DOE FECM's Advanced Turbines Program

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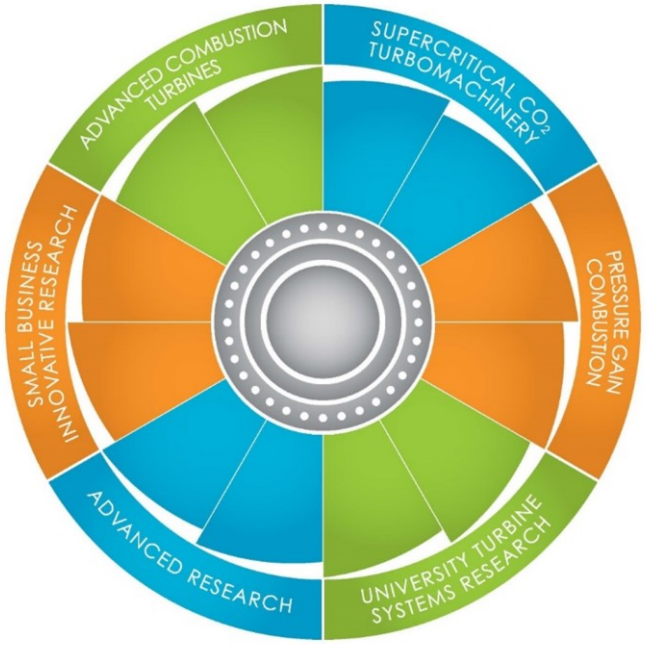
Preface

This presentation provides an overview of a Fossil Energy and Carbon Management (FECM) Advanced Turbines R&D Program. This program is implemented based on both Administration priorities and Congressional direction. Plans for future technology development reflect expected trajectories of current R&D, but these plans are subject to change. Furthermore, some stages of future technology development, although necessary for commercialization, may not be financially supported by the government.

Presentation Outline

UTSR & Advanced Turbines (AT) Program Review and Workshop

- Overview of Workshop
- DOE Mission & FECM Objectives for AT Program
- Status of AT FOAs
- Importance of Gas Turbine Efficiency
- Summary & Next Steps



Overview of UTSR Workshop

- **Day 1 – Focus on Hydrogen**
  - Keynote - Gas Turbines, Hydrogen, and the Evolving US Energy Sector, Tim Lieuwen, Strategic Energy Institute, Georgia Tech
  - 11 projects reviewed
- **Day 2 – Focus on sCO_2**
  - Keynote – Overview of Supercritical Carbon Dioxide Power Cycles, Tim Held, Echogen Power Systems
  - 11 projects reviewed
- **Day 3 – Focus on GT Efficiency**
  - Keynote - Gas Turbines, Past, Present & Future, John Gulen, Bechtel Infrastructure & Power, Inc.
  - 12 projects reviewed

DOE Mission

- Carbon free electricity by 2035
- Net-zero emissions by 2050
- Create new clean energy jobs
- Revitalize communities
- Advance environmental justice

WASHINGTON, D.C. (Nov. 5, 21) — U.S. Secretary of Energy Jennifer M. Granholm announced today the U.S. Department of Energy's (DOE's) new goal to remove gigatons of carbon dioxide (CO2) from the atmosphere and durably store it for less than $100/ton of net CO2-equivalent. The "Carbon Negative Shot," ….

AT Guidance in FY22 PBR

Major themes from the PBR for advanced turbines

Accelerate Carbon-Neutral Hydrogen Pathways

- Improve flexible operations to support renewables
- Use low- / no-carbon fuels, optimize for CCS, with low NOx
- Support efficiency goals of 67% (CC) and 50% (SC)
- Invest in a future 70% efficient CC machine
- Pressure gain combustion
- Apply AM and AI to attain efficiency goals

AT Program Objectives

DOE Mission Translated to Advanced Turbines Objectives Based on FY 22 PBR

DOE Mission

- Carbon free electricity by 2035
- Net-zero emissions by 2050
- Create new clean energy jobs
- Revitalize communities
- Advance environmental justice

Turbine Objectives

- H_2 based fuels, low NOx, optimize for CCS
- Support advanced efficiency
  - Near term 67% (CC) and 50% (SC)
  - Future 70% efficient CC machine
  - Pressure gain combustion
- Improve flexible operations
- Apply AM & AI to attain goals

Advanced Turbines FY21 FOAs

FOA 2397 UTSR Program – Focus on Hydrogen

- **AOI 1: Hydrogen Combustion Fundamentals for Gas Turbines**
  - **GA Tech** - Ignition, Flame Speeds, and Emissions, from High H2 Blended Fuels
  - **Central FL** - Fundamental Experimental & Numerical Comb. Study of H2 Containing Fuels
  - **San Diego State** – Develop. of Design Practices for Additively Mfg. Micro-Mix Hydrogen

- **AOI 2: Hydrogen Combustion Applications for Gas Turbines**
  - **Purdue** - Investigation of Flame Structure for Hydrogen Gas Turbine Combustion
  - **The OH State** – H2 Fuel Effects on Stability / Operation of Lean-Premixed and Staged GT Comb.
  - **UCA, Irvine** – Develop. / Application of Multipoint Array Injection Concepts for Operation of GT on Hydrogen Containing Fuels

- **AOI 3: Hydrogen-Air Rotating Detonation Engines**
  - **U AL** - A Robust Methodology to Integrate Rotating Detonation Combustor with GT to maximize Pressure Gain
  - **Purdue** - Physics-based integration of H2-Air Rotating detonation into GT Power Plant.

Advanced Turbines FY21 FOAs

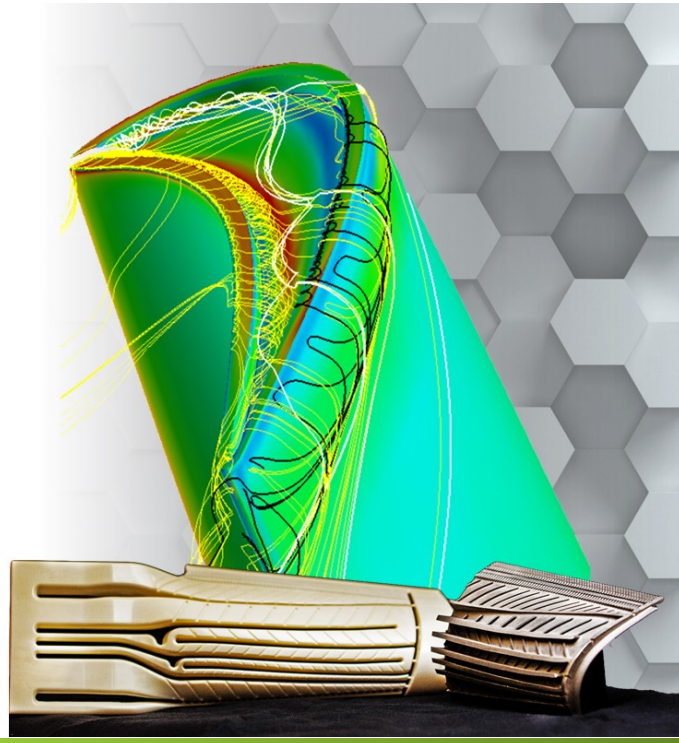
FOA 2400 FECM H_2 FOA – Advanced Turbines Areas of Interests

- **AOI 9 - Hydrogen Combustion Systems for Gas Turbines**
  - 9a - F-Class
  - 9b - Aeroderivative Class
  - 9c - Industrial Class – **Selection: Solar Turbines Inc.**

- **AOI 10 - Pre-commercial Testing of a Hydrogen Fueled Gas Turbine (Unfunded)**

- **AOI 11 - Ammonia Combustion Systems for Gas Turbines**

- **AOI 12 - Demonstration of a Rotating Detonation Engine in a Gas Turbine**



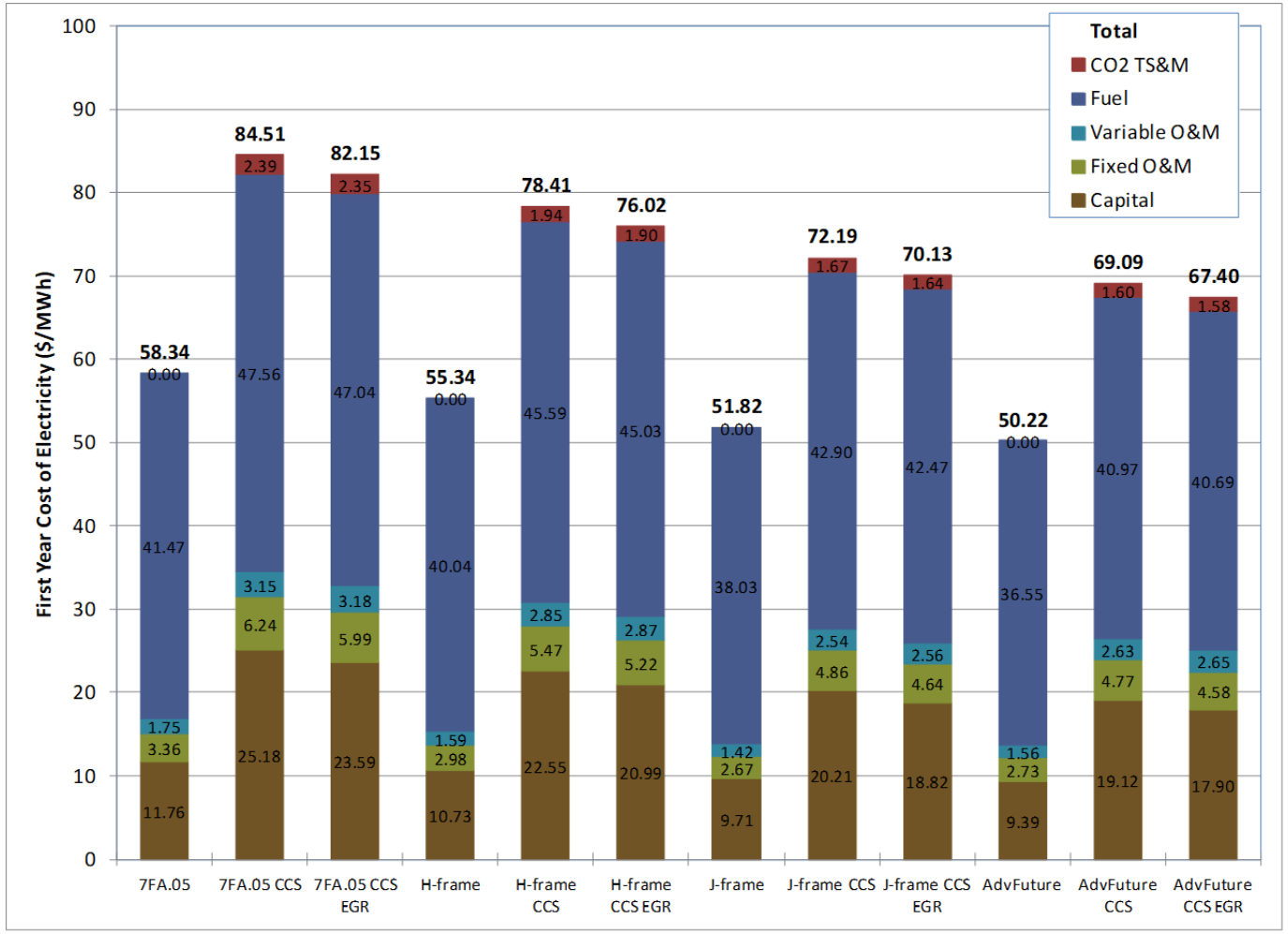
GT Efficiency, CCS and COE

Increasing GT efficiency dramatically reduces the impact of CCS on COE

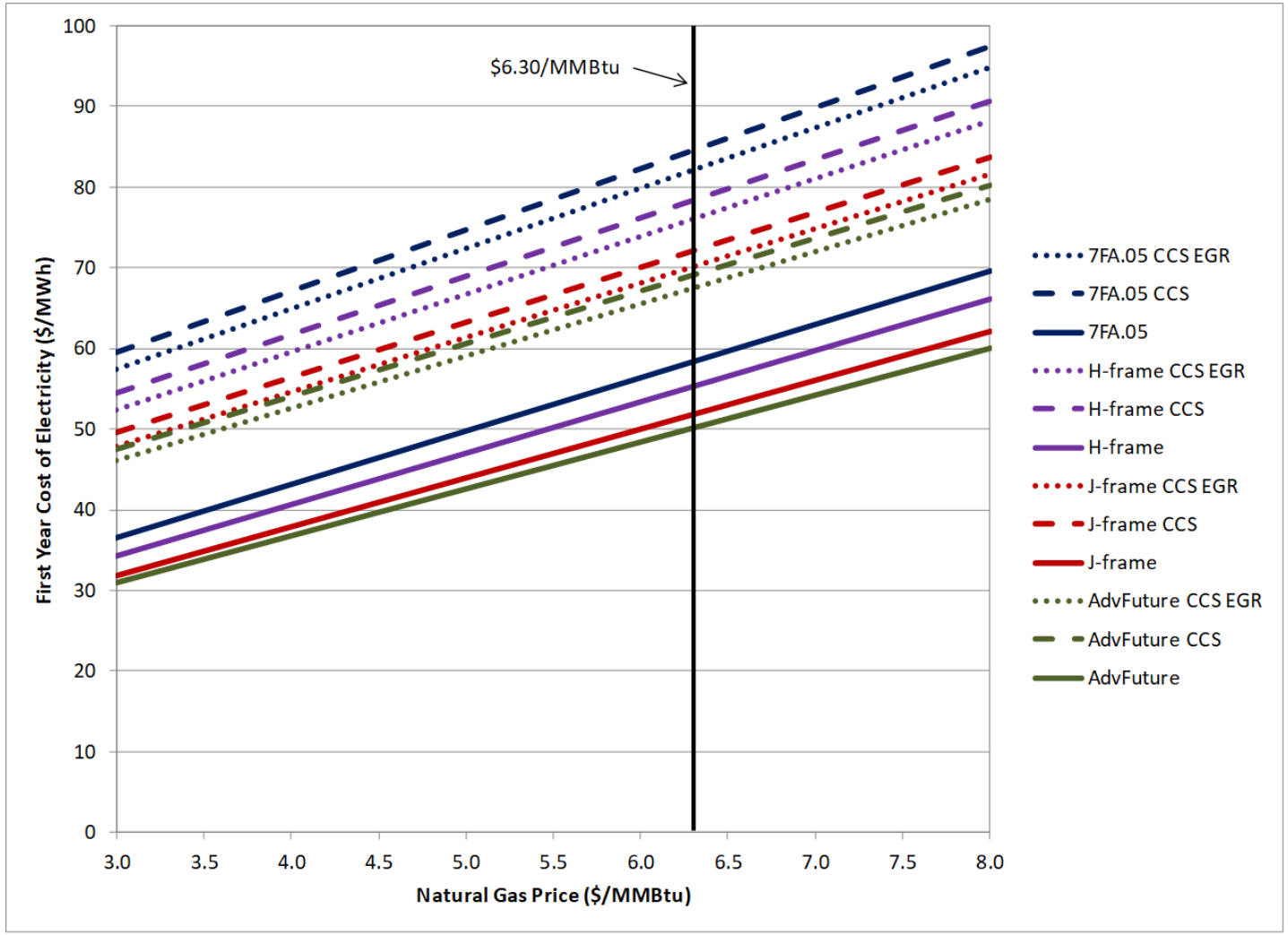
Turbine	Technology		Efficiency (% HHV/ LHV)	Net Power (MWe)	TOC ($/kW)	COE ($/MWh)	LCOE ($/MWh)	Cost of CO_2 avoided ($/ton)
SOA (based on "7FA.05")	1a	w/o CO_2 capture	51.8 / 57.4	634	836	58.34	73.96	n/a
	1b	w CO_2 capture	45.2 / 50.1	553	1,688	84.51	107.13	75.78
	1c	w CO_2 +EGR	45.8 / 50.7	563	1,746	84.90	107.62	68.79
SOA (based on "H")	2a	w/o CO_2 capture	53.7 / 59.5	820	762	55.34	70.15	n/a
	2b	w CO_2 capture	47.2 / 52.2	721	1,512	78.41	99.39	69.16
	2c	w CO_2 +EGR	47.7 / 52.9	738	1,549	78.43	99.42	61.88
Advanced (based on "J")	3a	w/o CO_2 capture	56.5 / 62.6	982	690	51.82	65.69	n/a
	3b	w CO_2 capture	50.1 / 55.5	870	1,355	72.19	91.51	64.25
	3c	w CO_2 +EGR	50.6 / 56.1	889	1,389	72.30	91.64	57.65
Advanced Future turbine	4a	w/o CO_2 capture	58.8 / 65.2	1,108	667	50.22	63.65	n/a
	4b	w CO_2 capture	52.5 / 58.1	989	1,281	69.09	87.58	61.92
	4c	w CO_2 +EGR	52.8 / 58.5	1,004	1,314	69.35	87.92	56.32

Fuel Cost Dominate COE in NGCC

COE for NGCC w/ or w/o CCS

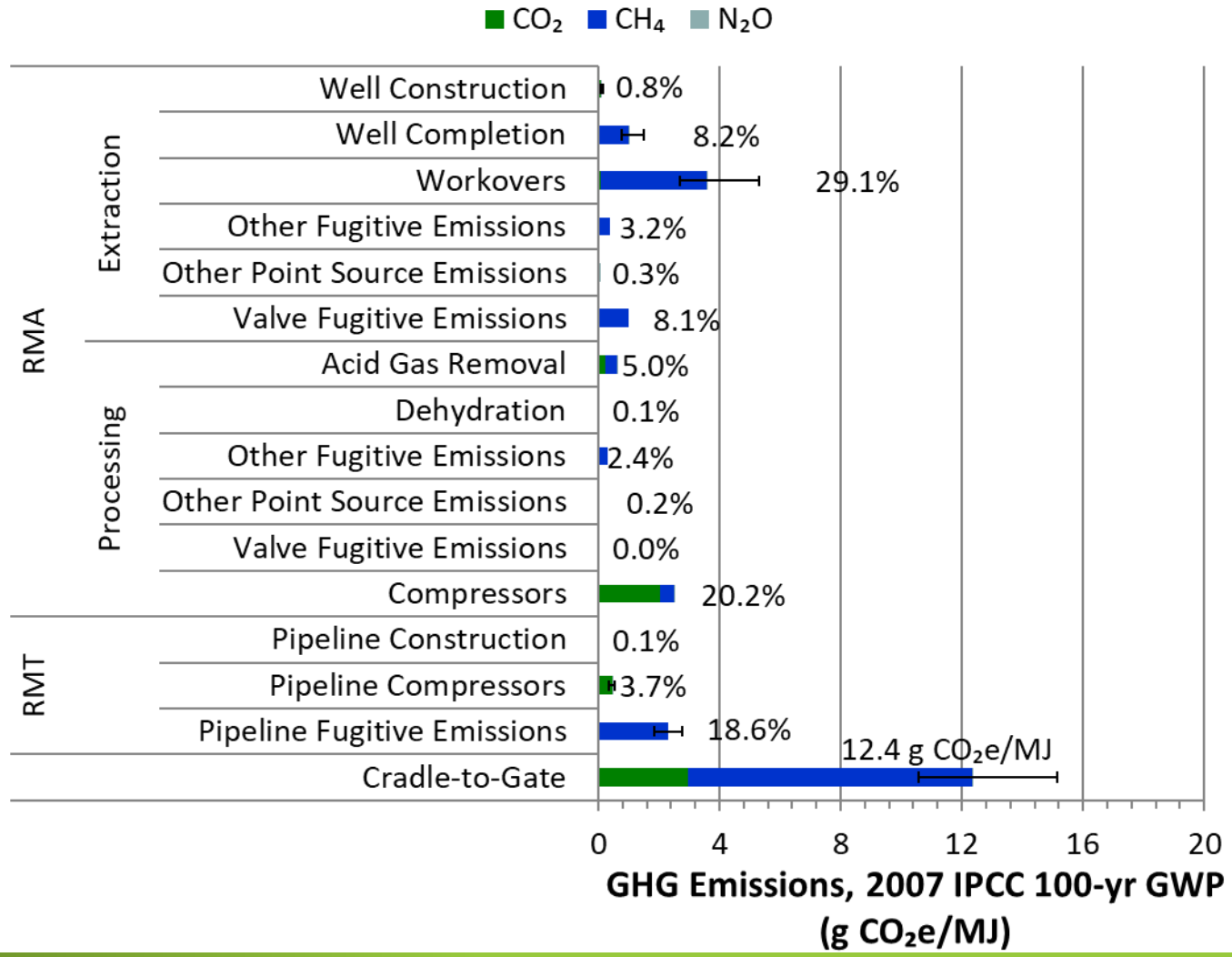


Fuel Cost Sensitivity on COE in CC Power Plants



Upstream GWP from Natural Gas

Barnett Shale Natural Gas Extraction and Transport



Summary

- The Advanced Turbines Program supports the DOE mission by providing options for decarbonizing the electric power sector
- FECM is making a considerable investment by developing gas turbines for carbon free fuels
- Improving gas turbine efficiency significantly reduces COE for hydrogen fueled turbines and systems with CCS

Questions?

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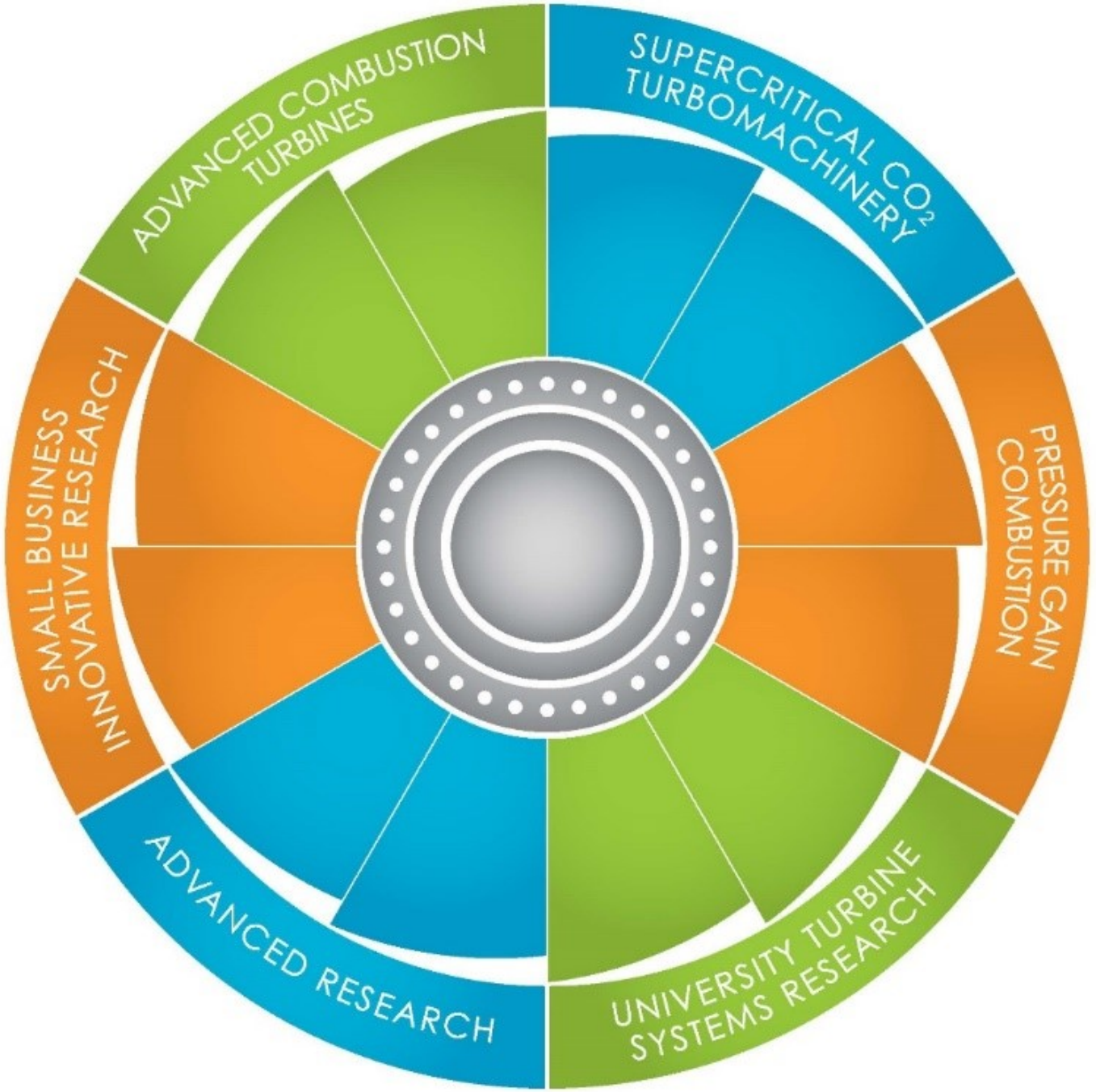
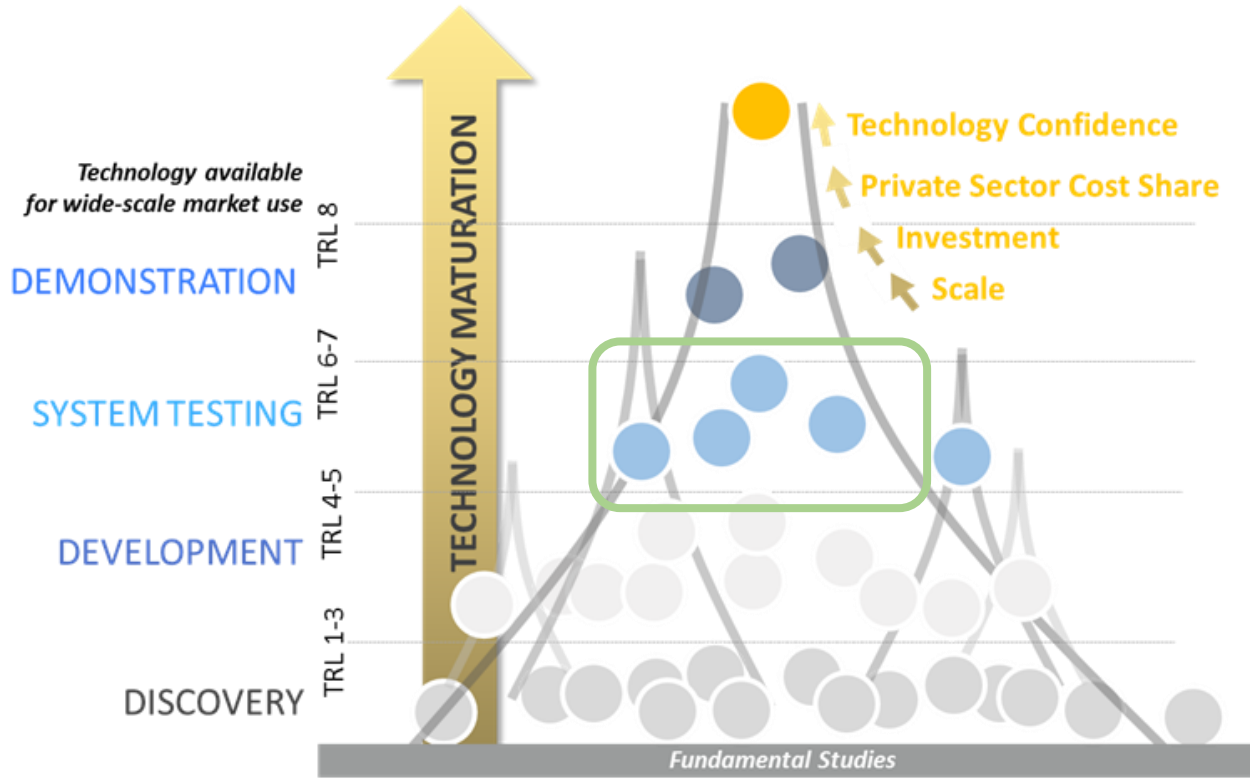


Takeaways

Uniquely positioned to deliver on 35-50 goals

Topical Areas:

- High Efficiency Combined Cycle
  - Net-zero / Net-negative
- sCO_2 Based Power Cycles
- Hybrid Heat Engines



The FECM Team

FECM has huge scope in the DOE carbon reduction / carbon negative strategy

- Jen Wilcox; PDAS & Acting AS for the Office of FECM
- Shuchi Talati; COS for FECM
- Emily Grubert; DAS for CM in FECM
- Sam Thomas; Division Director - H2 and Carbon Management
- Robert Schrecengost; Senior Program Manager – FECM H2 Program, Advanced Turbines & Advanced Energy Materials
- NETL – Strategic Engineering & Analysis, Lab-to-Pilot Scale R&D, and FECM Program Execution