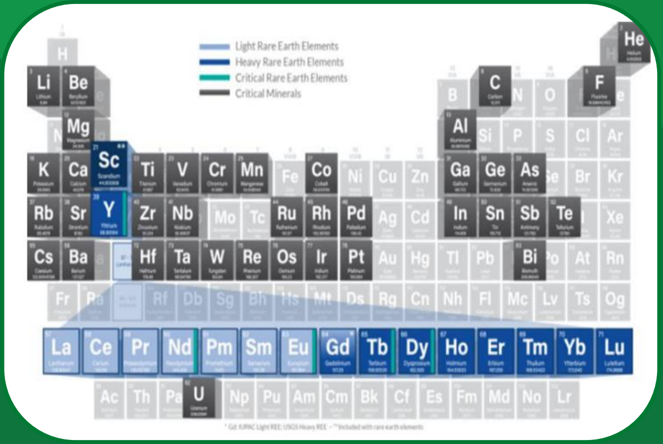
U.S. DEPARTMENT OF
ENERGY
Fossil Energy and
Carbon Management

Fossil Energy and Carbon Management Advanced Turbines Program

University Turbine Systems Research 2022 Project Review Meeting

September 28, 2022





Advanced Turbines Program Goals

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

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

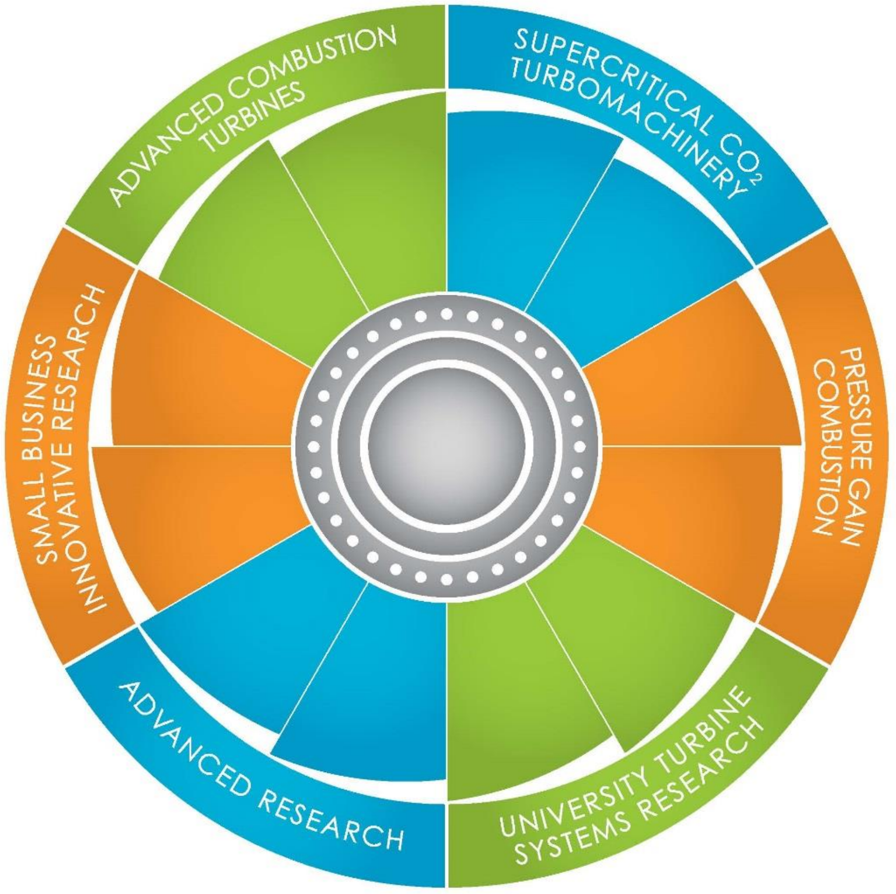
- **RD&D of gas turbines fueled with no-carbon fuels**
  - H_2, H_2 & NG blends + CCUS, NH_3 etc.
  - Low NOx and high performance
- **Pursue advanced efficiency**
  - Simple and combined cycle
  - RDE
- **Optimization for CCS**

CMC synergies with FECM Advanced Materials Program

Advanced Turbines (AT) Program Elements

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

- Use H_2 & H_2 blends while minimizing NOx
  - Natural Gas/H_2 blends, ammonia, ammonia/H_2 blend
- Invest in efficiency
  - 67% CC and 50% SC (LHV, NG basis)
  - 70% efficient CC machine (long term goal)
- Program Elements Include:
  1. Adv Comb Turbines,
  2. Pressure Gain Combustion/Rotating Detonation Engines,
  3. Modular Turbine-Based Hybrid Engines, and
  4. UTSR program
- Complementary awards by Adv. Energy Materials program of $4.7M for CMC materials



R&D Elements for Program Goals

Advanced Turbines Budget Line

- Hydrogen combustion
  - Combustion fundamentals and applications/micro-mixing injectors (low NOx performance)
  - Ammonia combustion fundamentals
- Pressure gain combustion
  - RDE Performance Optimization: 1) Inlet designs for positive pressure gain. 2) Thermal management. 3) Diagnostics.
  - RDE Integration with Turbine: 1) Diffuser design and optimization. 2) Turbine demonstration
  - Purpose built RDE turbine.
- Aerothermal heat transfer for higher Turbine Inlet Temperature
  - Unsteady heat transfer for RDE thermal management.
  - Advanced cooling architectures, thermal barrier coatings
- Advanced materials & manufacturing
  - CMC, Materials for H_2, Advanced Manufacturing

Keeping Cost of Electricity (COE) Low

Hydrogen Turbines for the Future

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

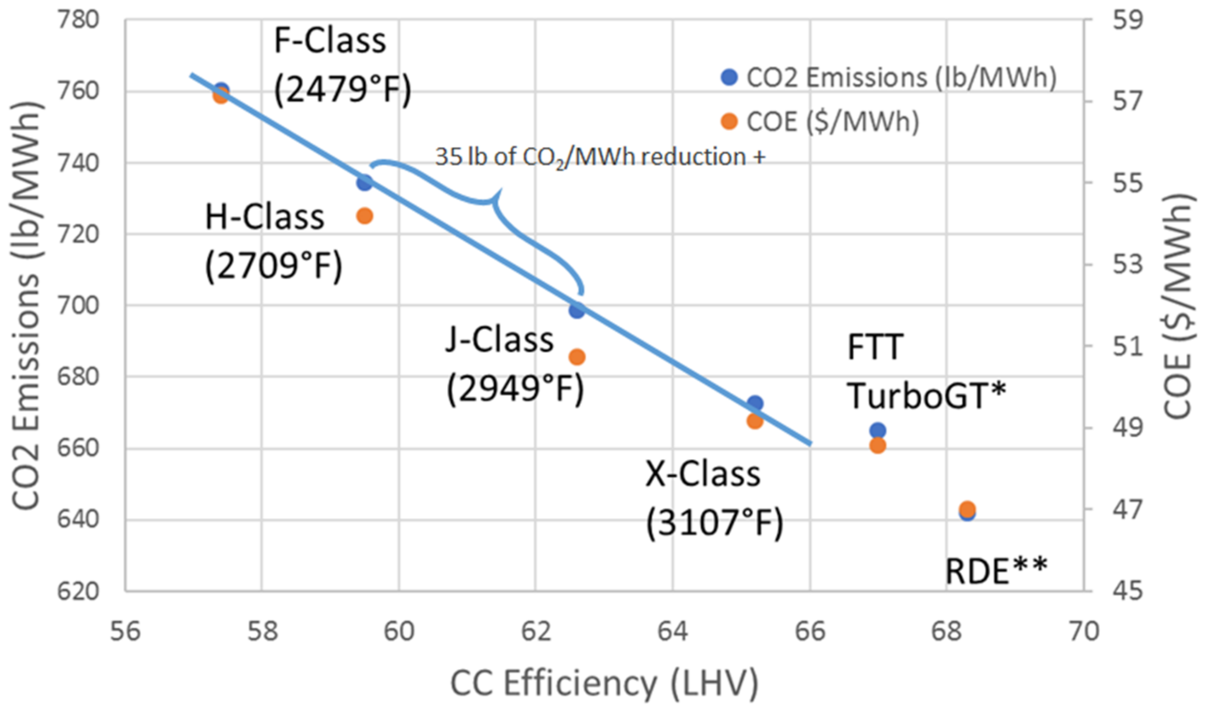


Figure is for natural gas fueled machines and illustrative of the impact of efficiency and firing temperature on efficiency and COE

Why Hydrogen Fueled Gas Turbines

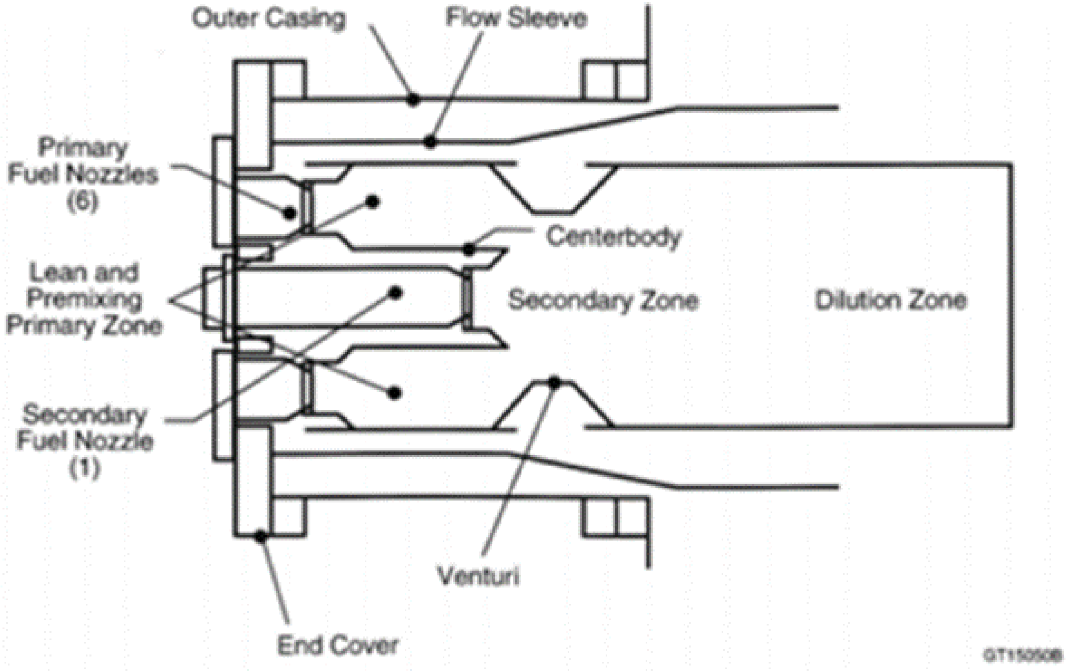
Deliver low cost, clean and carbon free electric power

- Carbon-free
- H_2 fuel blending
- Dispatchable
- Load following
- Existing infrastructure
- Firm, dispatchable grid-scale energy storage
- Technology demonstrations

Fundamentals of Hydrogen and NH_3 Combustion

Hydrogen and ammonia unique compared to natural gas

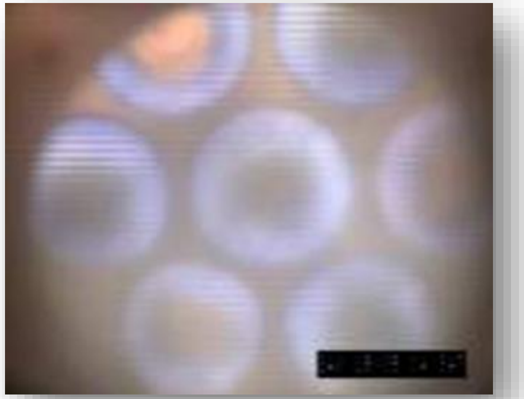
- Flame temperature (H_2: 2045°C, NH_3: 1800°C)
- Flame speed (H_2: 3 m/s, NH_3: 0.1 m/s)
- NO_x formation routes (thermal/fuel NOx)
- Mass density (H_2: 2 g/mol, NH_3: 17 g/mol)
- Volumetric energy density
    - H_2: 10,050 kJ/m^3
    - NH_3: 15,711 kJ/m^3
    - CH_4: 32,560 kJ/m^3
- Combustion instabilities
    - Flashback, thermoacoustic issues



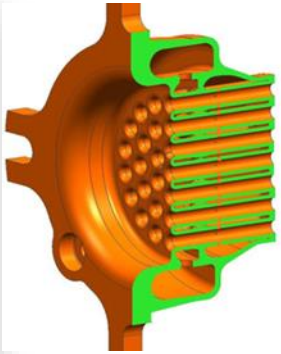
Advanced Turbines (AT) Program Goals

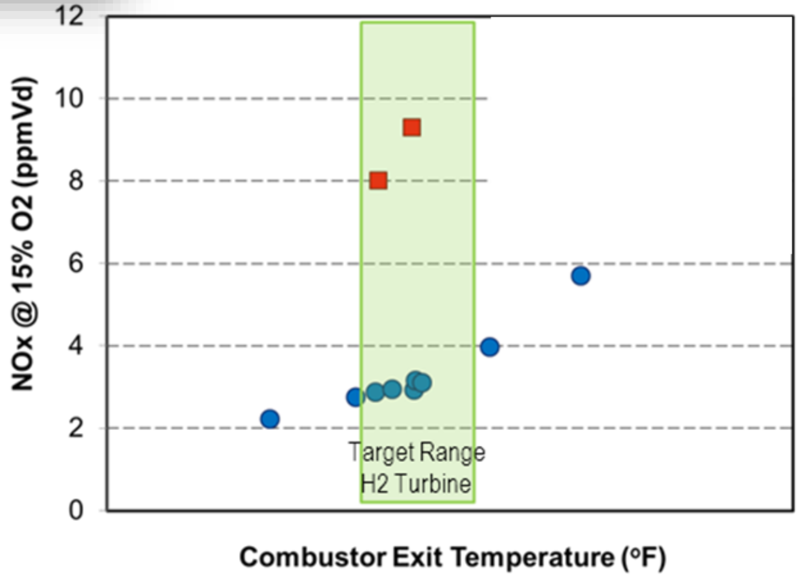
Mission - Deliver low cost, clean and carbon free electric power

- Tested at full F-class & advanced gas turbine conditions.
- 100+ hours full can combustor operation with > 90% H_2.
- 20 hrs operation with 100% H_2
- < 3 ppm NOx @15% O_2 at target temperature with N_2 diluent.
- NOx emissions for H_2 fuels likely similar to natural gas that have been demonstrated for full scale combustor geometries.



High-Hydrogen





H2IQ Hour webinar recording on H_2 NOx emissions available soon.
https://www.energy.gov/eere/fuelcells/hydrogen-and-fuel-cell-technologies-office-webinars

Ref: Proceedings of ASME Turbo Expo 2012, June 11-15, 2012, Copenhagen, Denmark, GT2012-69913; DEVELOPMENT AND TESTING OF A LOW NOX HYDROGEN COMBUSTION SYSTEM FOR HEAVY DUTY GAS TURBINES, W. York, W. Ziminsky, E. Yilmaz *

Recent UTSR Advanced Turbine Awards

FY 21 UTSR Awards ($6.2 M)

- Hydrogen/NH_3 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

What will be done

- 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 H_2 & NH_3 fuels
- Assess RDE combustion modes
- Develop design rules for micromixer injectors
- Develop CFD design tools

Recent Industry Advanced Turbine Program Awards

FY 22 Industry Awards ($28 M)

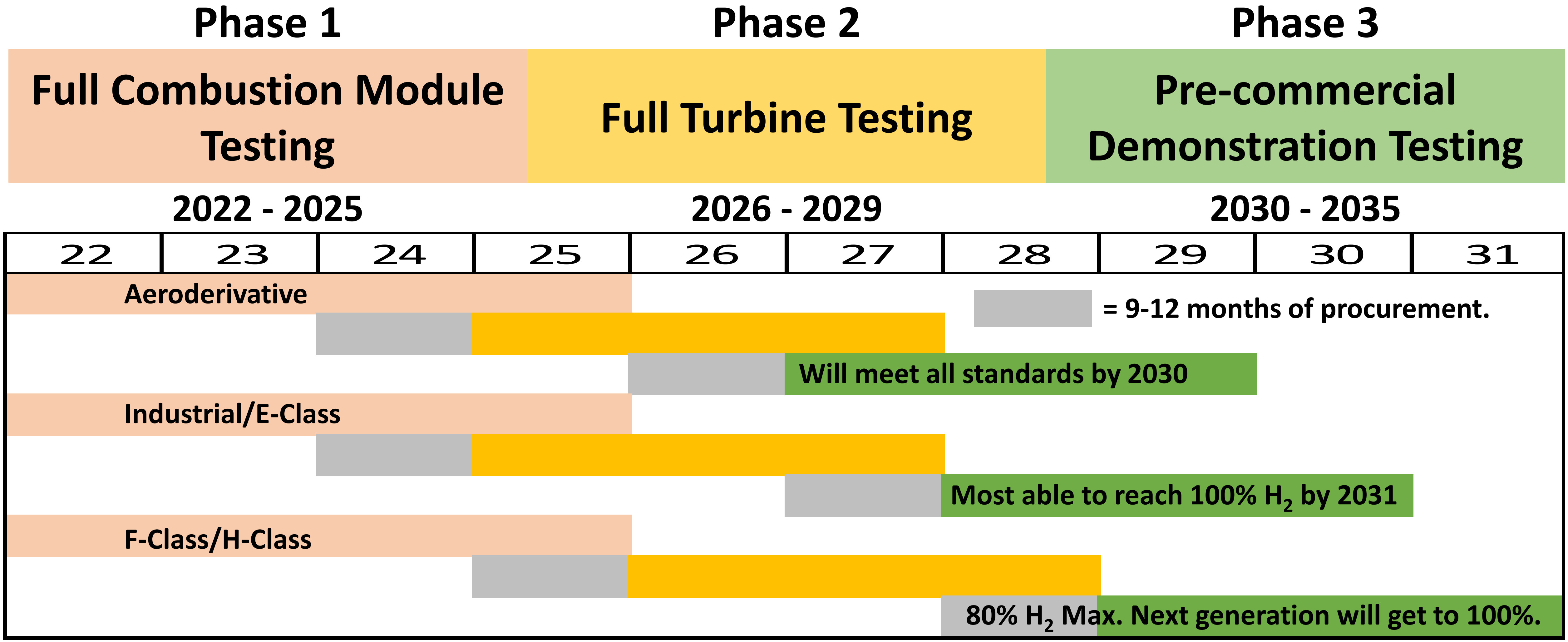
- **General Electric Company** – Combustors for H_2 F- Class Retrofit ($6M / $12M)
- **Raytheon Technologies** – H_2 Burner for FT4000 Aero Engine ($4.5M / $5.625M)
- **Solar Turbines** - GT Comb System for H_2 & NG Blends ($4.5M / $5.625M)
- **Raytheon Technologies** - Ammonia Comb. for Zero-Carbon Power ($3M / $3.75M)
- **GTI** - Investigation of Ammonia Combustion for Turbines ($3M / $4.2M)
- **GE Research** - GT-Scale RDC Demo at 7FA Cycle Conditions ($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 H_2 combustor technology to the next stage of testing & demonstration

Development Schedule for H2 Turbines

Current Status and Future Development by Class



U.S. Government Hydrogen Program and Funding

Inflation Reduction Act (IRA) - Hydrogen Provisions

On August 16, 2022, President Biden signed the IRA into law. The bill raises $737 billion in revenue and authorizes $369 billion for energy security and climate change-related spending, including for hydrogen specifically. According to White House analysis, the IRA sets the U.S. on track to decrease GHG by about 40% below 2005 levels by 2030. Key hydrogen-related funding covered in the bill includes:

Hydrogen Production and Storage

- Expands IRS Section 45V to introduce a new 10-year **clean hydrogen production tax credit (PTC)** of up to $3/kg multiplied by an applicable percentage for qualified facilities producing hydrogen after December 31, 2022. *See further details on right.*
- Expands IRS Section 48 **investment tax credit** (ITC) to include "energy storage technology", which can include hydrogen energy. The ITC starts at 6% but can increase to 40% if certain requirements are satisfied. Construction of facilities must begin before January 1, 2025. Generally, taxpayers cannot claim both the ITC and PTC for the same project.
- The IRA also includes a "direct pay option" for the same amounts instead of a tax credit. The direct payment for hydrogen and carbon capture facilities will be available for only the first 5 years of production.

Hydrogen Fuel Cell Technology

- $2 billion in grants administered by DOE for domestic production of efficient hybrid, plug-in electric hybrid, plug-in electric drive, and **hydrogen fuel cell** EVs, with a 50% recipient cost share requirement and up to 3% of funding reserved for program administration
- Revised tax credit available for EVs and hydrogen fuel cell vehicles, for a maximum credit of $7,000 for qualified taxpayers.

Kg of CO2 per kg of H2	Credit Value ($)
4 - 2.5 kg CO2	$0.60 / kg of H2
2.5 - 1.5 kg CO2	$0.75 / kg of H2
1.5 - 0.45 kg CO2	$1.00 / kg of H2
0.45 - 0 kg CO2	$3.00 / kg of H2

The clean hydrogen production tax credit will provide up to $3 per kg of qualified clean hydrogen produced based on a scaled metric of carbon intensity beginning at the base value of $0.60 per kg of hydrogen produced (seen above).

The term 'qualified clean hydrogen' denotes hydrogen which is produced through a process that results in a lifecycle greenhouse gas emissions rate of not greater than 4 kg of CO2e per kg of hydrogen.

Sources: Fuel Cell & Hydrogen Energy Association (link), WhiteHouse.gov (link)

U.S. Government Hydrogen Program and Funding

Bipartisan Infrastructure Law (BIL) – Hydrogen Provisions

On November 15, 2021, President Biden signed the BIL into law. The bill authorizes $1.2 trillion for a variety of infrastructure-related spending, including $8.5 billion to spur clean hydrogen supply chains, regional clean hydrogen hubs, and commercializing clean hydrogen in transportation, utility, industrial, commercial and residential sectors.

Hydrogen Hubs

- $8 billion authorized and appropriated (FY22-FY26) in grants to accelerate commercialization of, and demonstrate the production, processing, delivery, storage, and end-use of, clean hydrogen. Requires the Secretary of Energy to solicit proposals for regional clean hydrogen hubs and select four regional hubs, which will demonstrate the production, processing, delivery, storage, and end-use of clean hydrogen. Grants will be administered by the newly created DOE Office of Clean Energy Demonstrations (OCED).

Hydrogen R&D

- Establishes a DOE Clean Hydrogen Research and Development Program, which aims to advance R&D and commercialize the use of clean hydrogen in the transportation, utility industrial, commercial, and residential sectors; and (2) demonstrate a standard of clean hydrogen production in the transportation, utility, industrial, commercial, and residential sectors by 2040.
- $1 billion in grants administered through DOE Office of Energy Efficiency and Renewable Energy (EERE) for a newly established clean hydrogen electrolysis program, with the goal of reducing the cost of hydrogen to <$2/kg by 2026.
- $500 million in grants administered through DOE EERE for hydrogen manufacturing, recycling, and research projects.

Other

- Requires the DOE to create a national strategy, roadmap, and standard for carbon intensity of clean hydrogen production.
- $2.5 billion in grants for publicly accessible electric vehicle charging infrastructure and hydrogen/propane/natural gas fueling infrastructure.
- $250 million in grants to increase energy efficiency by leveraging high-efficiency systems which use natural gas and hydrogen.

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Questions?

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