Overview of DOE FECM Advanced Turbines Program

Producing State-of-the-Art Technology for Hydrogen Fueled Gas Turbines

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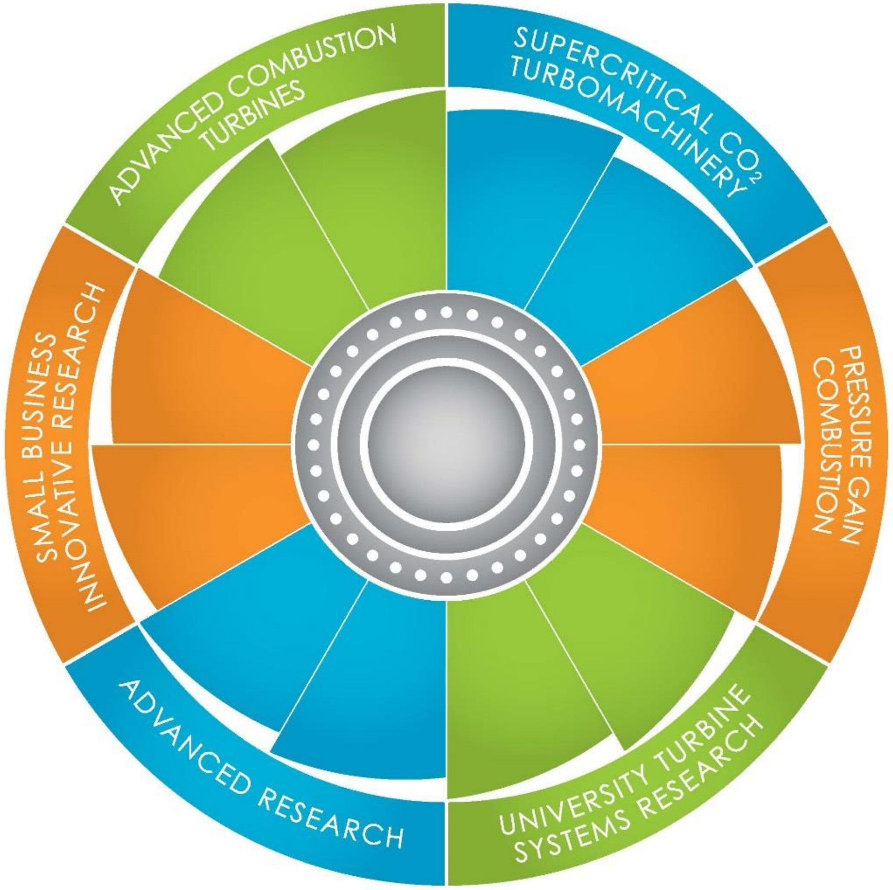


2022 University Turbines Systems Research Workshop and Advanced Turbines Program Review

San Diego State University
September 27 – 29, 2022
San Diego, CA

Preface

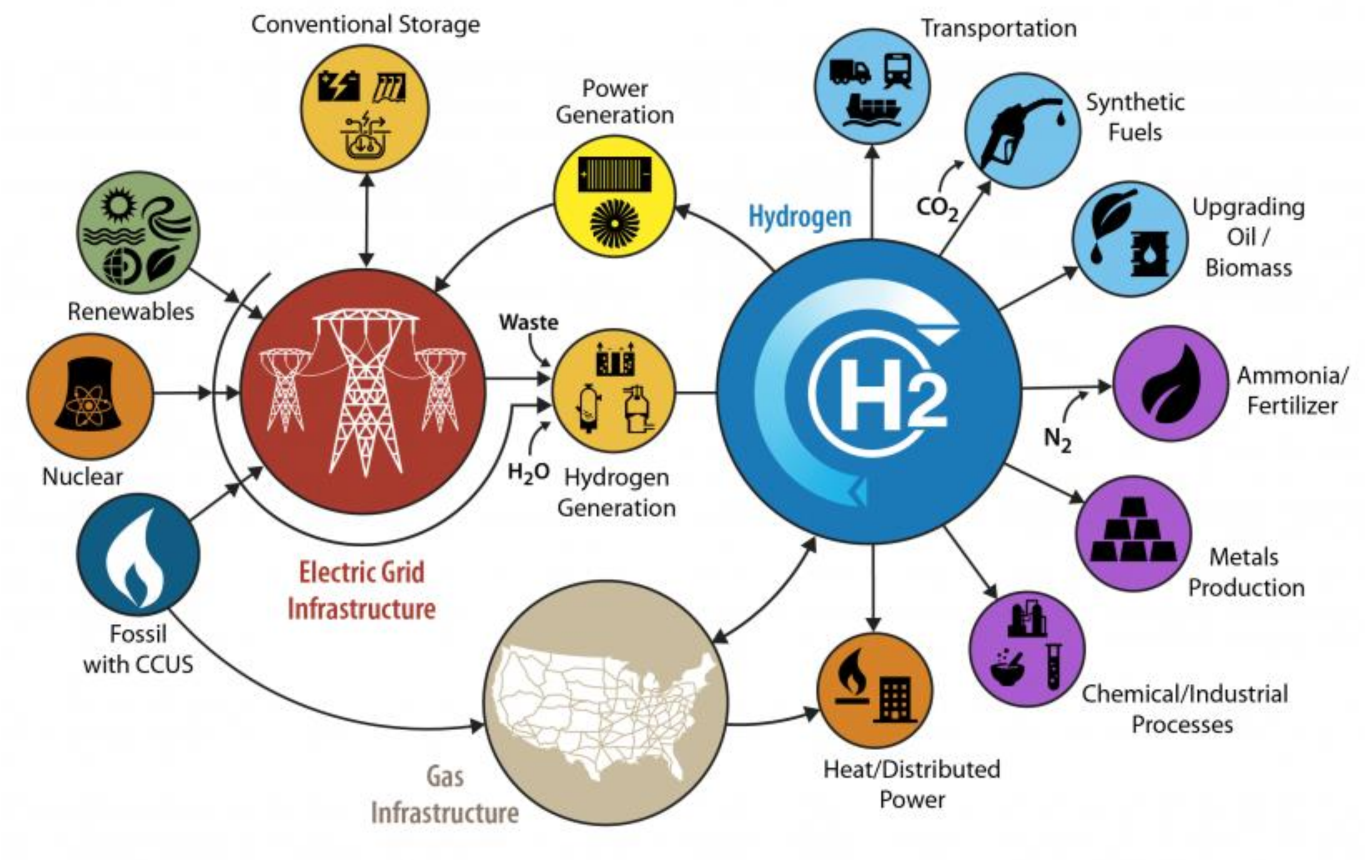
- This presentation provides an overview of a Fossil Energy and Carbon Management (FECM) R&D Program that is implemented based on both Administration priorities and Congressional direction. Plans for future technology development reflect expected trajectories of current R&D, but these plans are subject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

- New DOE and FECM strategic plans are currently under development. The goals presented here are subject to these plans, once available.

UTSR Workshop – Outline & Introduction

Producing State-of-the-Art Technology for Hydrogen Fueled Gas Turbines

- Introduction
- Program goals
- Recent awards
- Next steps



Advanced Turbines (AT) Program Goals

Mission - Deliver low cost, clean and carbon free electric power

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DOE Mission

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

AT Program Goals

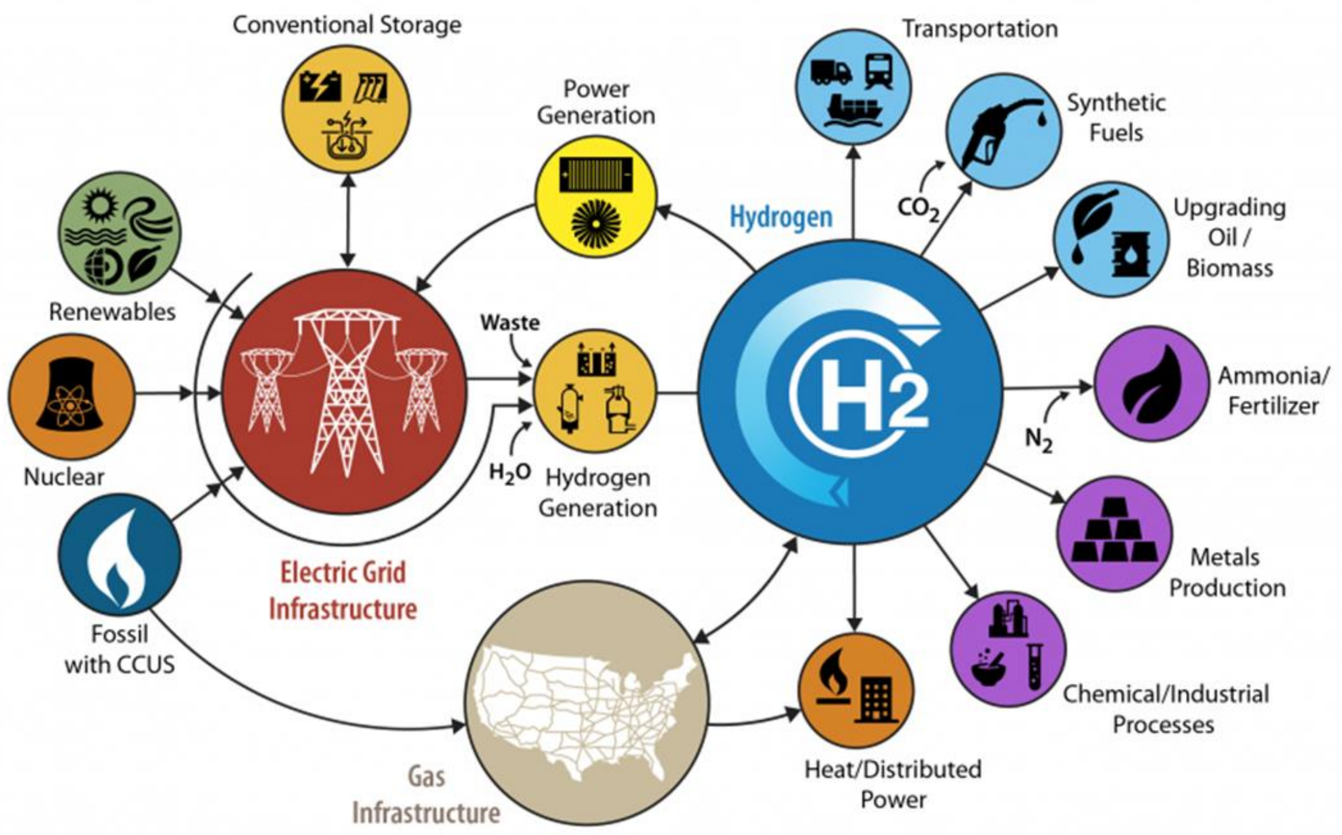
- **RD&D of gas turbines fueled with no-carbon fuels**
  - H2, H2 & NG blends, NH3 etc.
  - Low NOx and high performance
- **Pursue advanced efficiency**
  - Simple and combined cycle
  - RDE
- **Optimization for CCS**

CMC synergies with FECM Advanced Materials Program

Why Hydrogen Fueled Gas Turbines

Deliver low cost, clean and carbon free electric power

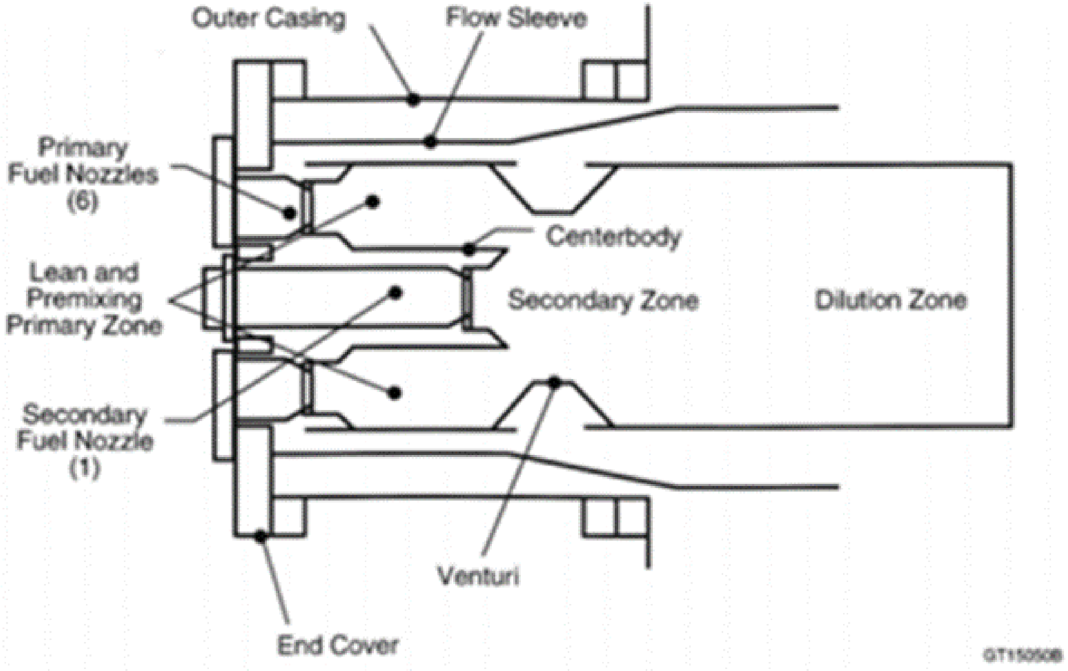
- Carbon-free
- H_2 fuel blending
- Dispatchable
- Load following
- Exiting infrastructure
- Technology demonstrations



Fundamentals of Hydrogen Combustion

Hydrogen is unique compared to natural gas

- High flame temperature (2045ºC in air)
- High flame speed (3 m/s)
- Low mass density (MW = 2g/mol)
- Low volumetric energy density (10,050 kJ/m3 H_2 vs. 32,560 kJ/m3 CH_4)
- Combustion instabilities
  - thermoacoustic issues
- Ignition delay



Nominal Combustor Module

Recent UTSR Advanced Turbine Awards

FY 21 UTSR Awards ($6.2 M)

- Hydrogen Combustion **Fundamentals** for Gas Turbines
  - Georgia Tech Research Corporation
  - The University of Central Florida
  - San Diego State University
- Hydrogen Combustion **Applications** for Gas Turbines
  - Purdue University
  - The Ohio State University
  - University of California, Irvine
- Hydrogen-Air **Rotating Detonation Engines (RDE)**
  - The University of Alabama
  - Purdue University

<u>What will be done</u>

- Explore chemical kinetics
- Investigate NOx & flame strain rate
- Investigate ignition delay times
- Measure flame speed
- Evaluate existing fuel injectors
- Flame structure and combustion dynamics for H2 & NH3 fuels
- Assess RDE combustion modes
- Develop design rules for micromixer injectors
- Develop CFD design tools

Recent Industry Advanced Turbine Awards

FY 22 Industry Awards ($28 M)

- **General Electric Company** – Combustors for H2 F-Class Retrofit ($6M / $12M)
- **Raytheon Technologies** – H2 Burner for FT4000 Aero Engine ($4.5M / $5.625M)
- **Solar Turbines** - GT Comb System for H2 & NG Blends ($4.5M / $5.625M)
- **Raytheon Technologies** - Ammonia Comb. for Zero-Carbon Power ($3M / $3.75M)
- **GTI** - Investigation of Ammonia Combustion for Turbines ($3M / $4.2M)
- **GE Research** - GT-Scale RDC Demo at 7FA Cycle Cond. ($7M / $8.75M)

What will be done

- Develop combustion modules for F-class, aeroderivative and industrial scale turbines
- Develop retrofit technologies
- Apply to 100% hydrogen & natural gas / hydrogen blends
- Assess ammonia fuels
- Advance the application of rotating detonation combustion systems for power generation
- Advance H2 combustor technology to the next stage of testing & demonstration

Program Record

NO$_x$ Emissions from Hydrogen Fueled Gas Turbines

- **Comprehensive literature survey**
- **Describes status of H_2 turbines**
- **Explains current biases in data that disadvantage hydrogen**
- **Peer reviewed**
- **Supports DOE's carbon free electric power goals**

Conclusions: *1.) Hydrogen turbines of the future will have comparable performance and emissions (NOx) compared to today's NG turbines. 2.) Appropriate standards for comparison, both scientific and legal, need to be developed for hydrogen.*

Gas Turbine NOx Requirements

NOx emission limits by turbine class, application, fuel and location (not shown)

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- **Average actual NO_x ratings:**
  - B-to-F-Class: 5-9 ppm (older models up to 25 ppm)
  - H-Class: 9-15 ppm
  - Aeroderivative: 9-25 ppm
- **Smaller turbines generally have higher NO_x ratings**
- **NSPS for NG do not apply to Hydrogen (“other fuel”)**

Current New Source Performance Standards (NSPS) (EPA)

EPA Category (Heat Input at baseload rating [HHV])	Market	Fuel	NO_x Limit @15% O_2 (based on gross energy output)
≤ 15 MW (50 MMBtu/hr.)	Power Generation	Natural Gas	42 ppm or 290 ng/J (2.3 lb./MW-hr.)
		Other Fuels	96 ppm or 710 ng/J (5.6 lb./MW-hr.)
	Mechanical Drive	Natural Gas	100 ppm or 690 ng/J (5.5 lb./MW-hr.)
		Other Fuels	150 ppm or 1100 ng/J (8.7 lb./MW-hr.)
15-250 MW (50-850 MMBtu/hr.)	Both	Natural Gas	25 ppm or 150 ng/J (1.2 lb./MW-hr.)
		Other Fuels	74 ppm or 460 ng/J (3.6 lb./MW-hr.)
≥ 250 MW (850 MMBtu.hr.)	Both	Natural Gas	15 ppm or 54 ng/J (0.43 lb./MW-hr.)
		Other Fuels	42 ppm or 160 ng/J (1.3 lb./MW-hr.)

Keeping Cost of Electricity (COE) Low

Hydrogen Turbines of the Future

- Hydrogen's higher flame temperature can allow for higher pressure ratios, higher efficiency and lower COE
- Modifications necessary to optimize hydrogen combustors for low NOx
- DOE's goal is to achieve 100% H_2 utilization without sacrificing turbine performance or COE

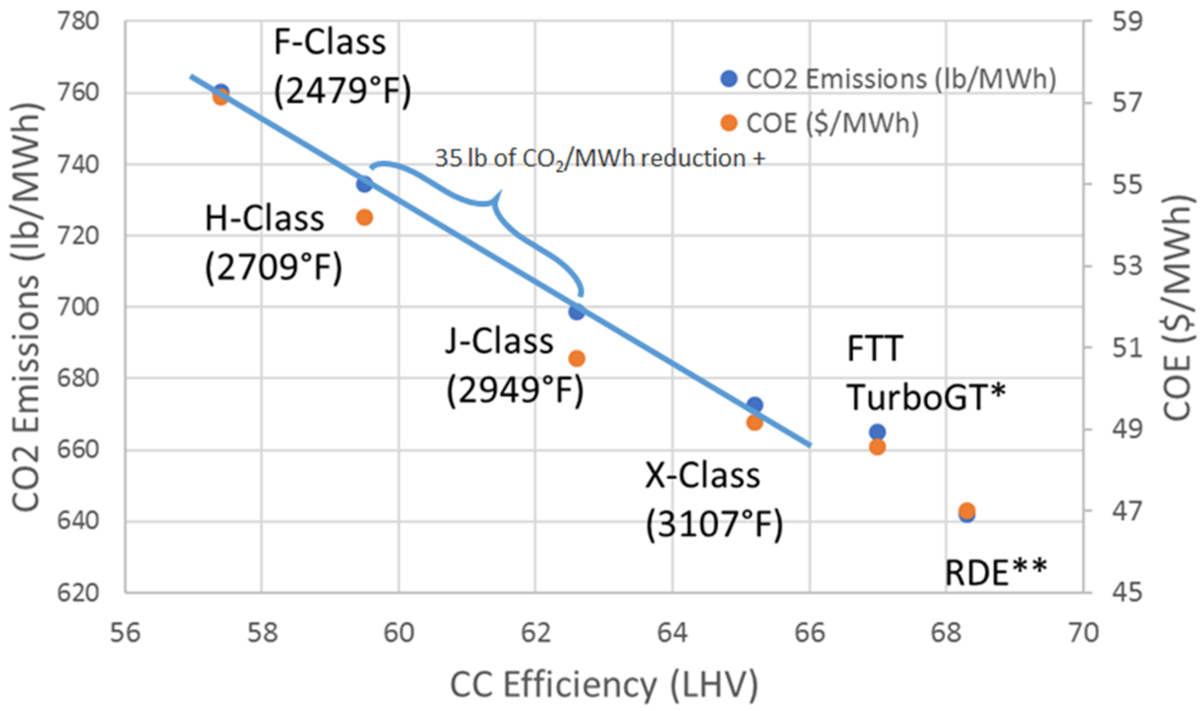
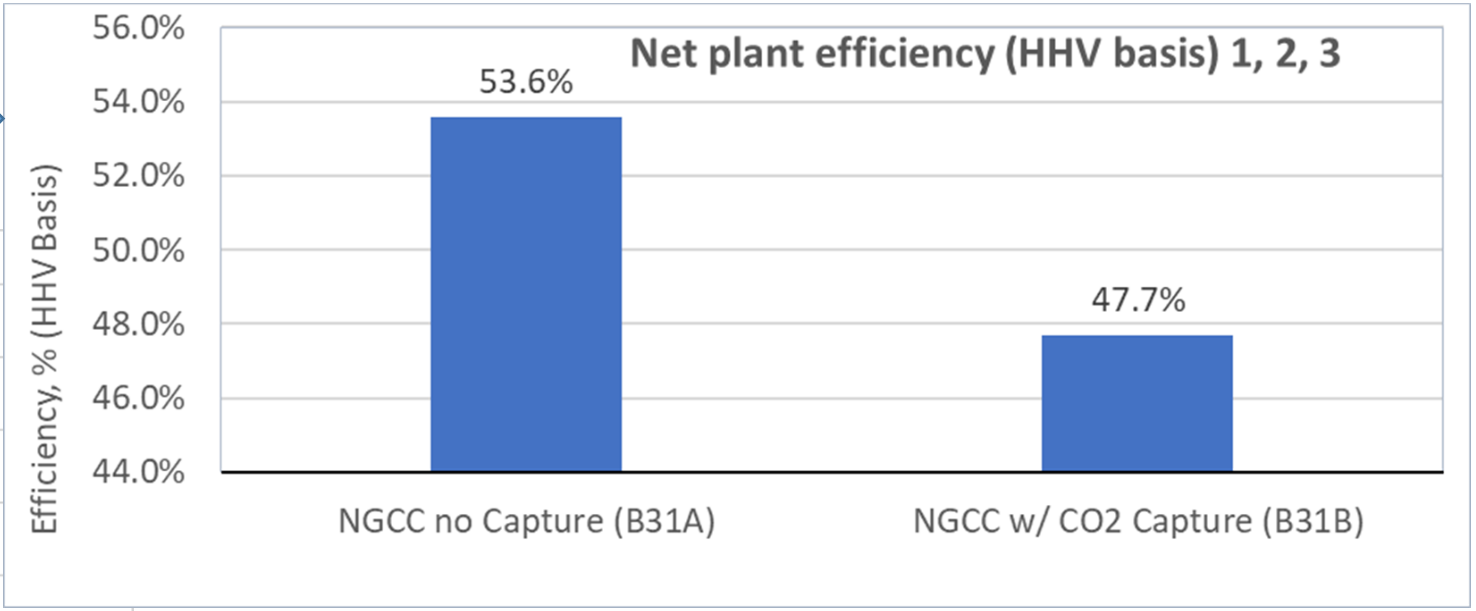
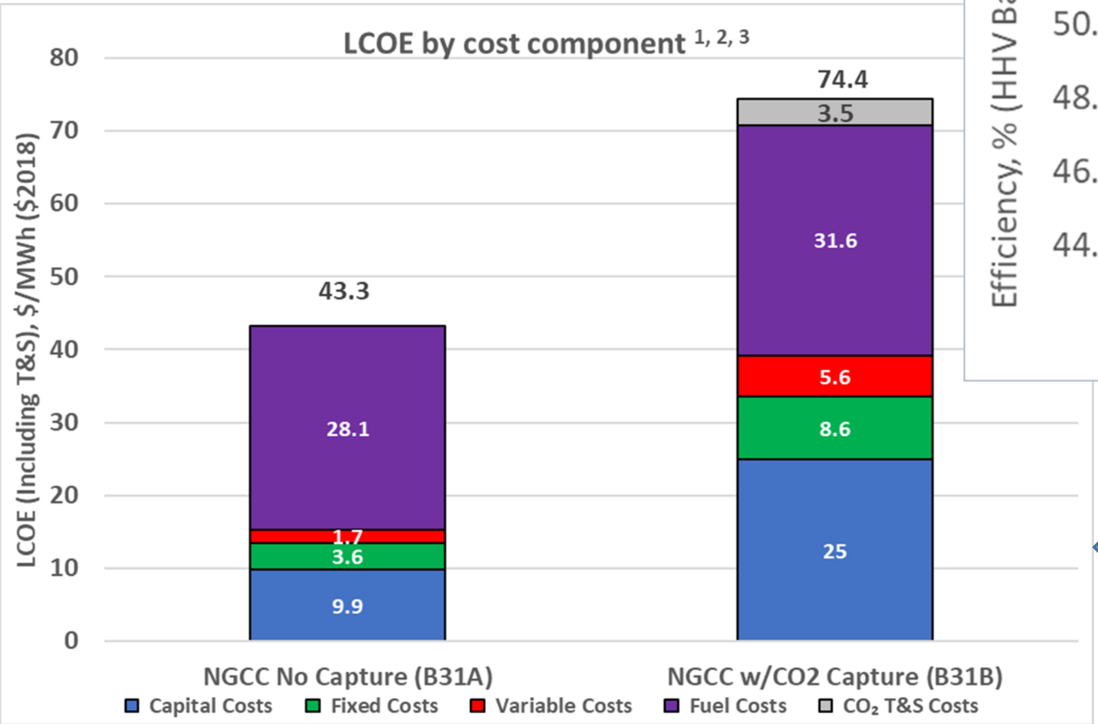


Figure is for natural gas fueled machines and illustrative of the impact of efficiency and firing temperature on efficiency and COE

CCS Impact on NGCC

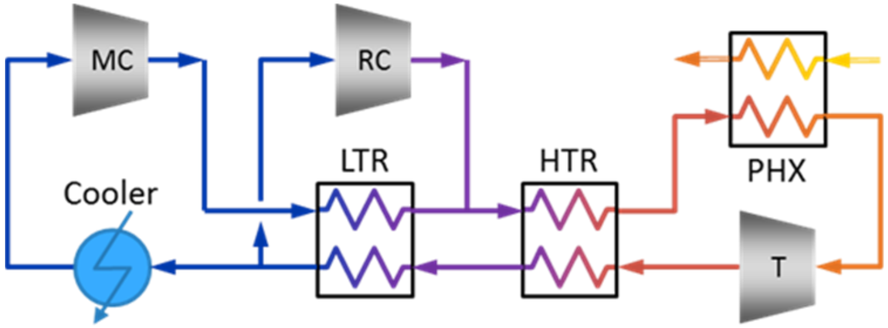
6% pts reduction in efficiency



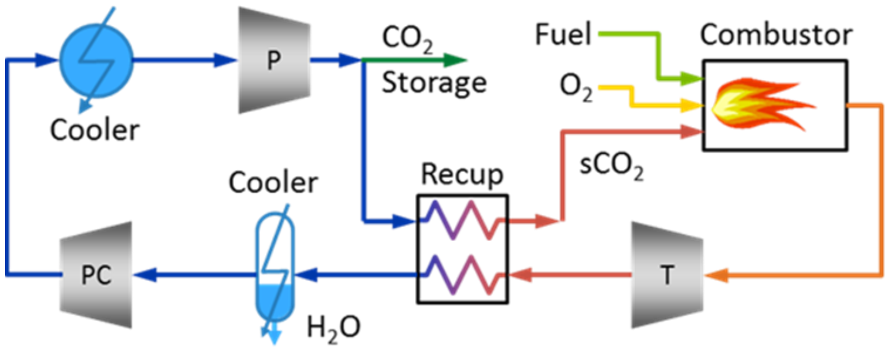


72 % increase in COE

sCO_2 Power Cycles



Recompression Brayton Cycle



Allam Cycle

UTSR as an Educational Opportunity

UTSR

University Turbine Systems Research

Next Steps

- Pursue advanced efficiency
- Consider an integrated RDE demo
- Execute a hydrogen turbine RD&D program that results in precommercial demonstrations