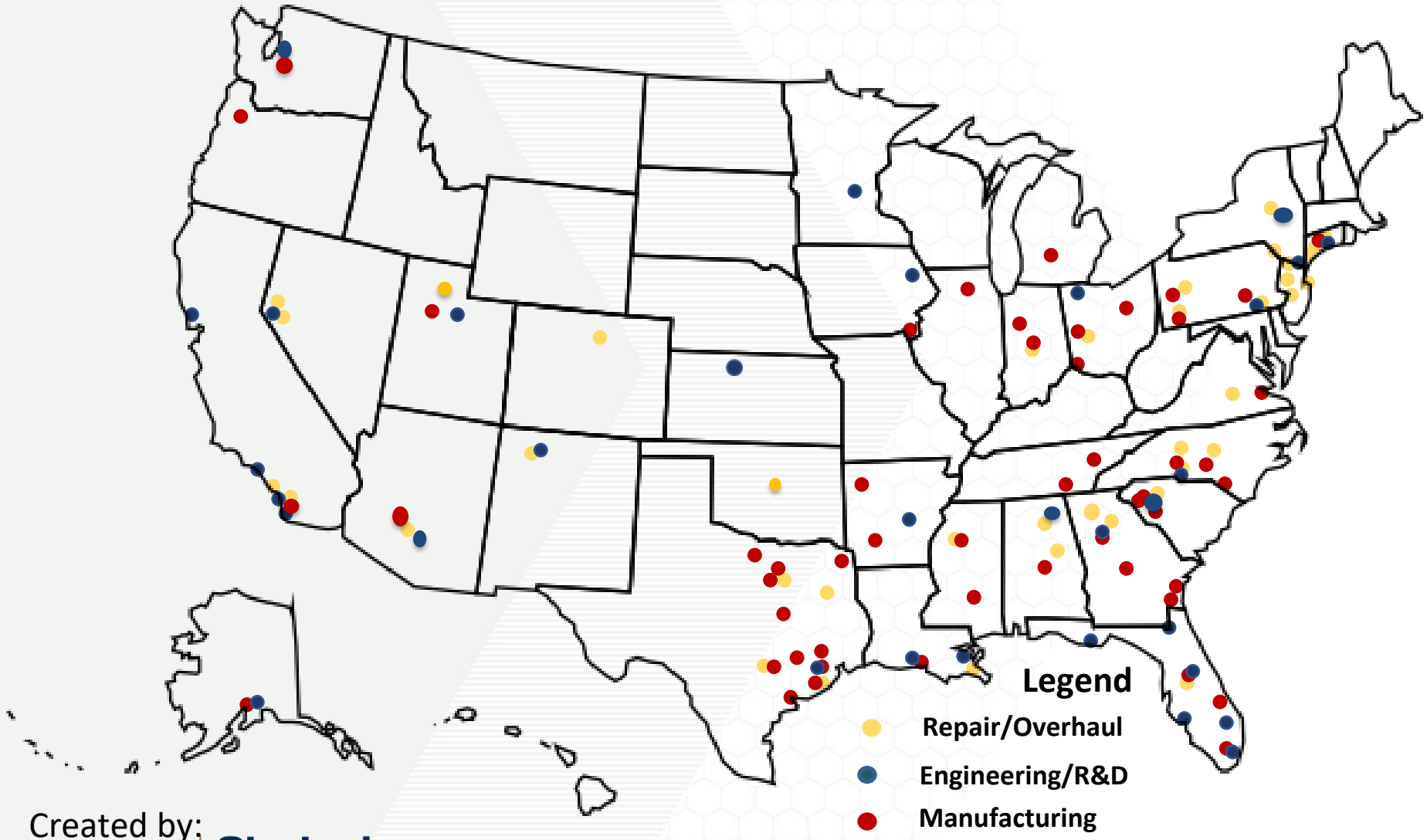
- Key platform technology with various industry applications

Aviation (civil & military)
100% of jet powered vehicles

Oil & Gas, Marine transportation, pipelines

Power Generation
1/3 of US Electricity

Geographically Distributed Industrial Base



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Georgia Tech Strategic Energy Institute

CREATING THE NEXT®

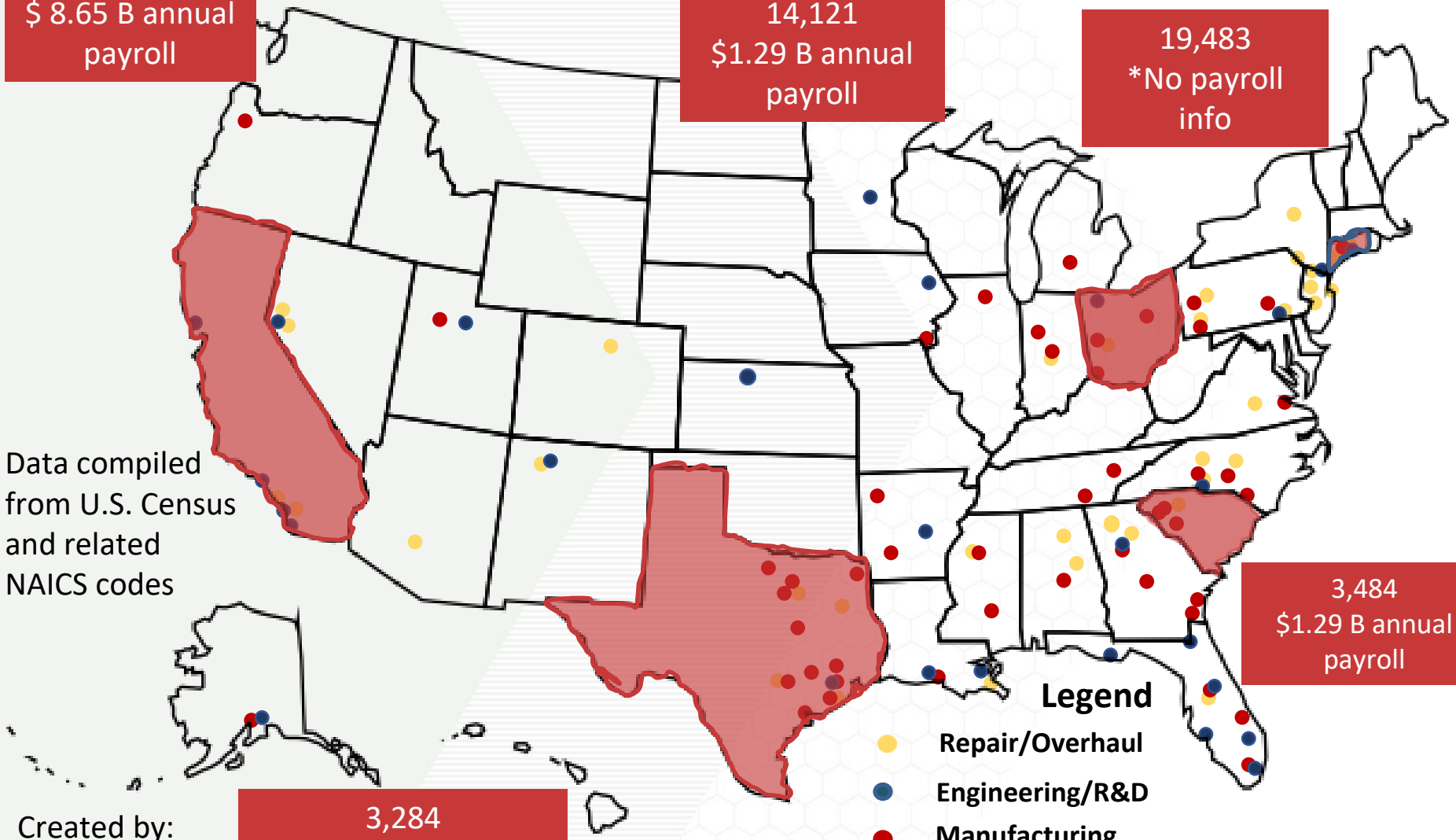
Gas Turbine Manufacturing Jobs & Payroll, 2012

Georgia Tech

10,806
$ 8.65 B annual payroll

14,121
$1.29 B annual payroll

19,483
*No payroll info



Data compiled from U.S. Census and related NAICS codes

3,484
$1.29 B annual payroll

3,284
$2.65 B annual payroll

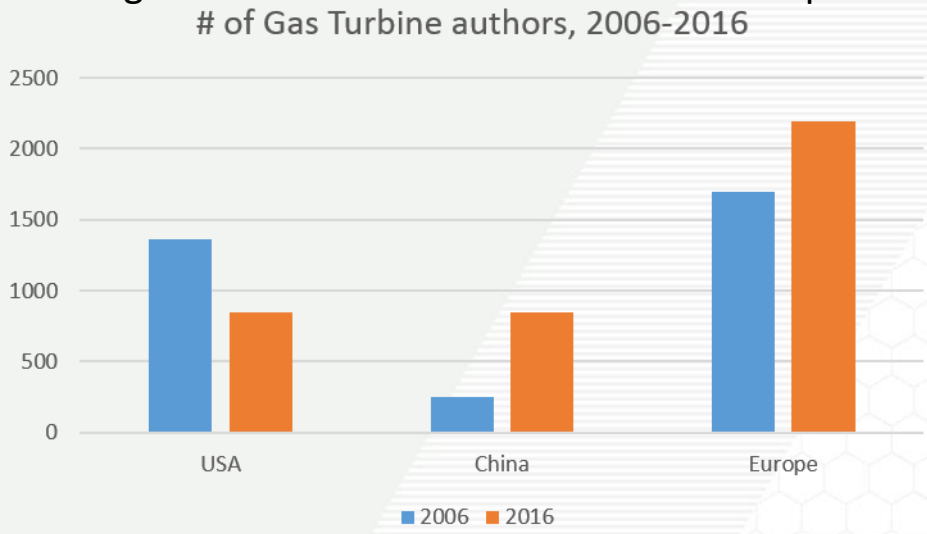
Created by:
Georgia Tech Strategic Energy Institute

CREATING THE NEXT®

Threats and opportunities

- Opportunities: 15 year outlook
  - Aviation - >$1Trillion market
  - Power generation >$600B

- Federal R&D investments needed to maintain global leadership!
  - Significant investments in China and Europe



China Forms Company To Make Jet Engines

By Chun Han Wong

BEIJING—China set up a new state-owned aircraft-engine maker to help fulfill ambitions to develop homegrown aerospace companies and become a significant competitor in global aviation.

Western-made engines.

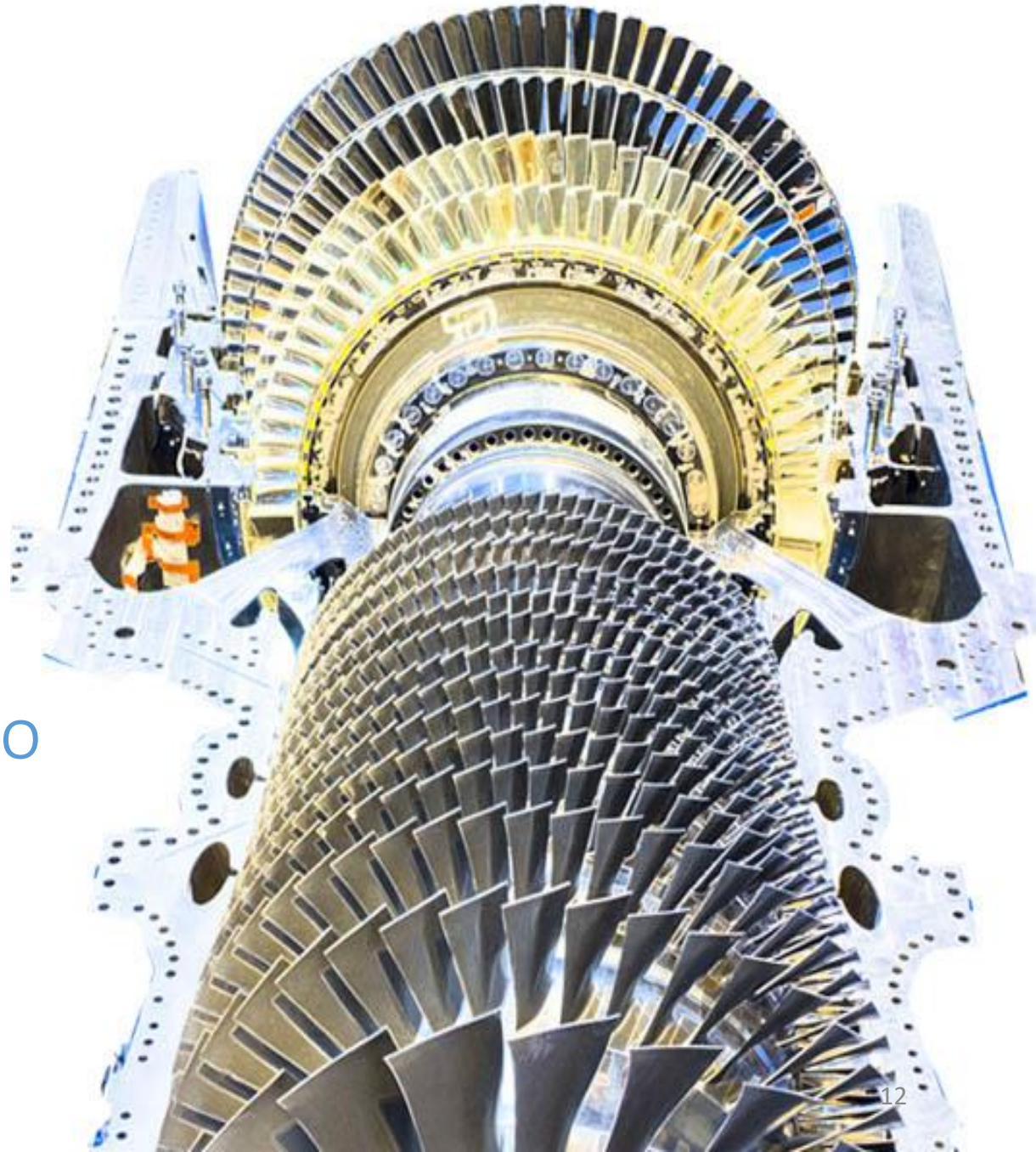
By setting up AECC, Beijing hopes to create a self-sufficient aerospace sector that could serve commercial and military aviation needs with homegrown technology, industry analysts say.

AECC consolidates existing

Wall Street Journal- August 28, 2016

Thomas Prete
Vice President, Engineering
Military Engines

Pratt & Whitney



Guy DeLeonardo

GE POWER

& Chairman, Gas Turbine Association

GTA

GAS TURBINE ASSOCIATION

THE VOICE OF THE
GAS TURBINE INDUSTRY

- Florida Turbine Technologies
- GE Power
- Meggitt Vibro-Meter
- PW Power Systems
- Pratt & Whitney
- Siemens Energy
- Solar Turbines
- Strategic Power Systems
- Power Systems Manufacturing

Industries and applications

Utility and IPP power generation

Industrial power generation

Distributed and mobile power generation

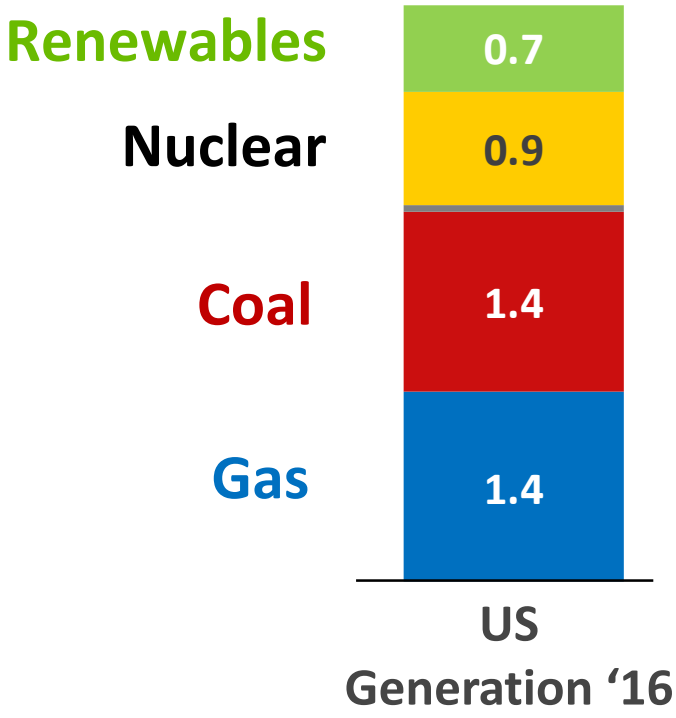
Industries and applications

Utility and IPP power generation

Industrial power generation

Distributed and mobile power generation

US Gas (Gas Turbine) Electrical Power Generation



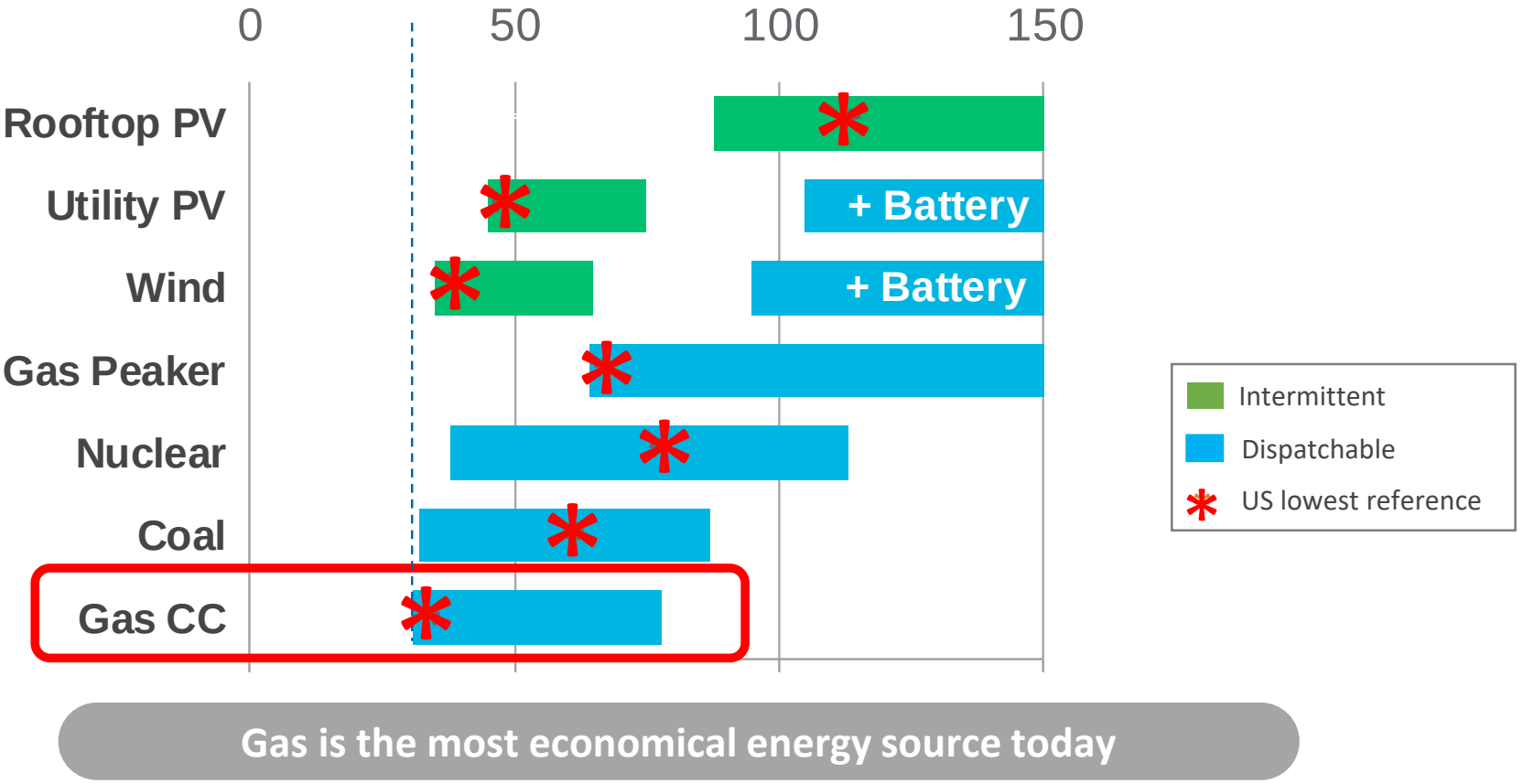
Gas / Gas Turbines = 1/3 US Electrical Power

Thousands of TWh/y

Sources: GE Power & GE Renewable Energy Marketing, IEA, IHS, BNEF, Lazard

Cost of Electrical Power Generation

Levelized cost of electricity (LCOE)
$/MWh with locational variation

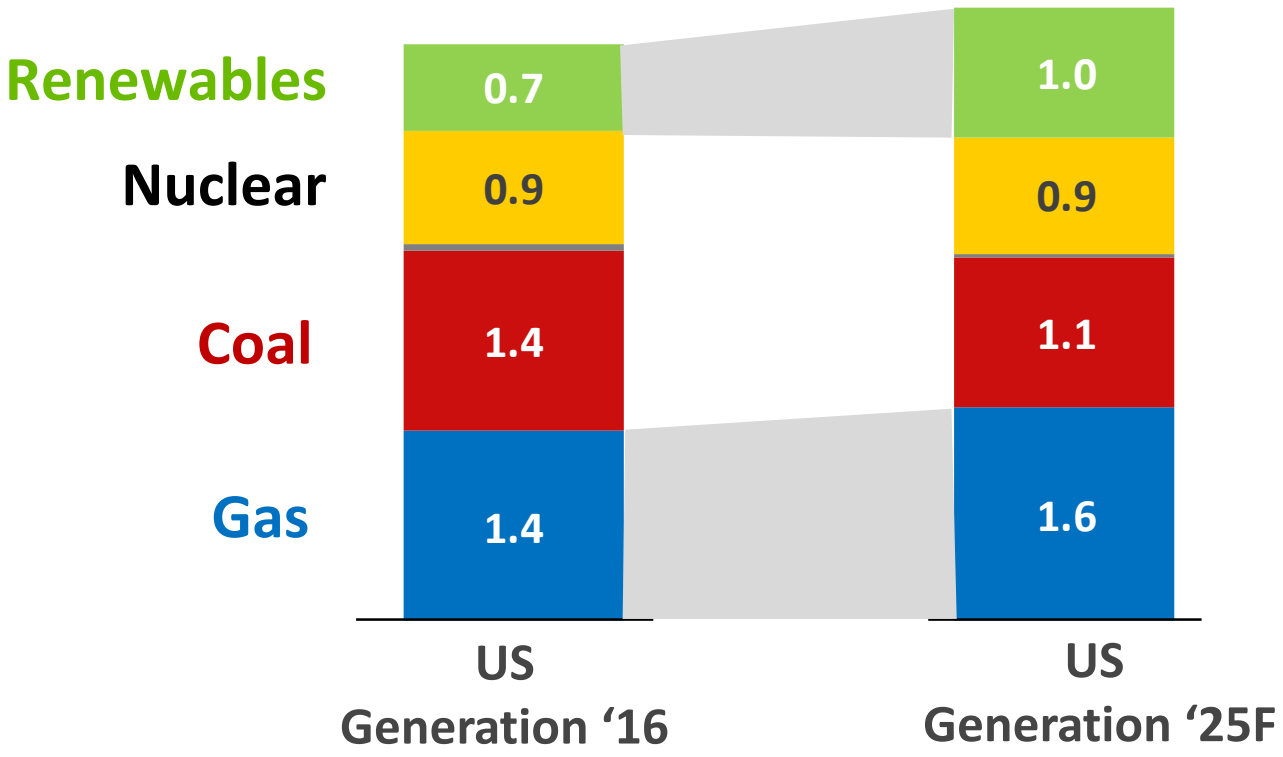


Gas is the most economical energy source today

Sources: GE Power & GE Renewable Energy Marketing, IEA, IHS, BNEF, Lazard

Notes: 1) Generation excludes oil recip & battery generation. 2) Efficiency gain results from electricity intensity reduction, Battery LCOE based on 2025 projected costs

US Gas (Gas Turbine) Electrical Power Generation

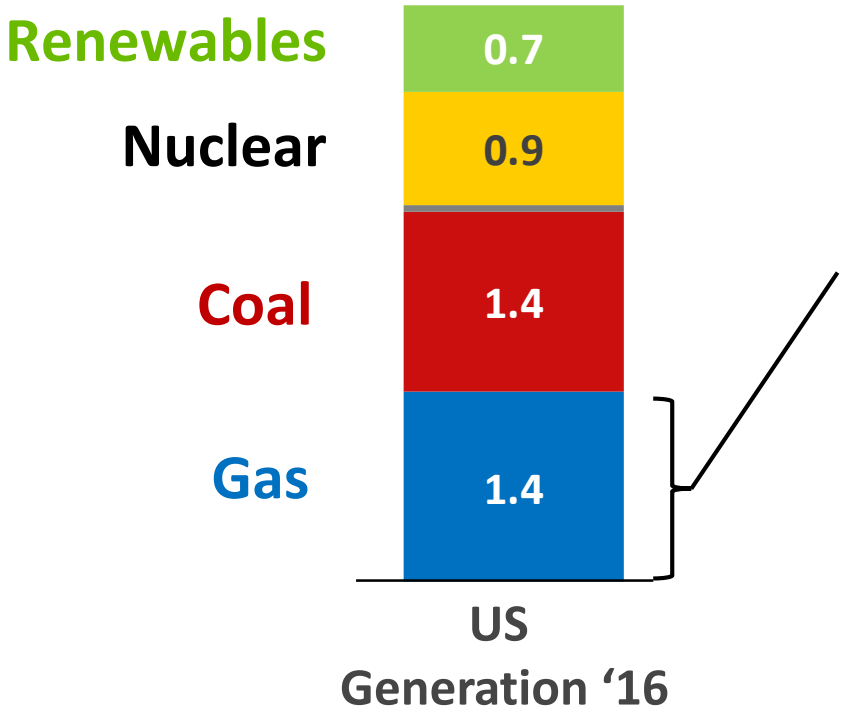


Growth in gas & renewables

Thousands of TWh/y

Sources: GE Power & GE Renewable Energy Marketing, IEA, IHS, BNEF, Lazard

Value from Technology Investment in Gas Turbines

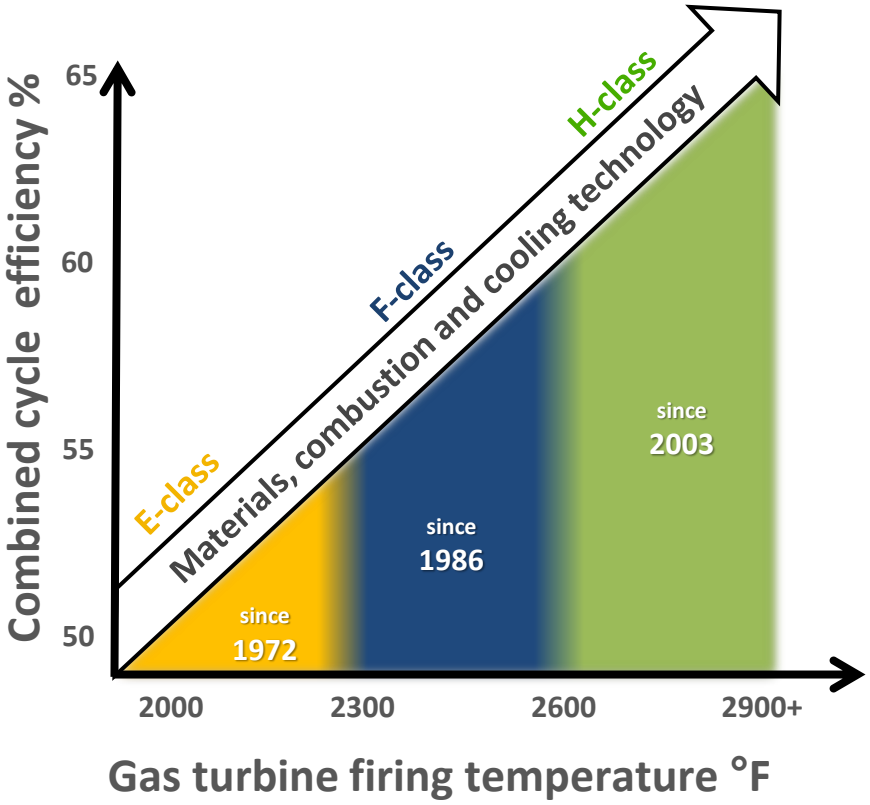


Over 10 years … a 1% point improvement in efficiency yields $7b economic value to US ratepayers

Thousands of TWh/y

Sources: GE Power & GE Renewable Energy Marketing, IEA, IHS, BNEF, Lazard

Technology drives efficiency & cost effectiveness

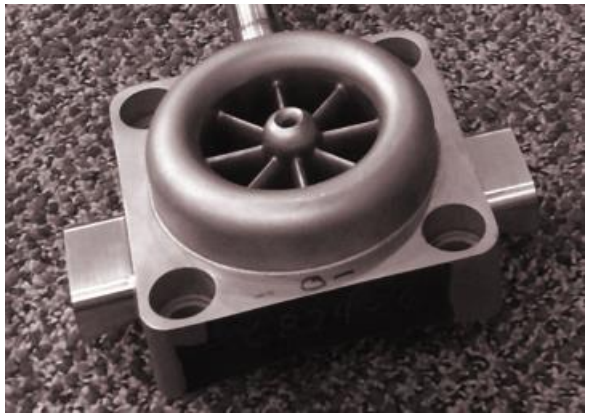


- Today: > 62% efficiency
- With DOE, path to 65%
- Opportunity … 67%

Additive manufacturing … just the beginning

Building better combustion systems with additive technology

- Quicker … testing and production
- Simplified assembly
- Features that challenge traditional manufacturing processes



DOUG RAWLINS
MANAGER, ADVANCED TECHNOLOGY

A CULTURE OF CUSTOMER CARE



Solar® Turbines
A Caterpillar Company

Solar Turbines Incorporated

- World's Largest Manufacturer of Industrial Gas Turbines (1 to 22 MW)
- Over 15,000 Gas Turbines Sold
- Over 6,000 Gas Compressors Sold
- Installations in over 100 Countries
- Direct End-to-End Sales & Service
- More than 2 Billion Fleet Operating Hours
- Global Workforce ~ 9,000 Employees
- U.S. Workforce ~ 5,500 Emplyees
- 65 Sales & Service Locations
- Based in San Diego, California, U.S.A.
- Subsidiary of Caterpillar Inc. Since 1981

GAS TURBINE MARKETS

- Oil & Gas Industry
- Utility and Industrial Power Generation
- Industrial Power Generation

OIL AND GAS APPLICATIONS

- Gas Transmission
- Storage and Withdrawal
- Waterflooding
- Gas Gathering
- Gas Lift
- Field Pressure Maintenance
- Air, Process, and Refrigeration Applications
- Electrical Power Generation

INDUSTRIAL AND PROCESSING FACILITIES

- Chemicals
- Pharmaceuticals
- Foods and Ingredients
- Dairies and Dairy Products
- Beverages
- Breweries
- Grain Processors
- Ceramics
- Cement / Gypsum
- Paper / Wood Products
- Plastics
- Tires / Rubber Products
- Refineries
- Manufacturing

BUILDINGS AND INSTITUTIONS

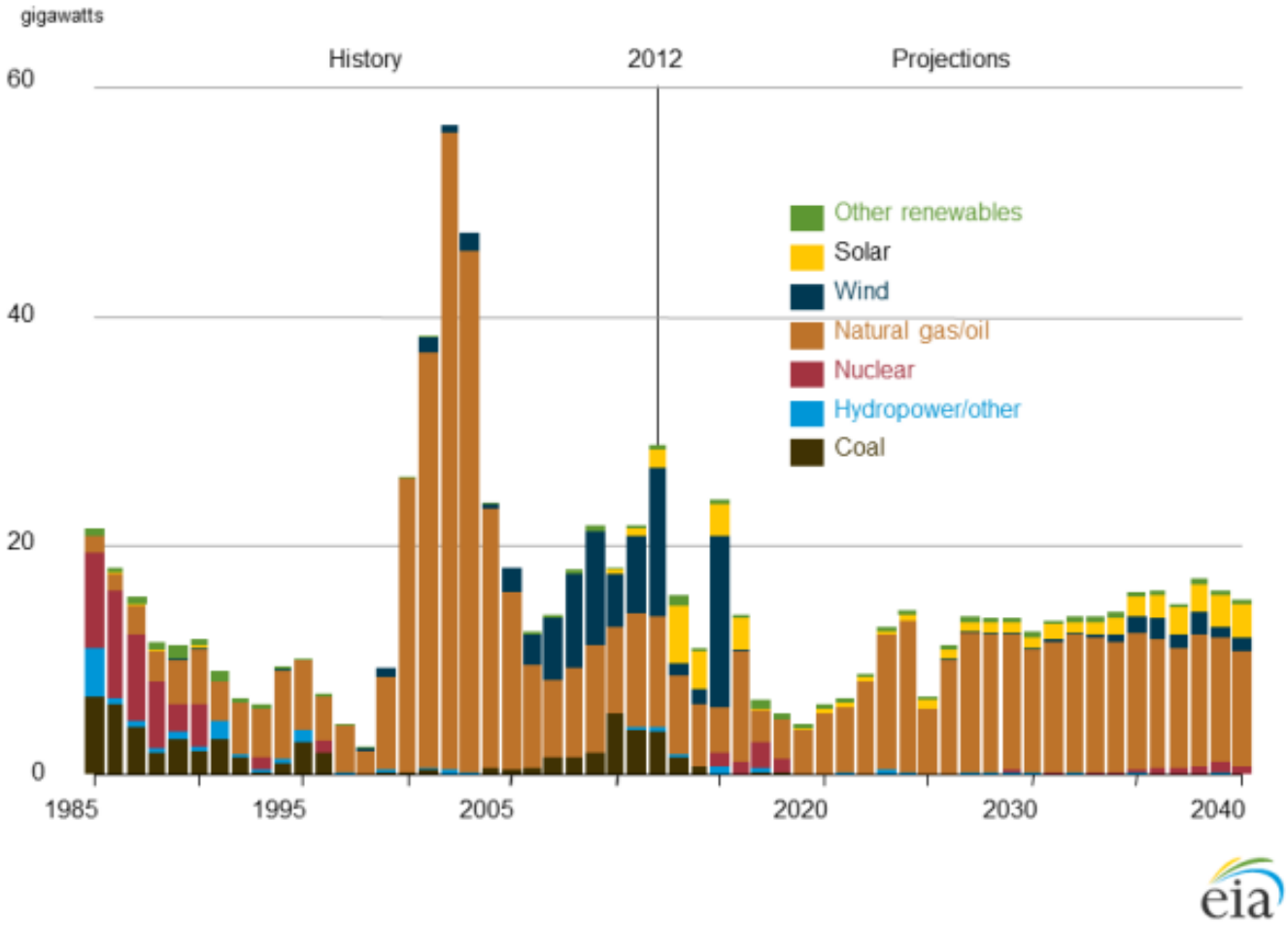
- District Heating and Cooling Plants
- Universities
- Hospitals
- Resorts and Hotels
- Commercial Buildings
- Telecommunications Complexes
- Computer Centers

DISTRIBUTED POWER GENERATION

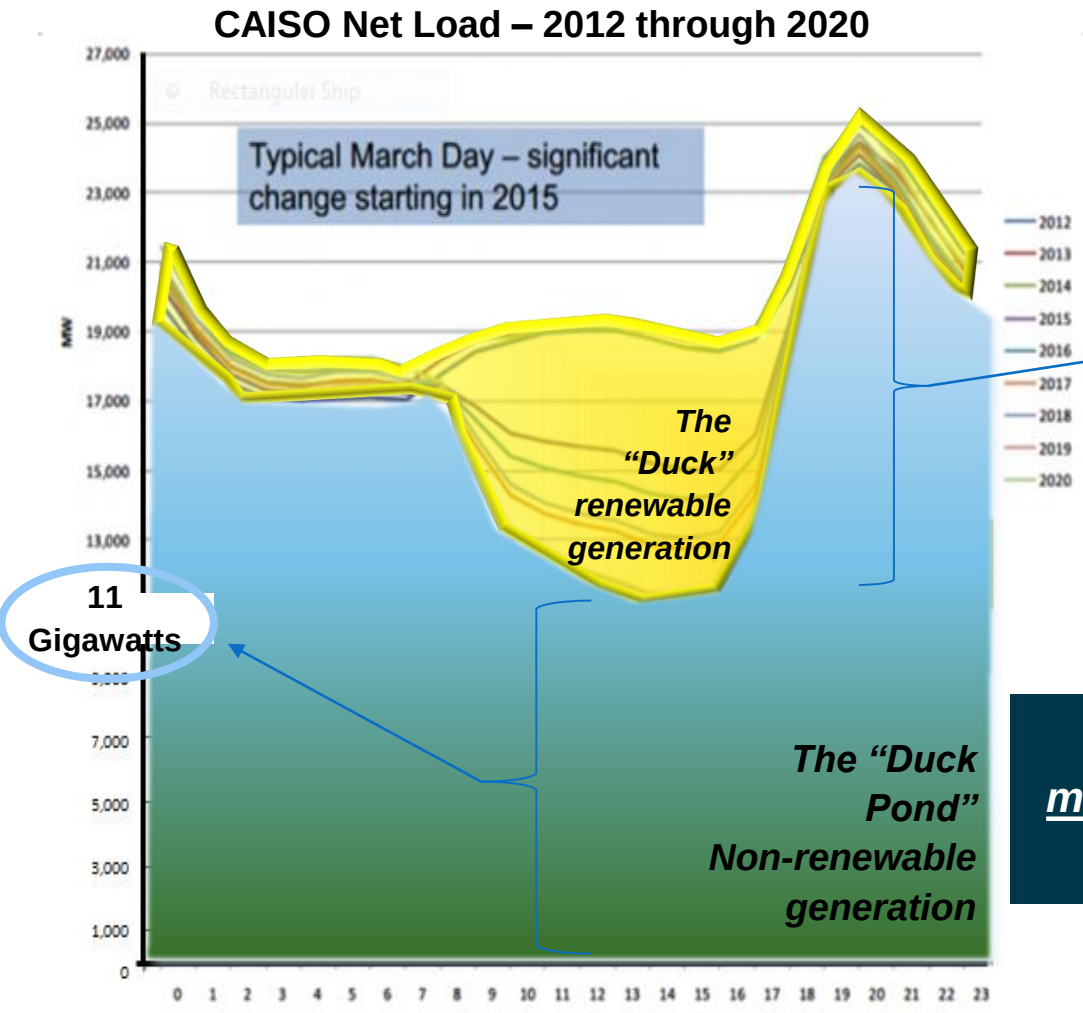
- Small Utilities
- Cogeneration
- Load Management
- Remote Locations
- Areas with Rapid Demand Growth
- Mobile Power

GENERATING CAPACITY ADDITIONS
REFERENCE CASE THROUGH 2040

Figure MT-32. Additions to electricity generating capacity in the Reference case, 1985-2040



POWER GENERATION ON GRIDS WITH RENEWABLES: NEED FLEXIBLE, CONTROLLABLE GENERATION SOURCES



Flexibility & dispatchability is key 10 GW – 12 GW ramp-up over ~4 hour period during PM peak

Lots of *non-renewable generation is operating all of the time*

Non-renewable sources remain more influential to overall power delivery than the renewable generation

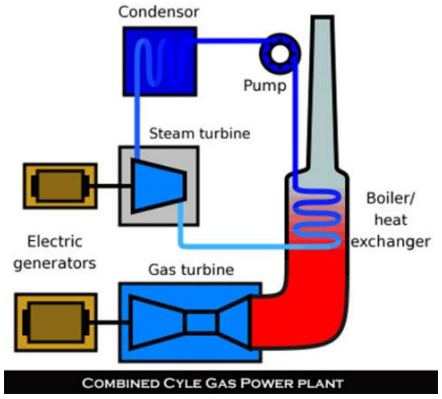
Source: CAISO

Gas Turbine R&D
Industry, Universities, and Government Collaborations Lead to Success

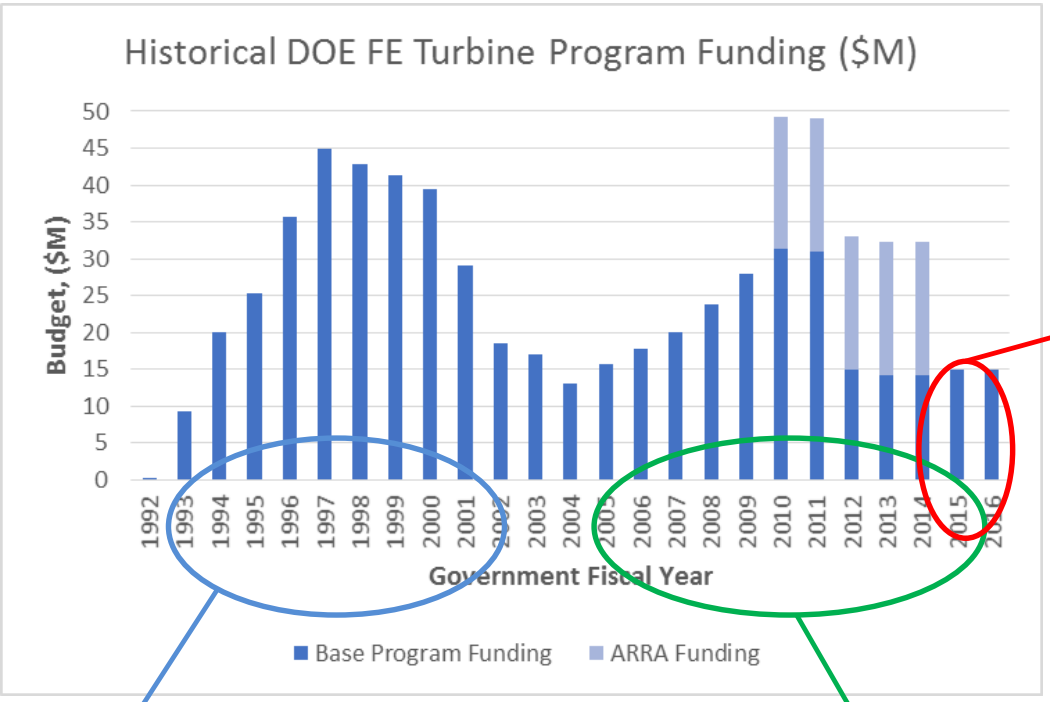
Karen A. Thole

Mechanical and Nuclear Engineering
Pennsylvania State University

PennState



DOE funding for turbine research is directly applicable to improving efficiencies (reducing impact to the environment)



ATS Program (1992-2002)

- **GE delivers most adv. 60% eff. NGCC**
- **Siemens produces adv. G-class components**
- **Focus on NG**

H_2 Turbine Program (2005-2015)

- **Solved H_2 combustion problem**
  - Revolutionized combustion
- **Advanced cooling architecture through advanced manufacturing**

AT Program (2014 – 2025)

- Moving to 65% efficiencies
- Full scale, full can combustion test at 3100F w/ < 25ppm NOx
- CMC nozzle design selected
- CMC combustor components down-selected from 50 concepts to 2
- Dry gas seal initial design completed for end seal in utility scale SCO2 expander

Courtesy of DOE-NETL

To achieve DOE's clean energy goals, they catalyze strong partnerships with industry and academia

Courtesy of DOE-NETL

For aero applications, research in gas turbines is needed to reduce impacts to the environment

1930s

1950s

2000s

6 Strategic Research & Technology Thrusts

Safe, Efficient Growth in Global Operations
- Enable full NextGen and develop technologies to substantially reduce aircraft safety risks

Innovation in Commercial Supersonic Aircraft
- Achieve a low-boom standard

Ultra-Efficient Commercial Vehicles
- Pioneer technologies for big leaps in efficiency and environmental performance

Transition to Low-Carbon Propulsion
- Characterize drop-in alternative fuels and pioneer low-carbon propulsion technology

Real-Time System-Wide Safety Assurance
- Develop an integrated prototype of a real-time safety monitoring and assurance system

Assured Autonomy for Aviation Transformation
- Develop high impact aviation autonomy applications

To achieve NASA's goals, they catalyze collaborations between universities and industry

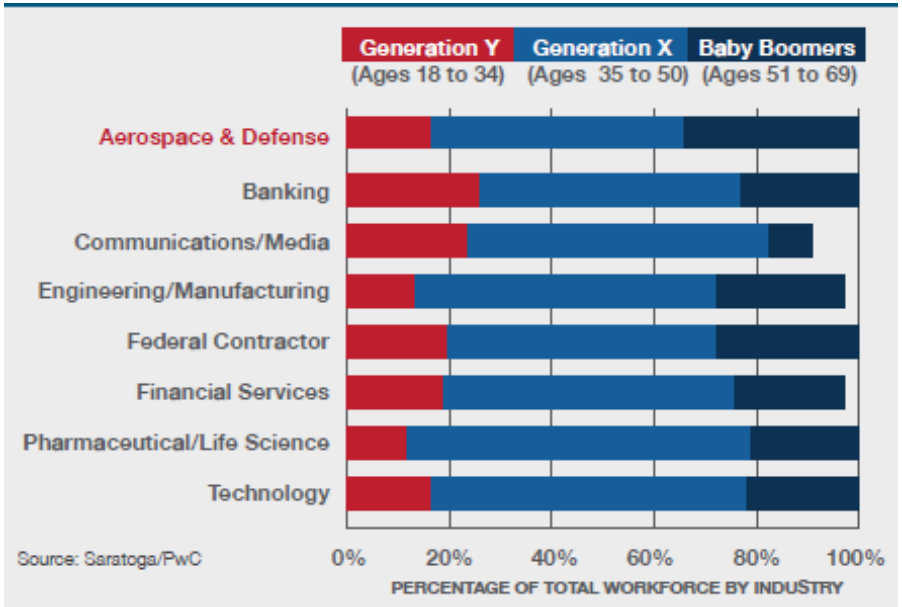
Courtesy of NASA

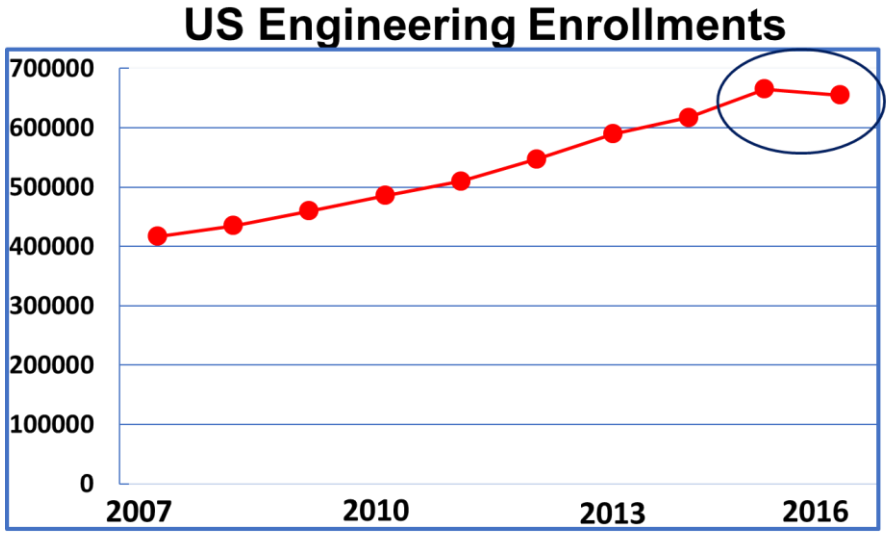
Three Main Components:

- NASA in-house research
- Collaborations with partners (OGA, Industry, Academia)
- Sponsored research by NASA Research Announcement (NRA)




Federal research support for universities + industry working together ensures a strong STEM workforce





Universities contribute to DOE's and NASA's goals by doing collaborative research with industry

Through teaching and research, universities educate the future workforce where advanced degrees with practical turbine experience are needed

PennState

Questions & Answers

PennState

Thank You!

Additional Background

Energy Florida and Gas Turbine Association

NIST AMTech Consortium for Advanced Production and Engineering of Gas Turbines & Rotating Machinery (CAPE)

- **Coordinating strategy for future development of the U.S. gas turbine industry**
- **Major Strengths of the U.S. Turbine Cluster**
  - **High Level of Innovation**
  - **Re-shoring Manufacturing to U.S.**
  - **Supply Chain Diversity/Depth**
  - **Over 100,000 jobs in U.S. tied to turbine design, manufacturing & maintenance**
- **Enormous market opportunity as demand for turbines and related parts and components expands around the world**

Gas Turbine Association (GTA)

- Founded in 1995
- The GTA Serves as the Unified Voice for the Gas Turbine Industry
  - Advocates for Gas Turbine R&D
  - Advocates for Rational and Achievable Emissions Regulations
- Committees
  - Government Affairs
  - Environment Affairs
  - Technical Affairs

GTA Member Companies

Alstom Power - Florida Turbine Technologies - GE Energy

Meggitt Vibro-Meter Inc. - OPRA Turbines - PCC Airfoils

Pratt & Whitney - PW Power Systems - Siemens Energy

Solar Turbines Incorporated - Strategic Power Systems

GTA GAS TURBINE ASSOCIATION