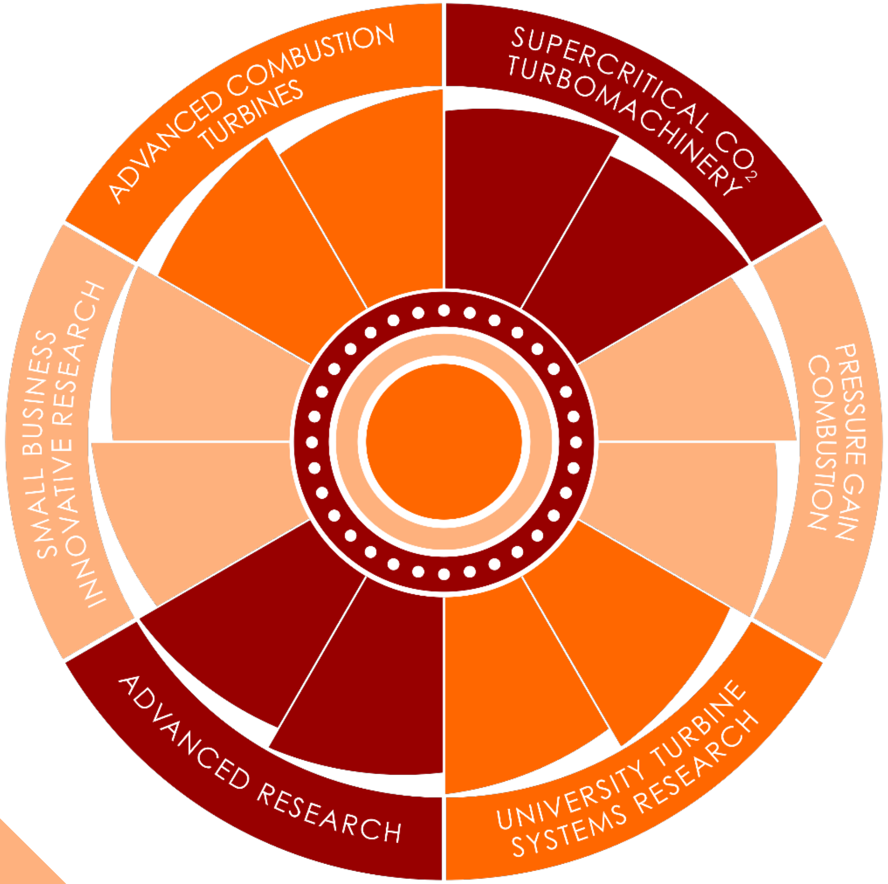
2017 UTSR
Request for Information (RFI)

NATIONAL ENERGY TECHNOLOGY LABORATORY



Rich Dennis
And
Mark Freeman
U.S. Department of Energy
National Energy Technology Laboratory

November 3, 2016

Virginia Tech, Blacksburg, VA

UTSR Request for Information (RFI) -- Update

Purpose of RFI

- Obtain stakeholder input to help formulate the next UTSR Funding Opportunity Announcement (FOA), including helping identify pertinent technical R&D topics/subtopics that supports the development of advanced gas turbine technologies and emerging concepts for supercritical carbon dioxide (sCO_2) based power cycles.
  - With a strong focus on applied- and/or bench-scale R&D, including very challenging combustion, aerodynamics/heat transfer, and materials technology issues

- Over the long history of the UTSR Program, the technical topics of interest have been updated as R&D results have successfully addressed technical needs (e.g., the UTSR program contributed significant insight towards the scientific understanding of the complex early ignition behavior of syngas and high-hydrogen content fuels) while "new" technical challenges emerge.
  - In this manner, the UTSR program portfolio continually seeks to conduct timely, highly scientific R&D across a variety of technical topics which are also of industrial relevance.

- Thus, the RFI mechanism is one means of contributing towards these goals by soliciting stakeholder feedback prior to issuing a future UTSR FOA.

UTSR Request for Information (RFI) -- Update

Recent History of UTSR Program

- In recent years, the UTSR program has been investigating technical issues related to the development of next-generation turbine technology with the goal of producing reliable, affordable, clean, efficient, and cost-effective energy supplies and to address the need for engineering and scientific solutions for advanced air breathing combustion turbines and turbomachinery for sCO_2 power cycles.

- Under the FY15 UTSR FOA, four technical subtopics were identified:
  - Three subtopics on 'air breathing machines' with the goal of achieving 65 percent combined cycle energy efficiency — including research on low NOx combustion, pressure gain combustion, and turbine cooling.
  - A subtopic on oxy-combustion machines for direct–fired sCO_2 power cycles was also included.

The FY15 UTSR FOA resulted in 9 Awards in a highly-competitive solicitation (where many solid applications were submitted). And these projects are presenting the first year of their results at this workshop.

Low-NOx Combustion R&D – Georgia Tech, Penn State

Pressure Gain Combustion R&D – University of Michigan, Purdue, Penn State

Turbine Cooling R&D – Ohio State, University of Pittsburgh

Direct-Fired sCO_2 Power Cycles R&D – University of Central Florida, Georgia Tech

As a reminder, DOE turbine program funding limitations basically determines the maximum number of UTSR awards that can be realistically made under the FOA … and thus, not all of the highly ranked applications (after a thorough independent review) are able to be funded. Program funding limitations are also the main reason the UTSR FOA has not been held annually -- but rather every other year -- in recent years.

UTSR Request for Information (RFI) -- Update

The RFI was issued on September 29 and closed October 24

A total of 52 suggestions were submitted (with participation from 12 organizations) outlining various technical topics/subtopics and technology R&D challenges for possible consideration in order to help plan the next UTSR FOA.

- This stakeholder response to the RFI included a cross-section of universities, gas turbine manufacturers, and research institutes offering helpful technical comments.

- **Of the 52 suggestions (Topics/Subtopics), about half (27) would easily fit within the traditional/historical UTSR Topics for 'air breathing gas turbines' (that would be relevant to IGCC/coal-derived syngas, NGCC, etc.) with only minor rephrasing of prior UTSR FOA language:**
  - For example, 14 could be easily grouped within 'prior Aerothermal/Heat Transfer topics' such as advanced film cooling R&D, etc.
  - With another 9 grouped into 'prior Combustion topics' (including expanding fuel flexibility)
  - With another 4 grouped into 'prior Advanced Materials topics' such as advanced thermal barrier coatings, etc.
- **In terms of sCO_2 Power Cycles, there were 11 suggestions (topics/subtopics)**
  - This raise consideration of whether it would be appropriate to have one sCO_2 topic or further subdivisions (sCO_2 Combustion, sCO_2 Materials, sCO_2 Aerothermal/Heat Transfer/Bearings/Seals)
- **There were also many potentially 'new areas'** ***– although what would be 'new' for UTSR consideration may not be new from the standpoint of other R&D Programs***

UTSR Request for Information (RFI) -- Update

Included among the suggestions that would easily fit within the traditional/historical UTSR Aerothermal/Heat Transfer Topics for 'air breathing gas turbines' (relevant to IGCC/coal-derived syngas, NGCC, etc.) with only minor rephrasing of prior UTSR FOA language:

- Unsteady behavior of aerodynamic and film cooling effectiveness
- Effects of unsteady combustor flows on component film cooling; unsteady impingement cooling
- Optimization of turbine blade cooling
- Reduce gas turbine blades tip leakage flow
- Advanced manufacturing for innovative cooling methods (transpiration cooling, lattice-type cooling)
- Efficient use of endwall leakage flow for turbine cooling
- Advanced sealing concepts and advanced film cooling techniques
- Improved physics-based correlations for turbulence impact on heat transfer (and deviation from closure models); explain RANS limitations; correlations for combined convective/radiant heat transfer
- Improved correlations (and modeling) of very low aspect ratio channels with large turbulators; also unsteady impingement cooling

UTSR Request for Information (RFI) -- Update

Included among the suggestions that would easily fit within the traditional/historical UTSR Combustion Topics for 'air breathing gas turbines' (relevant to IGCC/coal-derived syngas, NGCC, etc.) with only minor rephrasing of prior UTSR FOA language:

- Low NOx combustion R&D, including more expanded fuel flexibility (e.g., syngas from biomass)
- Natural gas composition effects on gas turbine performance (e.g., effect of ethane/propane)
- Natural gas composition effects on turbulent flame speeds (e.g., effect of ethane/propane)
- Scaling rules for single element to multi-element combustors
- High frequency combustion instabilities
- Advanced high-temperature combustion strategies
- Combustion physics of piloted flames
- Reactor model of highly turbulent premixed flame emissions

As with the Aerothermal/Heat Transfer R&D suggestions, these Combustion R&D suggestions would also involve comprehensive experimental work and modeling efforts focused on the 'science' as well as the practical, industry-relevant implications

UTSR Request for Information (RFI) -- Update

Included among the suggestions that fit within the traditional UTSR Advanced Materials Topics for 'air breathing gas turbines' (relevant to IGCC/coal-derived syngas, NGCC) relative to prior FOA language:

- Advanced Materials, Alloys and Ceramic-Matrix-Composites (CMCs)
- Advanced Turbine Blade Coatings
- New Refractory Metals for high temperature applications
- High Entropy Alloys (HEA)
- Ceramic-Matrix-Composites (CMCs) -- develop new fibers, CMC building block materials or new classes of CMC materials

UTSR Request for Information (RFI) -- Update

Included among the sCO_2 Power Cycles suggestions:

- Develop innovative sCO_2 turbine and turbo compressor designs, including improved resistance to particle erosion (e.g., including particles from spallation of corrosion products of different materials/locations within the supercritical CO_2 loop)
- Reduction in turbine nozzle erosion (e.g., improve turbine nozzle toughness to reduce nozzle replacement/replacement)
- Develop innovative sCO_2 heat exchanger geometries and materials
- Improved sCO_2 compressors – more robust designs (and enabling more robust designs with improved surge/stall/fluid dynamics analyses and updating aerodynamic design codes taking into account property variations)
- Oxy-Combustion for sCO_2 Cycle Applications (e.g., flame stabilization; experiments/modeling to support combustor requirements)
- sCO_2 Material Compatibility Issues throughout the entire system
- sCO_2 Thermal Management (including film cooling, regenerative cooling, impingement cooling, pin-fin cooling; and more accurate heat transfer correlations at high Reynolds numbers)
- sCO_2 Bearings/Seals (improved seal configurations, seal materials, inboard/outboard bearings, reduce rotor dynamic stability risk)

UTSR Request for Information (RFI) -- Update

Many 'new' topics/subtopics were also suggested based on RFI Responses

- Advanced Instrumentation, Sensors and Diagnostics
- Harsh Environment Sensors for Advanced Gas Turbine Engines
- Sensors for Development of Advanced Cycles (e.g., Pressure-Gain Combustion Engines)
- Sensors for Gas Turbine Combustion Dynamics and Emissions
- Maintenance, Repair & Overhaul
- Repair through Additive Manufacturing
- Single Crystal Repair
- Joining of Disparate Materials
- Additive Manufacturing
- Additive Manufacturing Qualification and Quality Control
- Non-Destructive Evaluation and Inspection
- The Industrial Internet Applied to Turbines
- Combustor – Turbine Interactions
- Cross-Cutting Technology between Aviation and Power Generation Turbines
- Electrical Component Heat protection at High pressure
- Improved computational methods for multistage axial compressors

Although what might be 'new' for UTSR consideration may not be new from the standpoint of other R&D Programs, such as University Coal Research (UCR), Small Business Innovative Research (SBIR), etc.

……

And the UTSR budget is not very large to begin with!

……

Which in turn limits the number of 'new' UTSR topics that could realistically be considered

UTSR Request for Information (RFI) -- Update

Questions/Comments

How does the group feel about the RFI responses to-date from a technical standpoint?

Are there some technology areas that should be higher priority or perhaps lower priority?

Are there other 'new' potential topic areas that we should be considering instead?

What is the sense of the broader direction of the UTSR Program – in the next year, or where we might think about trying to be in 3-5 years

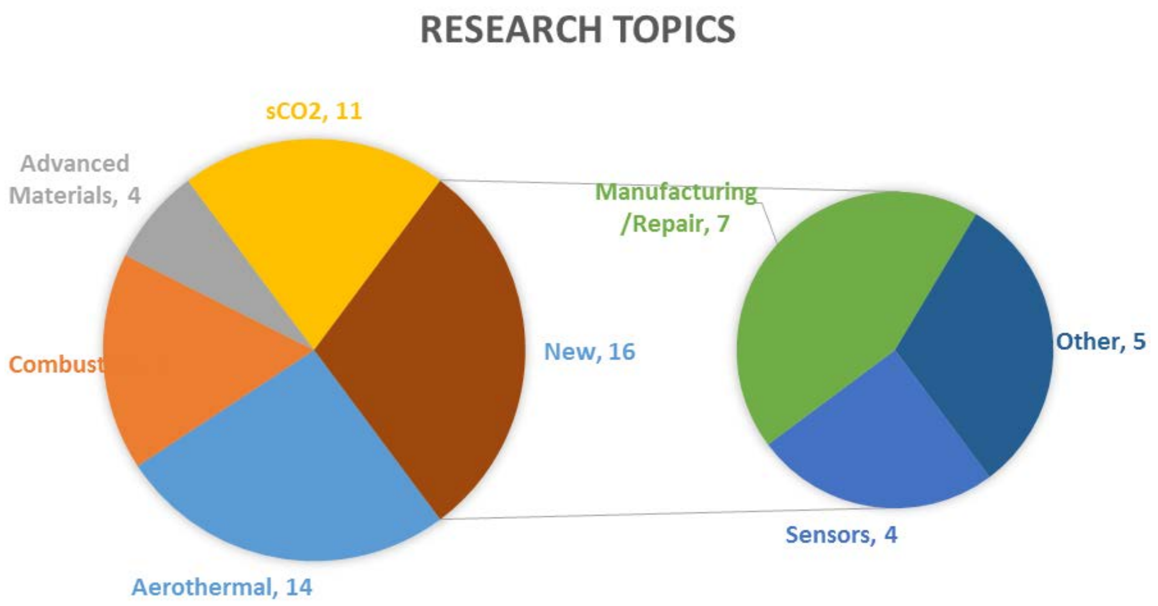
Do workshop attendees (or your colleagues who can't be with us today) feel it might be wise to extend the RFI to obtain even more stakeholder input?

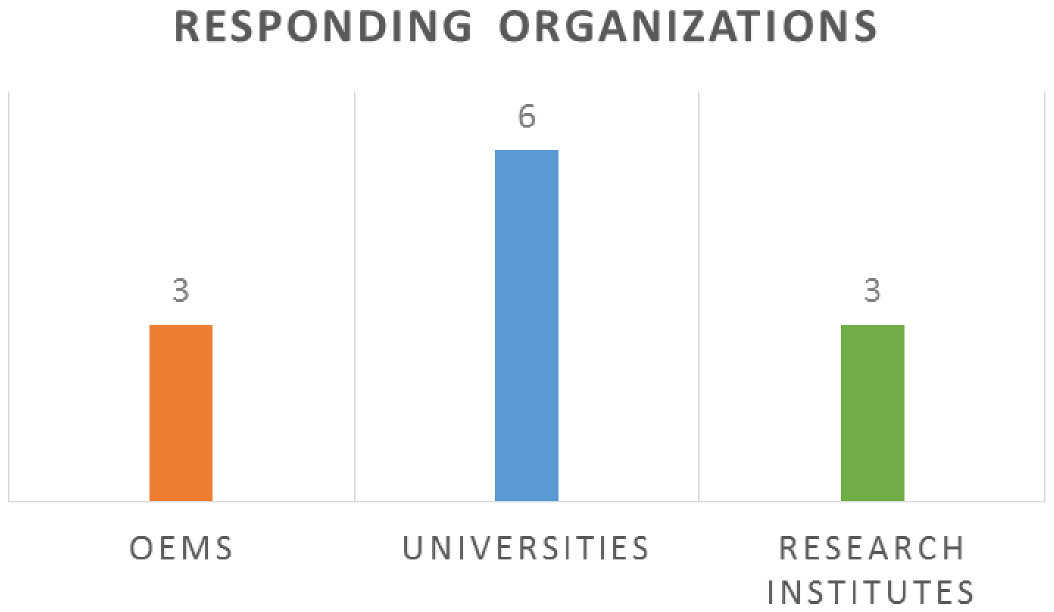
Perhaps after digesting the results and key findings of the workshop based on the presentations/discussions?

Open Discussion

UTSR RFI Results at a Glance

- **12 Responding Organizations**
- **52* Research Topics**
  - 27 in “Traditional” UTSR Categories
  - 11 sCO2
  - 16 “New” Research Categories in 3 topics





* Numbers do not add up due to some overlap in categories

Backup Slides

UTSR FY15 FOA Summary (for background reference)

Topics
- 1 – Low NOx Combustion R&D
- 2 – Pressure Gain Combustion R&D
- 3 – Turbine Cooling R&D
- 4 –SCO_2 Oxy-combustion R&D

Result

9 Awards
- Topic 1-2
- Topic 2-3
- Topic 3-2
- Topic 4-2

UTSR FY15 FOA (for background reference)

NATIONAL ENERGY TECHNOLOGY LABORATORY

Topic 1 – Low NOx Combustion R&D

The key goal of this topic area is to acquire fundamental knowledge and understanding to facilitate the development of efficient, robust, reliable, and low emissions combustion systems for air-breathing gas turbines. Achieving 65% combined cycle efficiency will likely require increased turbine inlet temperatures (~3100°F). Fundamental R&D is sought for air breathing gas turbine combustion concepts that support load following capabilities to meet the demand of a modern grid, and operate with low NOx emissions across the expected range of operation. Fundamental R&D is sought to support technologies and approaches that will allow turbine inlet temperatures to reach 3,100° F while limiting peak flame temperature for NOx mitigation.

Topic 2 – Pressure Gain Combustion R&D

The goal of this topic area is to acquire the fundamental knowledge and understanding necessary to support the development of unique, pressure gain combustion (PGC) systems designed for potential integration with air breathing gas turbines in combined cycle applications. The methodology resulting in a pressure-gain across the combustor relies on the Humphrey (or Atkinson) cycle, and is seen to have great potential as a means of achieving 65% combined cycle efficiency in gas turbine power systems, potentially contributing 4-6% for simple cycle systems and 2-4% in combined cycle systems. While conventional gas turbine engines undergo steady, subsonic combustion, resulting in a total pressure loss, PGC utilizes multiple physical phenomena, including resonant pulsed combustion, constant volume combustion, or detonation, to affect a rise in effective pressure across the combustor, while consuming the same amount of fuel as the constant pressure combustor. Potential technical challenges include fuel injection, fuel and air mixing, backflow prevention, detonation initiation, wave directionality, maintaining a pressure gain, controlling emissions of NOx and carbon monoxide (CO), as well as unsteady heat transfer and cooling flow challenges resulting from integration with the turbine hot gas path expansion components. Collaboration with industrial partners with PGC experience is strongly encouraged for the proposed R&D plan.

UTSR FY15 FOA (for background reference)

Topic 3 – Turbine Cooling R&D

The key goal of this topic area is to support the development of advanced internal cooling strategies including advanced impingement for airfoil cooling and advanced near wall cooling techniques. In state of the art air breathing gas turbines, approximately 20% of the mass flow is taken from the working fluid to cool hot gas path components. Reducing this cooling air requirement can allow more of the working fluid to be utilized, thus increasing the efficiency of the gas turbine. The increased turbine inlet temperature likely required to achieve 65% combined cycle efficiency will further increase turbine component heat loads, requiring even more advanced, efficient, and effective cooling techniques. Therefore, research is needed in this topic area that can support manufacturers as they design hot gas path components with sufficient cooling capabilities

Topic 4 –SCO_2 Oxy-combustion R&D

The goal of this topic is to address challenges associated with oxy-combustion systems in directly heated SCO_2 power cycles. These cycles utilize natural gas or syngas oxy-combustion systems to produce a high temperature SCO_2 working fluid and have the potential to be efficient, cost effective and well-suited for carbon dioxide (CO_2) capture. Preliminary studies have shown that direct cycles operating at turbine inlet temperatures and pressures of 1150°C and 300 bar could exhibit efficiencies comparable to Natural Gas Combined Cycle plant efficiencies while capturing nearly 100% of the CO_2 produced. To realize the benefits of this power cycle, challenges associated with oxy-combustion at the conditions noted above must be addressed. These challenges include combustion stability, flowpath design, thermal management, pressure containment, and definition of turbine inlet conditions. Fundamental R&D is needed to address these challenges.

Please note the UTSR Final FOA language is not meant to be overly long – and as a reminder, proposal applications should seek to provide compelling technical justifications for the proposed R&D