Overview of the US DOE Advanced Turbines Program

2018 UTSR Workshop & Program Overview
DOE, DOD & NASA Synergies in Gas Turbine Technology

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Advanced Turbines and SCO2 Power Cycles
U.S. Department of Energy
National Energy Technology Laboratory
Presentation Overview

Overview of the US DOE Advanced Turbines Program

• Overview of NETL
• Observations of Gas Turbine Market

• Overview of the US DOE Advanced Turbines R&D Program
  • Advanced combustion turbines for syngas, NG and H₂ fuels
  • Pressure gain combustion for combustion turbines
  • Modular turbine based hybrid heat engines
  • Supercritical carbon dioxide (sCO₂) based power cycles

• DOE, DOD & NASA Synergies in Gas Turbine Technology
• Conclusions & Summary
## DOE FE NETL Program Areas

### Advanced Energy Systems
- Transformational Power Generation
- Advanced Combustion, Gasification, Fuel Cells, and Gas Turbines
- Efficient Energy Conversion
- Coal Beneficiation

### Carbon Capture
- Cost-Effective Capture Systems
- Minimize Energy Penalty for Capture and Compression
- Smaller Capture System Footprint

### Carbon Storage
- Safe, Effective, Long-Term Storage
- Monitoring, Verification, Accounting, and Assessment
- Demonstrate Storage Infrastructure
- Utilization of Captured Carbon Dioxide

### Crosscutting Research & Analysis
- High-Performance Materials
- Sensors and Controls
- Simulation-Based Engineering
- Water Management
- University Training and Research

### STEP (Supercritical CO₂)
- High-Efficiency Power Cycle
- Reduced Water Consumption and Air Emissions
- Reduced Power Cycle Footprint

### Rare Earth Elements
- Efficient Rare Earth Element (REE) Recovery
- Cost-Competitive Domestic Supply of REEs
Electricity Generation Mix (Short Term)

U.S. electricity generation by fuel, all sectors
million megawatthours per day

Note: Labels show percentage share of total generation provided by coal and natural gas.
Source: Short-Term Energy Outlook, July 2018

EIA = Energy Information Administration
US and Worldwide IGT Orders by Class

Noticeable decrease in orders

Penetration of low cost renewables

Ref: From Strategic Horizons, Renewables Costs: A Global Comparison of Wind and Solar, October 24, 2018 after IHS Markit Power, Gas, Coal & Renewables
Historical CO₂ Emissions - Potential Pathways
Pathways to stabilization or global warming

<table>
<thead>
<tr>
<th>Year</th>
<th>Billions of Tons of Carbon Emitted Per Year</th>
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<tbody>
<tr>
<td>1954</td>
<td>7</td>
</tr>
<tr>
<td>2004</td>
<td>14</td>
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Stabilization Wedges

How big and or significant is a wedge?

7 Wedges are needed to build the stabilization triangle.

1 Wedge avoids 1 billion tons of carbon emissions per year by 2054.
## Potential Stabilization Wedges

**Options to reduce carbon emissions by 25 GtC over 50 yrs.**

### Potential Wedge Option

<table>
<thead>
<tr>
<th>Potential Wedge Option</th>
<th>Level of Effort</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficient vehicles</td>
<td>Increase MPG from 30 to 60 for 2 billion cars</td>
</tr>
<tr>
<td>Efficient buildings</td>
<td>Reduce emissions by ( \frac{1}{4} ) in all buildings / appliances by 2054</td>
</tr>
<tr>
<td>Efficient base load coal plants</td>
<td>Produce twice today’s coal power at 60% vs. 40% efficiency (32% today’s average)</td>
</tr>
<tr>
<td>Base load coal w/CCS</td>
<td>Introduce CCS at 800 GW of coal plants (compared to 1060 GW existing coal)</td>
</tr>
<tr>
<td>Wind power for coal</td>
<td>Add 2 M 1-MW peak windmills (50 times current capacity)</td>
</tr>
<tr>
<td>PV power for coal</td>
<td>Add 2000 GW peak (700 times current capacity)</td>
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</tbody>
</table>

Summary of Observations

• 2013 - 15 surge in combustion turbine installations is over
• NG price forecasts indicate a slow rise
• Long term trend for electricity is an increase in NG and a reduction in coal
• Renewables continue to deploy creating new requirements for FE power systems
  • Highly efficient modular coal plants
  • Dynamic and efficient gas turbines
  • Will energy storage be required and who will own it
• FE AT provides technological solutions to CO$_2$ emission by addressing stabilization wedges
  • Highly efficient gas turbines for coal based IGCC
  • SCO2 power systems for coal combustion
  • All compatible with FE’s CO$_2$ capture & storage programs
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Advanced Turbines Program for US DOE FE Mission

Focused Research in Four Key Technology Areas

• **Adv. combustion turbines for syngas, NG and H₂ fuels (IGCC, NGCC)**
  • CC eff. ~ 65 % (LHV, NG bench mark), TIT of 3,100 °F
  • Transformational performance benefits by 2025 for coal based IGCC w/ CCS (ready for full scale demo); another $20/T reduction in CO2 capture cost

• **Pressure Gain Combustion (IGCC, NGCC)**
  • Alternate pathway to high efficiency
  • TRL 2 ~ 3 (risky, long term, high pay back)

• **Modular Turbine Based Hybrid Heat Engines**
  • Supporting modular coal systems and stranded gas assets

• **SCO₂ Turbomachinery (ACS, gasification, NG)**
  • FE’s SCO₂ Base Program – Shared with AT, ACS and XC
  • SCO₂ turbines for **indirect** and **direct** applications
  • Modular
  • Leverage and coordinate with DOE SCO₂ Initiative (STEP)
Advanced Combustion Turbines
Coal based IGCC and natural gas combined cycle applications

• Objective: Enable CC efficiency of 65%+ (LHV, bench mark), TIT of 3,100°F

• Approach
  • Focus R&D on turbine components
  • Pursue higher TIT, reduce cooling flows, and develop new materials and coatings
    • Increase efficiency and reduce COE
  • Components can be offered in new commercial products or retrofit onto the existing fleet
    • Accelerating TRL increase and deployment
• 2016 phase II awards nominally $6M ea., 4 yr. projects
  • Advanced Multi-Tube Mixer Combustion for 65% Efficiency (GE)
  • High Temperature CMC Nozzles for 65% Efficiency (GE)
  • CMC Advanced Transition for 65% Combined Cycle Efficiency (SE)

• 2018 phase I awards (18 months), Ph II down select in FY20
  • Additive Manufactured Metallic 3D OxOx CMC Structures (SE)
  • Low-Weight Ti-AL Airfoils (SE)
  • Low NOx Axial Stage Combustion System (SE)
  • High-Temperature Additive Architectures (GE)
  • High-Temperature, High AN2 Last-Stage Blade (GE)
  • Aero-Thermal Technologies (GE)
  • Hybrid Ceramic-CMC Vane with EBC(UTRC)
Advanced Multi-Tube Mixer Combustion

65% efficiency combined cycle goal

**PROJECT NARRATIVE**

- Fully develop multi-tube mixer combustion
- Low NOx up to 3100°F TIT supporting load following with an ultra-compact design that minimizes NOx formation and minimizes cooling requirements
- Develop a revolutionary fully Integrated Combustor Nozzle (ICN) in an elegantly yet simple design that includes multi-tube pre-mixer, transition nozzle and CMCs

**BENEFITS**

- Contributes to DOE goal of 65+% CC efficiency
- Enables robust fuel flexibility

**BUDGET**

<table>
<thead>
<tr>
<th>DOE</th>
<th>Participant</th>
<th>Total</th>
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<tr>
<td>$6,608,516</td>
<td>$2,832,221</td>
<td>$9,440,737</td>
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**GENERAL ELECTRIC CO.**

FE0023965
Partners: GE Power & Water, GE Global Research
1/01/2015 – 8/31/2019
Objective: Realize 2 – 3 % points improvement in combined cycle efficiency

Approach
- Continue investment in fundamental and applied R&D
- Resolve issues with fuel and air inlet
- Resolve issues with kinetic energy recovery as a pressure gain
- Work in a collaborative framework with US DOD, industry, universities and National Laboratories (NETL)
  - Pursue a fully integrated engine demonstration
Projects Supporting Pressure Gain Combustion
Alternate pathway to 65% CC goal

• 2016 phase II award nominally $6M, 4 yr. project
  • RDC for GT and System Synthesis to Exceed 65% Eff. (Aerojet Rocketdyne)

• Other project activities in PGC
  • Fuel injection dynamics and composition effects on RDE performance (UTSR - University of Michigan)
  • NETL Modeling and air / fuel inlet conditions
  • NETL and Air Force Research Lab to demonstrate PGC in small engine
PROJECT NARRATIVE

• Develop & validate RDC system models for CC power plant (PH 1)
• Characterize and optimize the fluid and mechanical interface between the RDC and a turbine cascade.
• Multiple test programs using 10 cm, 21 cm and 31 cm combustors & advanced diagnostics
• CFD models developed and anchored as design tools for maximizing RDC turbine performance.

BENEFITS

• Alternative path to DOE 65% CC goal (2 – 3% points)
Modular Hybrid Heat Engines for FE Applications

Highly efficient and low cost modular heat engines

- **Objective:** Develop heat engines for modular coal gasification, stranded gas assets and other DG-like applications (NG compressor stations, etc.)

- **Approach**
  - System studies to analyze promising configurations and identify benefits, markets, and technology gaps
  - Pursue testing to close technology gaps and develop designs
  - Support development of highly successful technologies
Projects Supporting Hybrid Heat Engines
Modular heat engines for small low cost high efficiency power systems

Six 2018 phase I awards (18 months), Ph II down select in FY20

- Turbo-Compound Reheat GT CC – Bechtel National
- Optimization and Control of a Hybrid GT with sCO₂ Power System – Echogen
- Advanced Modular Sub-Atmospheric Hybrid Heat Engine – GTI
- Modular Heat Engine for the Direct Conversion of NG to H₂ and Power – GTI
- Novel Modular Heat Engines with sCO₂ Bottoming Cycle Utilizing Advanced Oil-Free Turbomachinery – General Electric
- Advanced Gas Turbine and sCO₂ Combined Cycle Power System – SwRI
**Advanced Gas Turbine and sCO₂ Combined Cycle Power System**

Southwest Research Institute & Solar Turbines

**PROJECT NARRATIVE**

- CC sCO₂ based waste heat recovery system (WHRS) to the discharge of an existing gas turbine package
- Demonstrate advantage of a sCO₂ bottoming cycle compared to steam based cycle
- Develop commercially competitive WHRS < $1000/kW

**BENEFITS**

- Increased performance of existing gas turbine installations, including natural gas compressor stations
- Reduced operating costs and footprint
- Cleaner and more efficient operation
- Enhanced load-following capability

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**Southwest Research Institute**

FE0031619

Partners: Hanwha Power Systems Americas, Solar Turbines, Williams

7/9/2018-1/9/2020

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<tbody>
<tr>
<td>Waste Heat Recovery System</td>
<td>$500,000</td>
<td>$125,000</td>
<td>$625,000</td>
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sCO₂ Power Cycles for FE Applications

Two related cycles for advanced combustion and gasification applications

Indirectly-heated cycle (RCBC)
- 10 MWe project (GTI, GE & SwRI)
- Applicable to adv. coal combustion
- Incumbent: USC/AUSC boilers
- >50% cycle efficiency possible
- Compact turbomachinery
- Ideal for constant temp. heat source

Directly-heated cycle (Allam Cycle)
- 25 MWe sCO₂ pilot plant (8 Rivers)
- Applicable to coal syngas & NG
- Incumbent to beat: NGCC and IGCC with CCS
- R&D compatible w/ indirect cycle
- >95% CO₂ capture at pressure
- Net water producer, if dry-cooled

Source: NETL
Projects Supporting sCO₂ Power Cycles
Component development for SCO₂ turbomachinery

• Two Ph. II 2016 awards nominally $6M ea., 4 yr. projects
  • Low-Leakage Shaft End Seals for Utility-Scale sCO₂ Turbo Expanders (GE)
  • High Inlet Temp. Comb. for Direct Fired Supercritical Oxy-Combustion (SwRI)

• One Ph 1 award, 18 mo. Ph II down select in FY20
  • Development of Oxy-fuel Combustion Turbines with CO₂ Dilution for Supercritical Carbon Dioxide (SCO₂) Based Power Cycles

• Other sCO₂ Projects
  • NETL sCO₂ techno-economic system studies (NETL)
  • Development of advanced recuperators (Thar Energy)
  • Design, build, and operate 10MWe STEP pilot facility (GTI)
  • sCO₂ National Lab R&D Plan (SNL)
  • sCO₂ power cycle market deployment study (Deloitte)
**Supercritical Carbon Dioxide 10 MWe Pilot Plant Test Facility**

Gas Technology Institute

**Objectives**
- Plan, design, build, and operate a 10 MWe sCO$_2$ Pilot Plant Test Facility
- Demonstrate operability of the sCO$_2$ power cycle
- Verify performance of components
- Evaluate system / component capabilities
  - Steady state, transient, load following, limited endurance operation
- Demonstrate potential for producing a lower COE and thermodynamic efficiency greater than 50%

**STEP Facility Configuration**
- Located at SwRI’s San Antonio, TX campus
- 10 MWe Recompression closed Brayton cycle
- 700°C turbine inlet temperature

**Budget**

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DOE, DOD & NASA Synergies
Many synergies driven by extreme performance requirements

• Materials
  • CMC
  • SX

• Advanced manufacturing
  • New parts
  • MRO

• Cooling requirements
  • Facilitating high temperature

• Power density
  • Modular hybrid heat engines
  • Mission driven

• Advanced designs
  • SCO2 Power Cycles

• Combustion
  • PGC
• Five technical topic areas:
  • Pressure Gain Combustion
  • Adv. Materials Develop. for Hot Gas Path Turbine Components
  • Adv. Mfg Development for Hot Gas Path Turbine Components
  • Fundamental Research for sCO2 Power Cycle Development
  • Fossil Fuel-Based Power Generation w/Large-Scale Energy Storage

• Read the full NOI at Grants.Gov (http://www.grants.gov) or FedConnect (http://www.fedconnect.net/FedConnect).
Gas turbine deployments are declining
Natural gas prices remain low
Renewables affecting GT performance requirements
AT well positioned to deal with CO2 emissions thru efficiency improvements and making CCS affordable
DOE FE is supporting a robust program in four areas and finding synergies with DOD and NASA R&D
New work planned in FY2019 UTSR FOA
Mark Your Calendars!
March 19 & 20, 2019; Berlin, Germany

Visit the symposium website to submit an abstract:
www.asme.org/events/amrgt
Back-up Slides

• Provided on request