

DOE University Turbine Systems Research Program



Turbines for Dispatchable Zero-Carbon Power

September 2024

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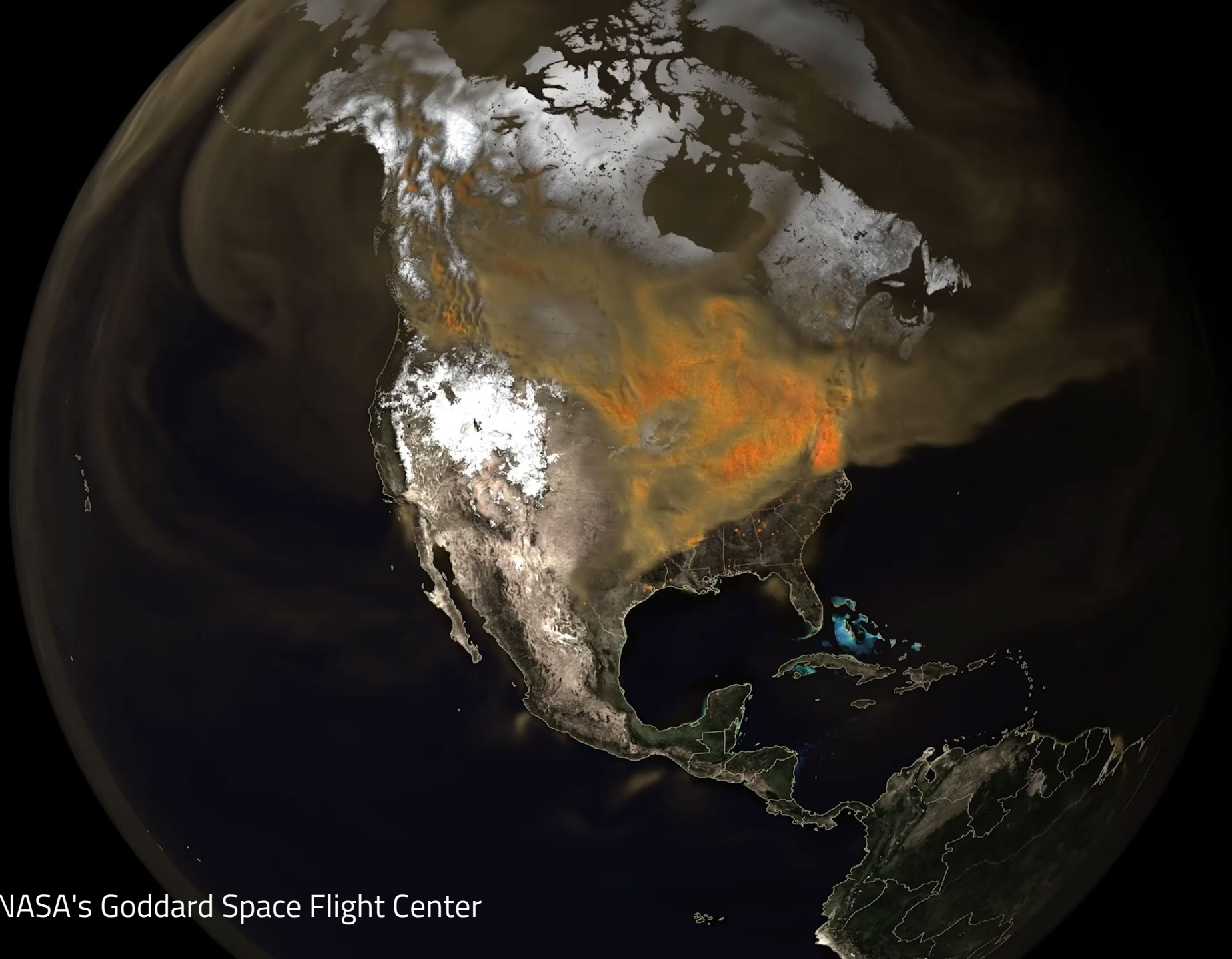


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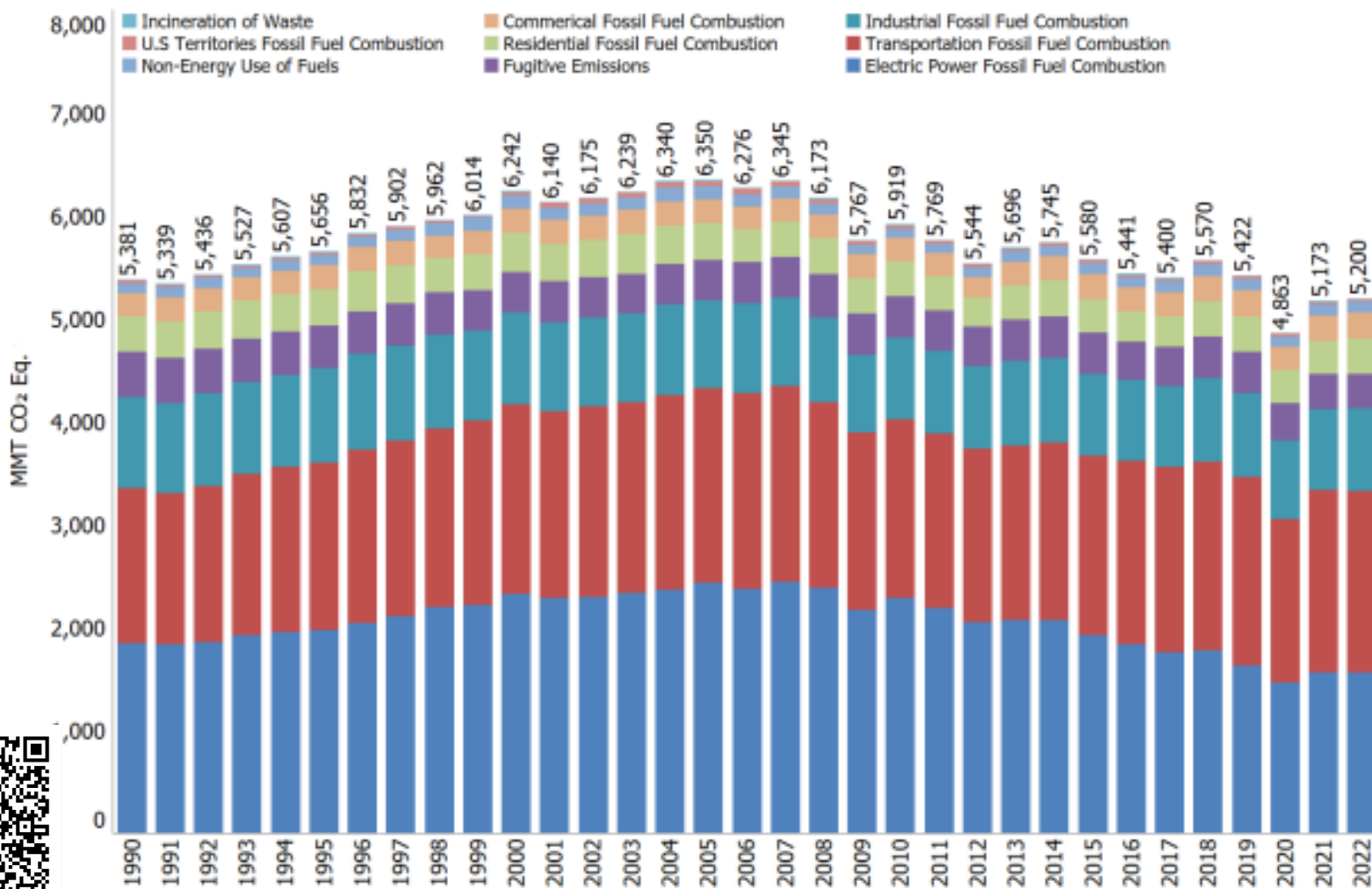
NASA's Goddard Space Flight Center

GHG Emissions in the U.S. Power Sector

From U.S. Environmental Protection Agency (2024)



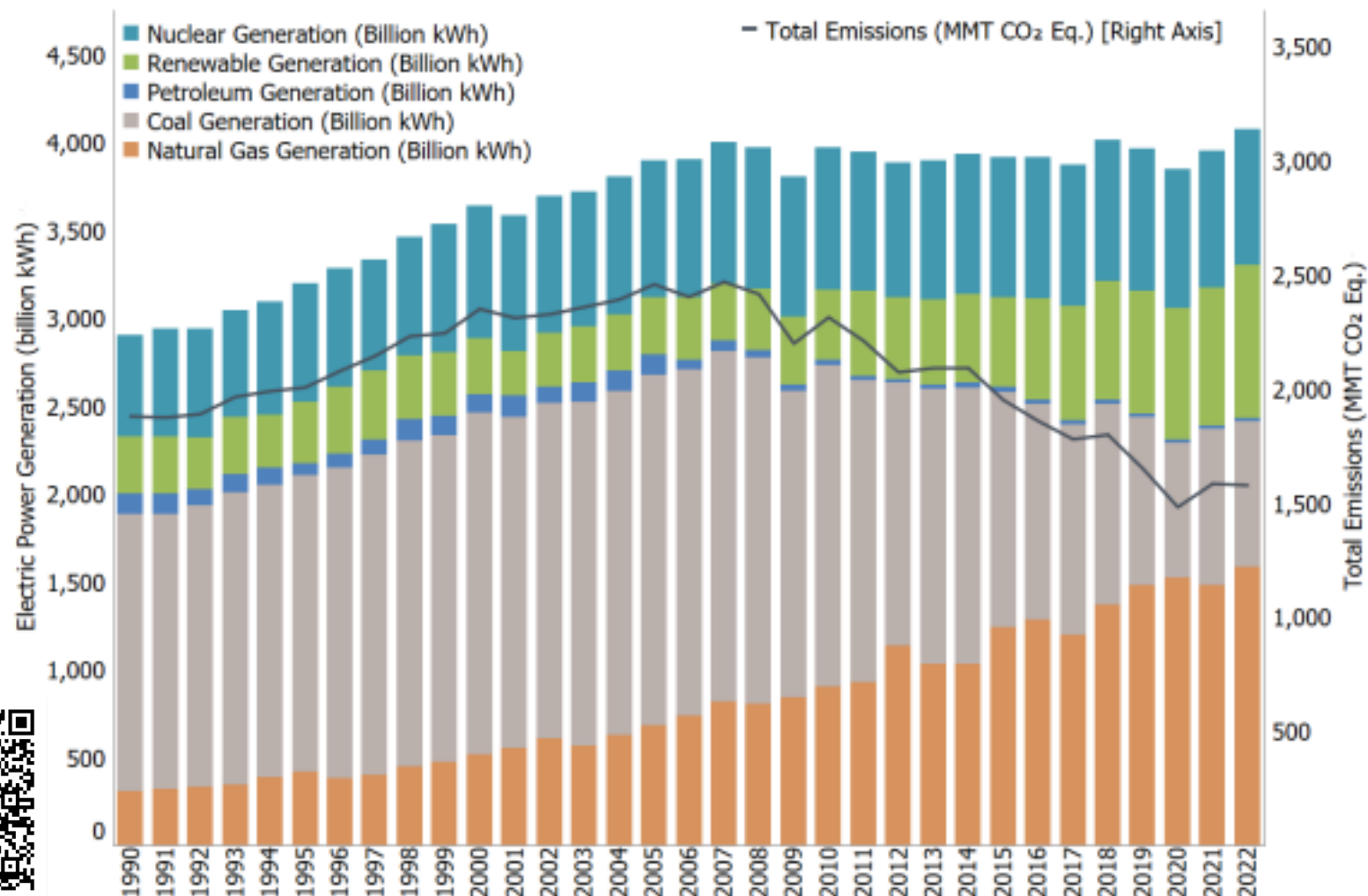
- From EPA – total GHG emissions in Energy Applications > 5 billion tonnes in 2021
 - 4.86 billion tonnes CO₂ from fossil fuel comb.
 - 1.54 billion tonnes CO₂ from electricity
- Total emissions have steadily declined since 2007



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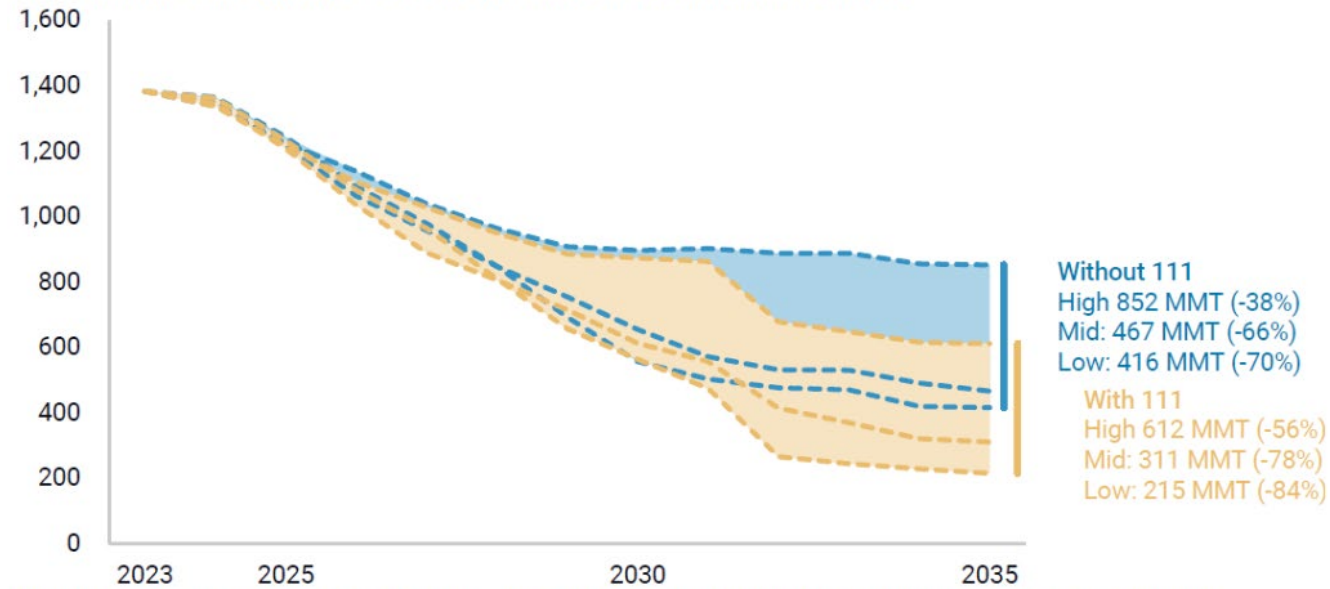


Electricity Emissions Forecast

From Rhodium Group Analysis of Proposed EPA 111 Rules

US electric power sector emissions

Million metric tons (MMT) of CO₂ and percent reduction from 2023 levels



Source: Rhodium Group. The high, mid, and low ranges reflect uncertainty around fossil fuel prices, economic growth, and clean technology costs.

TABLE 1

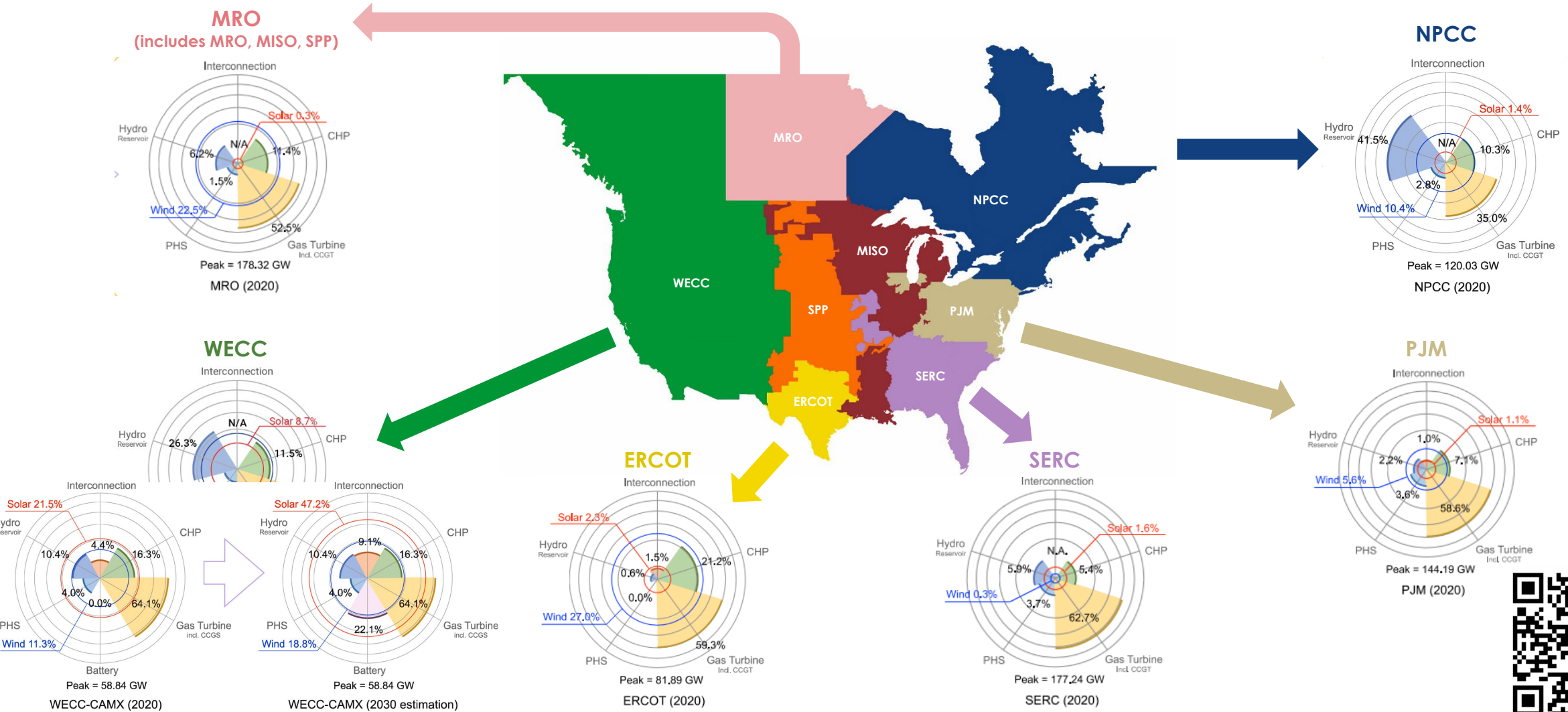
Fossil generation capacity without and with EPA regulations (in GW)

Plant Type	2022	2035 Without 111	2035 With 111
Coal	198	57-62	6-11
Coal with carbon capture	0	4-9	7-11
Combined cycle natural gas	280	251-312	253-319
Combined cycle gas with carbon capture	0	0-18	2-24
Simple cycle natural gas (peakers)	146	216-330	210-334
All other fossil	75	54-61	71-94
Total	699	524-703	545-759

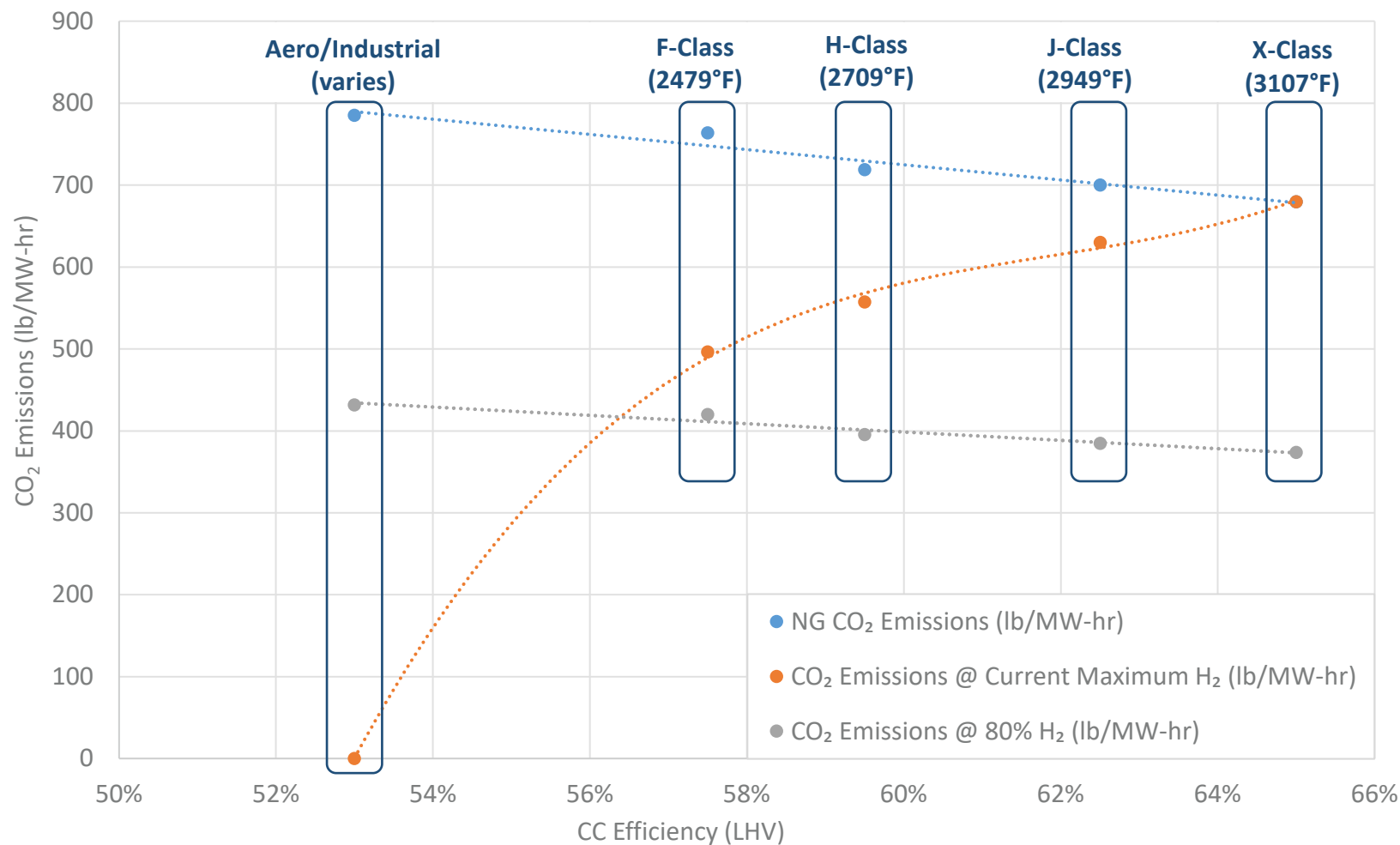


RTO Grid Flexibility for Stability (2020)

<https://doi.org/10.1016/j.rser.2022.113116>



Efficiency vs. Decarbonization



FOA Notice of Intent

DE-FOA-0003409



NATIONAL ENERGY TECHNOLOGY LABORATORY
Albany, OR • Morgantown, WV • Pittsburgh, PA



Notice of Intent (NOI) No.: DE-FOA-0003413

Issue Date: July 25, 2024

DISCLAIMER: This “Notice of Intent to Issue” is for informational purposes only; the Department of Energy is not seeking comments on the information in this notice and applications are not being accepted at this time. Any information contained in this notice is subject to change.

This is a Notice of Intent to Issue

Funding Opportunity Announcement No. DE-FOA-0003409

“Pre-Commercial Testing of Low-Carbon Emissions Gas Turbine”

The Department of Energy (DOE) National Energy Technology Laboratory (NETL) intends to issue Funding Opportunity Announcement (FOA) No. DE-FOA-0003409 on behalf of the Office of Fossil Energy and Carbon Management (FECM) in the 2024 calendar year.

TECHNICAL OBJECTIVES

In support of Executive Order 14008 (dated January 27, 2021), “[Tackling the Climate Crisis at Home and Abroad](#),” and to further past decades of DOE-supported carbon management research, development and demonstration (RD&D) done in cooperation with industry and academia, DOE-FECM anticipates issuing a FOA. DOE-FECM will seek applications for financial assistance awards supporting research and development (R&D) projects to develop technologies reducing carbon emissions from gas turbines providing baseload and dispatchable power to the US power grid to enable net-zero carbon energy production.

If issued, this FOA will seek to develop technologies to enable the existing gas turbine power infrastructure to achieve net-zero carbon energy through the utilization of carbon-free fuels or through the enhancement of post-combustion carbon capture technology via exhaust gas recirculation.

This notice is issued so that interested parties are aware of the DOE’s intention to issue a FOA in the near term. DOE envisions awarding multiple financial assistance awards in the form of cooperative agreements in response to this FOA.

If released, this FOA is anticipated to focus on two areas of interest (AOIs).

ANTICIPATED AREAS OF INTEREST

AOI 1. Hydrogen Combustion Systems for Gas Turbines

Enabling the utilization of high-purity hydrogen fuel in existing gas turbine power generation infrastructure is a key component for decarbonization of the electric grid. Decarbonization will require further development of gas turbine combustor modules capable of safe, efficient, and low emissions operation while burning hydrogen-based fuels.

This AOI seeks to develop hydrogen fuel capable combustion modules for aeroderivative and industrial (also known as “heavy-duty”) gas turbines. The goal of this AOI is to complete rig testing of hydrogen fuel capable combustors to prepare the combustors for subsequent engine integration and field testing in a potential future FOA.

AOI 2. Exhaust Gas Recirculation Systems for Gas Turbines

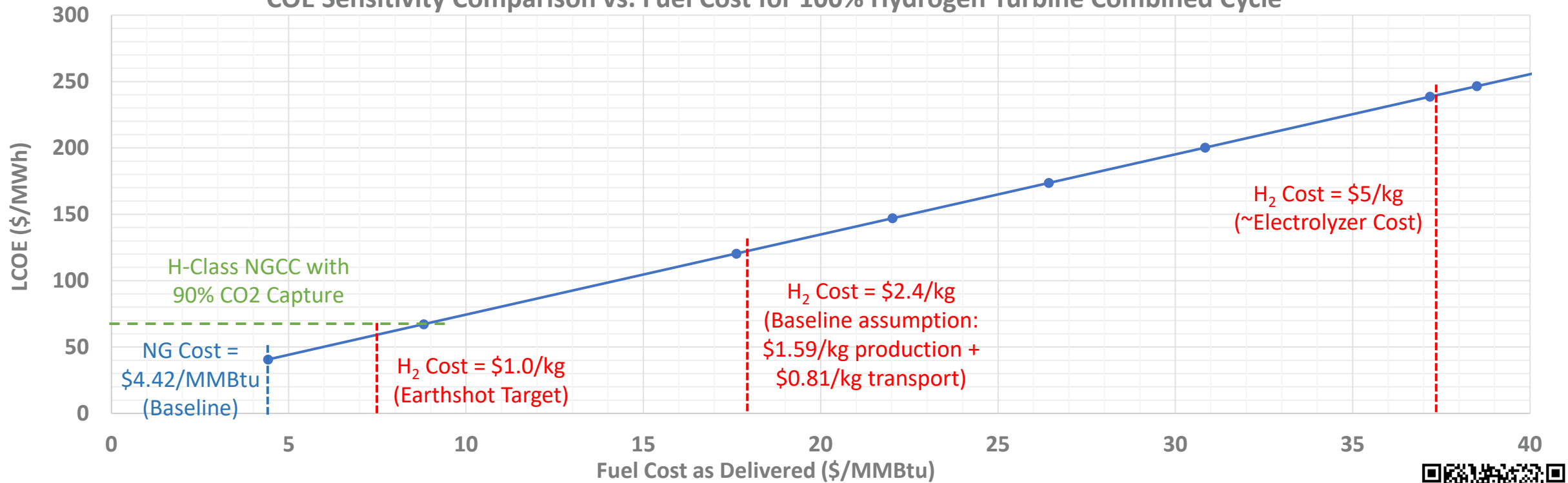
Enabling the recirculation of exhaust gases in existing gas turbine power generation infrastructure will enhance the efficiency of state-of-the-art carbon capture equipment, a key component for decarbonization of the electric grid. This requires further development of gas turbine combustor modules that are capable of safe, efficient, and low emissions operation while burning fuels with greater inert reactants such as carbon dioxide.

This AOI seeks to develop exhaust gas recirculation modules for aeroderivative and industrial (also known as “heavy-duty”) gas turbines to research robust flame stabilization methods to maximize the amount of exhaust gas recirculation (EGR) without impacting combustion stability. The goal of this AOI is to complete rig testing of high-EGR combustors to enable engine integration and field testing in a potential future FOA.

Cost Analysis for H₂ Combined Cycle

Fuel Price Sensitivity

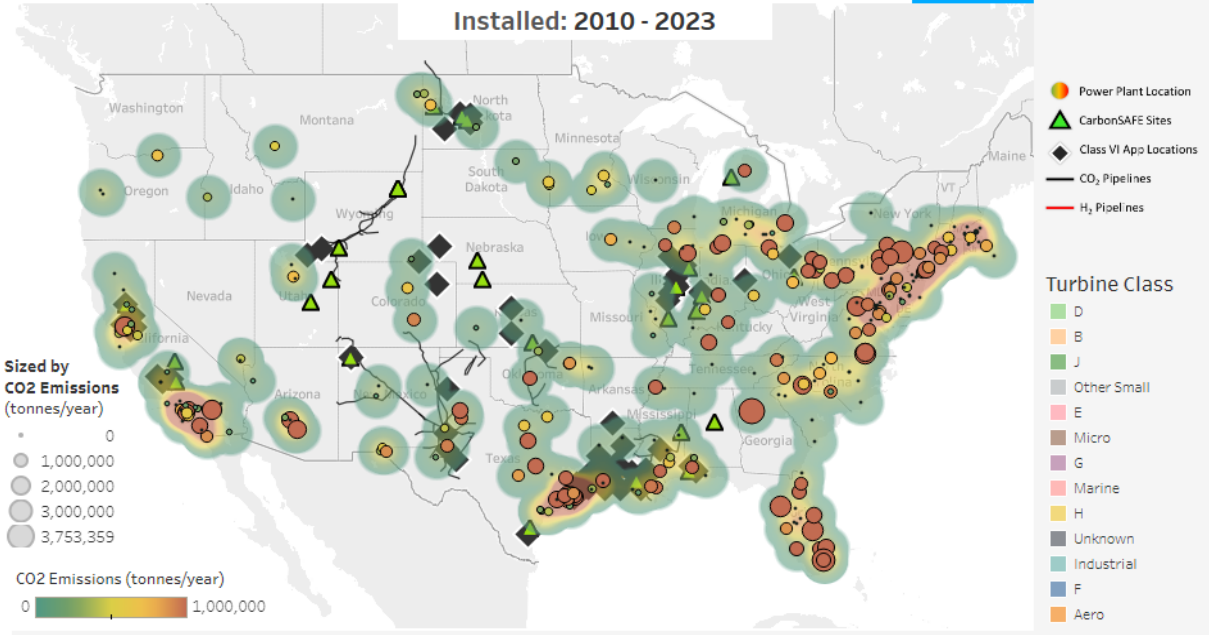
COE Sensitivity Comparison vs. Fuel Cost for 100% Hydrogen Turbine Combined Cycle



Interactive Turbines CO₂ Emissions Map

Estimated 2023 US Gas Turbine Fleet Emissions

This data represents select gas turbines operating within the United States that were installed since 2010. Legacy power plant units (2009 or earlier) are generally excluded. Emissions data is estimated based on an empirical relation using turbine class or turbine inlet temperature when known. Turbine operational data is gathered from the Energy Information Administration (EIA) monthly reports (EIA-860 and EIA-923) as well as independent public sources. [Show Filters](#)



Overview

PWR Graphs

Turbine Builder

Builder	Count	CO ₂ Emissions (MMT/year)
Gen Electric	348	96.82
Unknown	129	0.00
Siemens	112	38.30
Solar	101	2.40
Mitsubishi	43	26.31
Pratt & Whitney	4	0.91
Capstone	3	0.00
Gas Turbine Count		CO₂ Emissions (MMT/year)

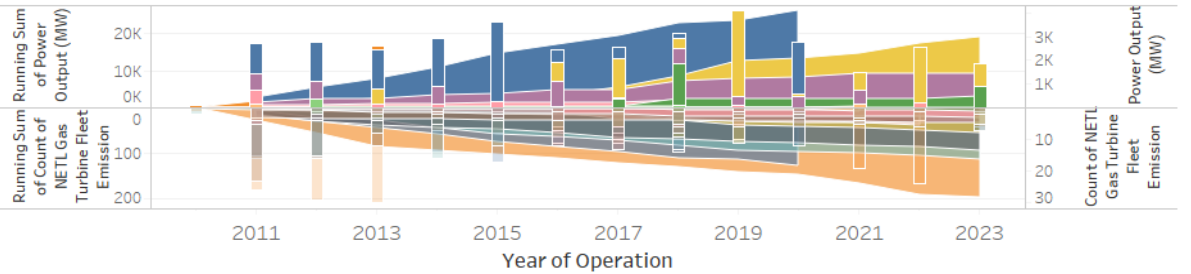
Turbine Class

Class	Count	CO ₂ Emissions (MMT/year)	Power Output (MW)
Grand Total	740	164.7	83,994
Aero	196	35.4	13,470
F	126	53.6	26,259
Industrial	112	3.3	1,307
Unknown	93	0.0	7,084
H	56	39.2	19,099
Marine	38	0.0	1,301
G	33	19.8	9,286
Micro	32	0.0	9
Gas Turbine Count		CO₂ Emissions (MMT/year)	Power Output (MW)

Turbine Model by Class

Model	Count	Avg. CO ₂ Emission Factor (lb/MW-hr)
Aero LM6000PC	54	785.3
LMS100	36	780.6
LM6000	35	786.6
Trent 60	17	782.7
LM6000PF	10	786.6
LMS100PA	6	782.7
LM6000PC S...	6	786.6
LM6000PF S...	5	786.6
TM2500+G4	4	782.7
LM6000PC	1	782.7
Gas Turbine Count		Avg. CO₂ Emission Factor (lb/MW-hr)

Turbine Power by Class



- 84 GW dispatchable turbine power installed since 2010
- Total emissions ~165 MMT in 2023
- Displays proximity to existing infrastructure (CO₂ pipelines, H₂ pipelines, Class VI sequestration wells)
- Filter by firing class, manufacturer / model, ISO, energy source, sector...
- Recent transition to H-class and Aero-derivative installations (No F-class installations since 2020)
- Majority installed in PJM, Southeast, and MISO



Interactive Turbines CO₂ Emissions Map



Power Generation by FERC Region - Midpoint yr: 2018

PJM	16,683	6,091
Southeast	14,825	6,847
MISO	4,855	4,889
ERCOT	5,595	3,164
CAISO	6,300	1,229
ISO-NE	2,328	1,033
SPP	3,276	59
Southwest	1,296	1,120
Northwest	2,356	17
NYISO	904	794
Null	335	
	Power Generation (MW)	Power Generation (MW)

Power Generation by Turbine Class - Midpoint yr: 2018

F	22,648	3,611
H	8,512	10,587
Aero	9,271	4,199
G	7,314	1,973
Unknown	4,558	2,526
J	2,218	923
E	1,884	291
Industrial	768	539
Marine	856	445
D	502	
B	166	145
Other Small	48	
Micro	7	2
	Power Generation (MW)	Power Generation (MW)

Power Generation by Turbine Builder - Midpoint yr: 2018

Gen Electric	26,216	18,098
Siemens	18,533	1,368
Mitsubishi	9,671	2,896
Unknown	3,448	2,528
Solar	536	352
Pratt & Whitney	344	
Capstone	4	
	Power Generation (MW)	Power Generation (MW)

Power Generation by Industrial Sector - Midpoint yr: 2018

Electric Utility	32,988	14,250
IPP Non-CHP	22,120	9,505
Industrial CHP	1,019	763
Oil & Gas	1,075	574
IPP CHP	586	22
IPP	597	
Commercial CHP	288	95
Industrial Non-CHP	28	33
Commercial Non-CHP	39	
Industrial Non-CHP	13	
	Power Generation (MW)	Power Generation (MW)

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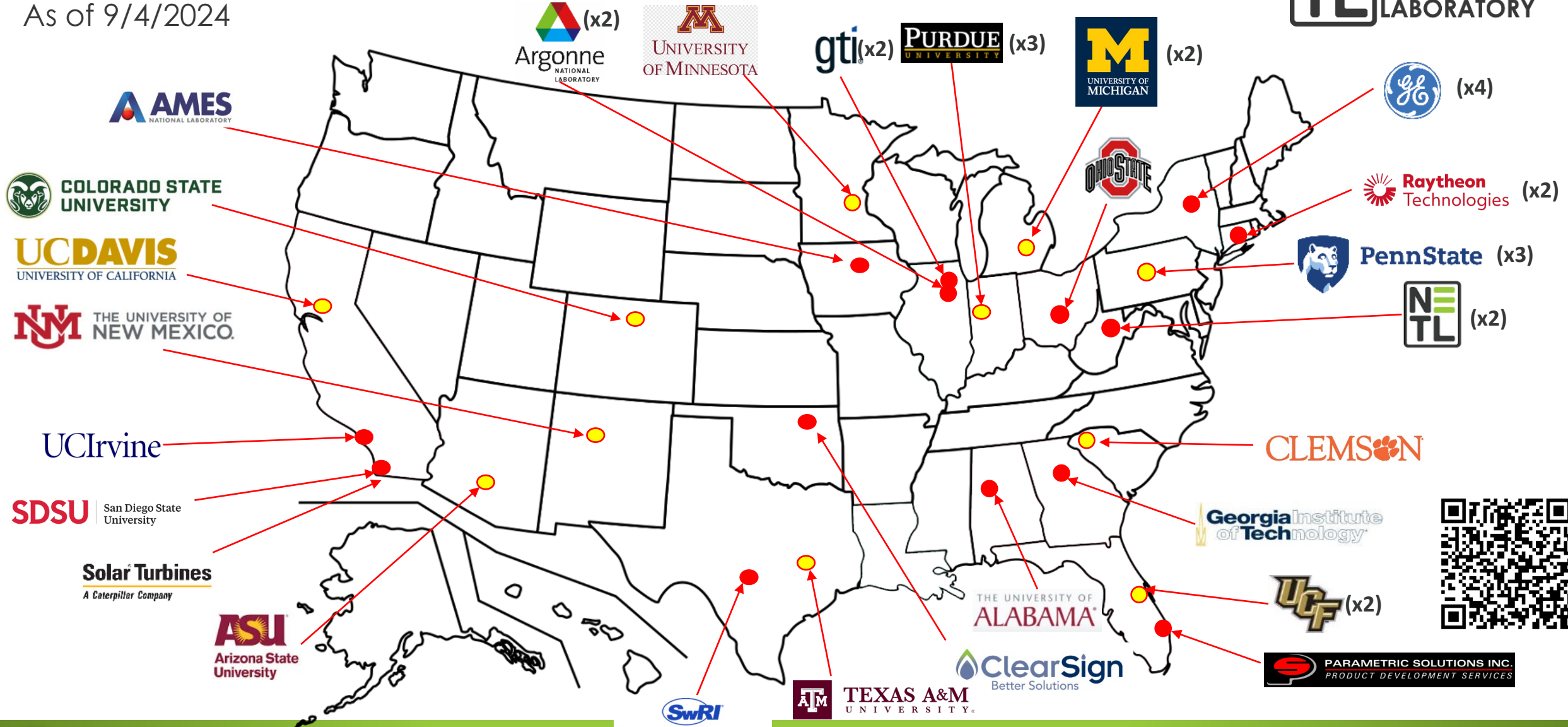
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Advanced Turbines Program Projects Map

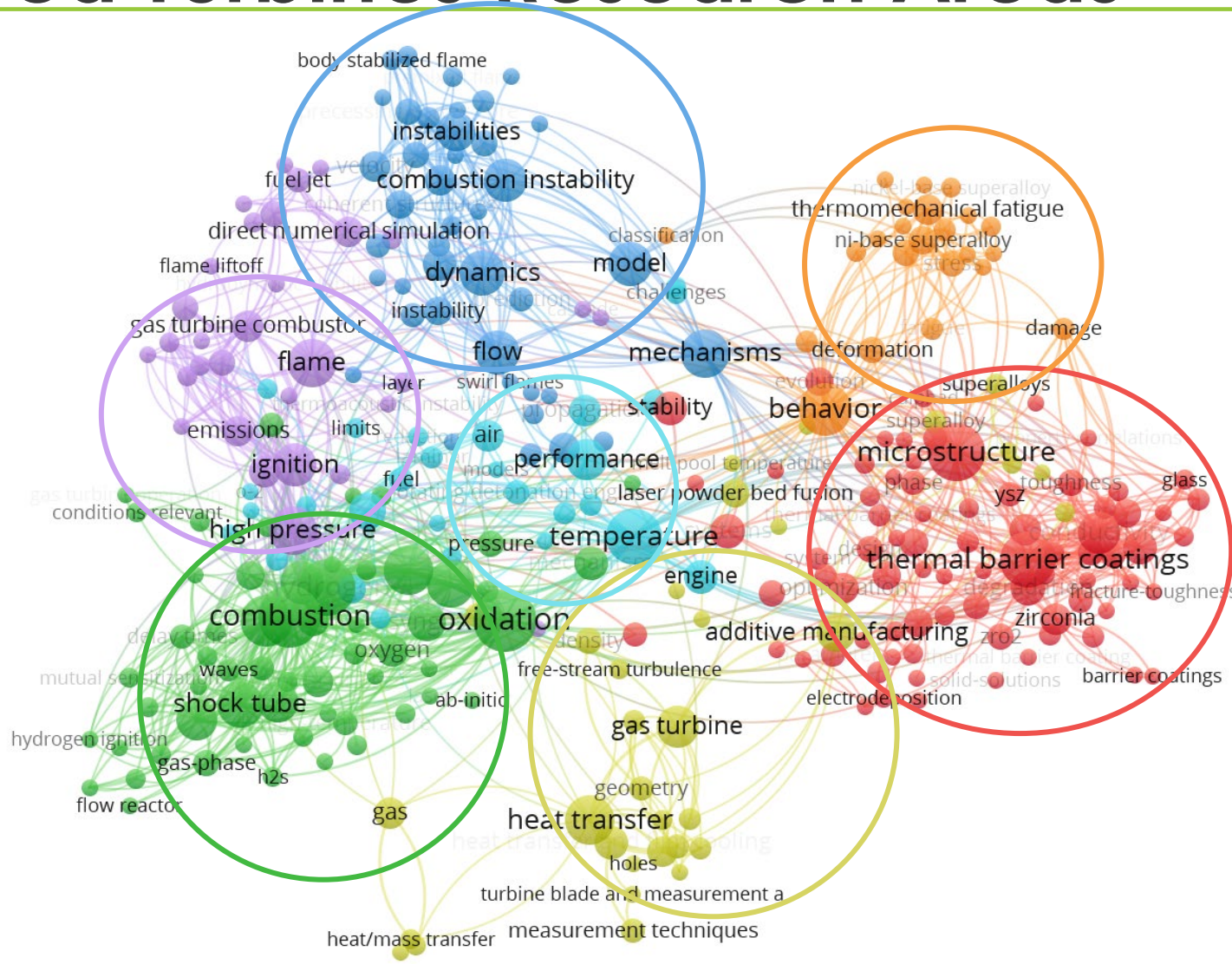


As of 9/4/2024



Advanced Turbines Research Areas

2010-2024



Publication Keywords
Co-occurrence
Color: Research Cluster

Thermal Barrier Coatings

Combustion Instabilities

Advanced Alloys & Lifting

Staged Comb & Emissions

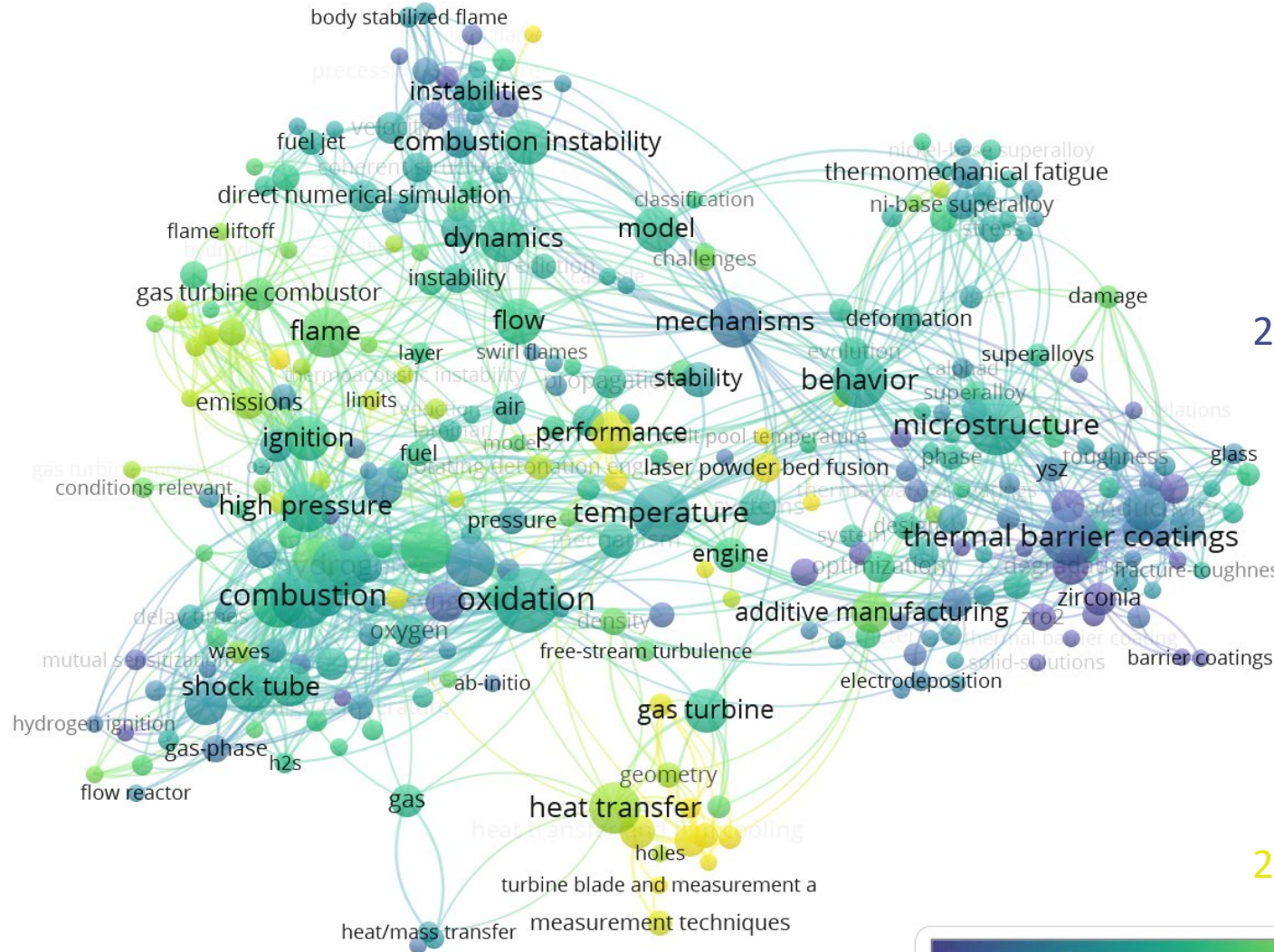
Hydrogen Combustion

Additive Mfg & Heat Trans

Rotating Detonation Engines

Advanced Turbines Research Areas

2010-2024

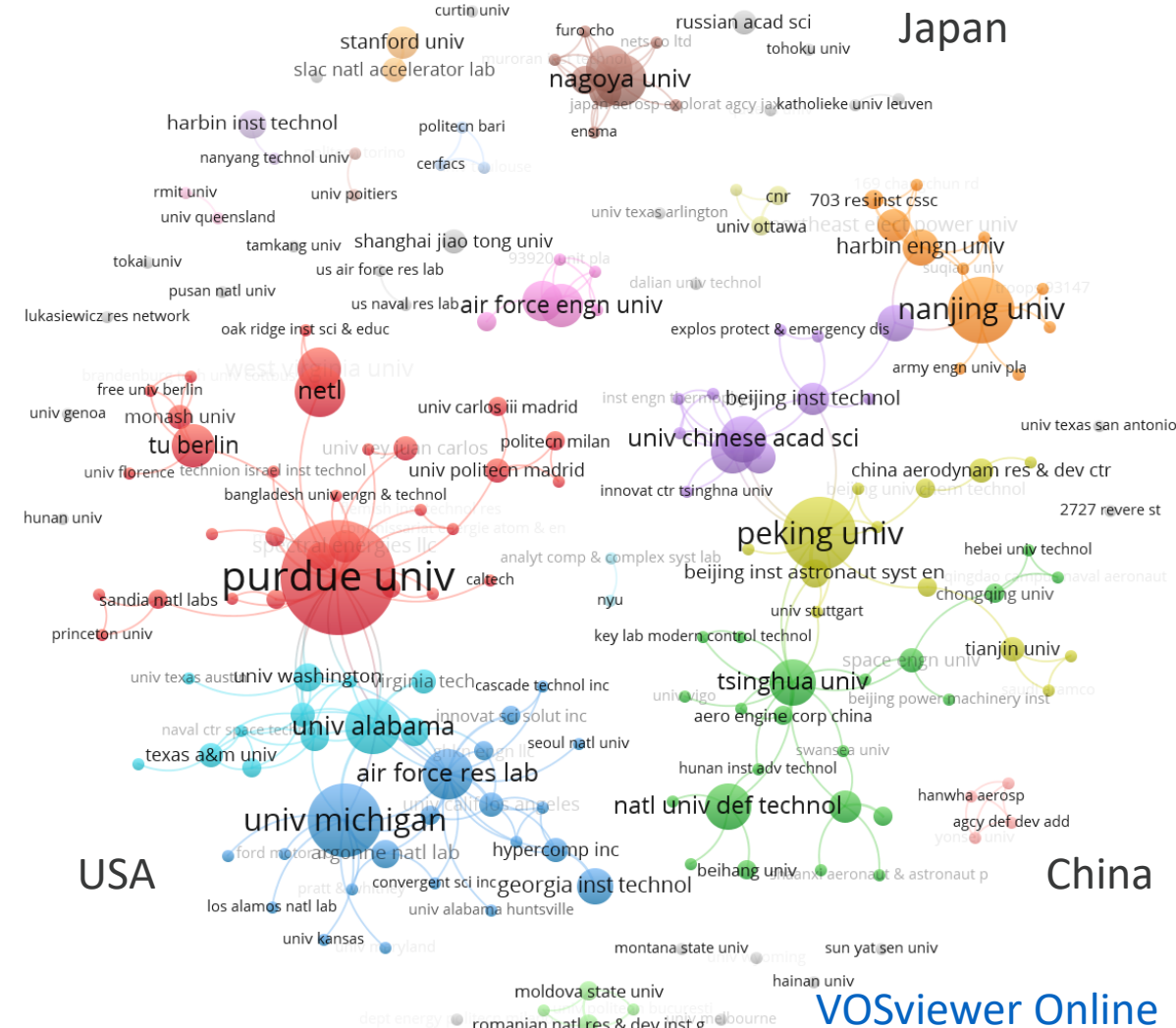
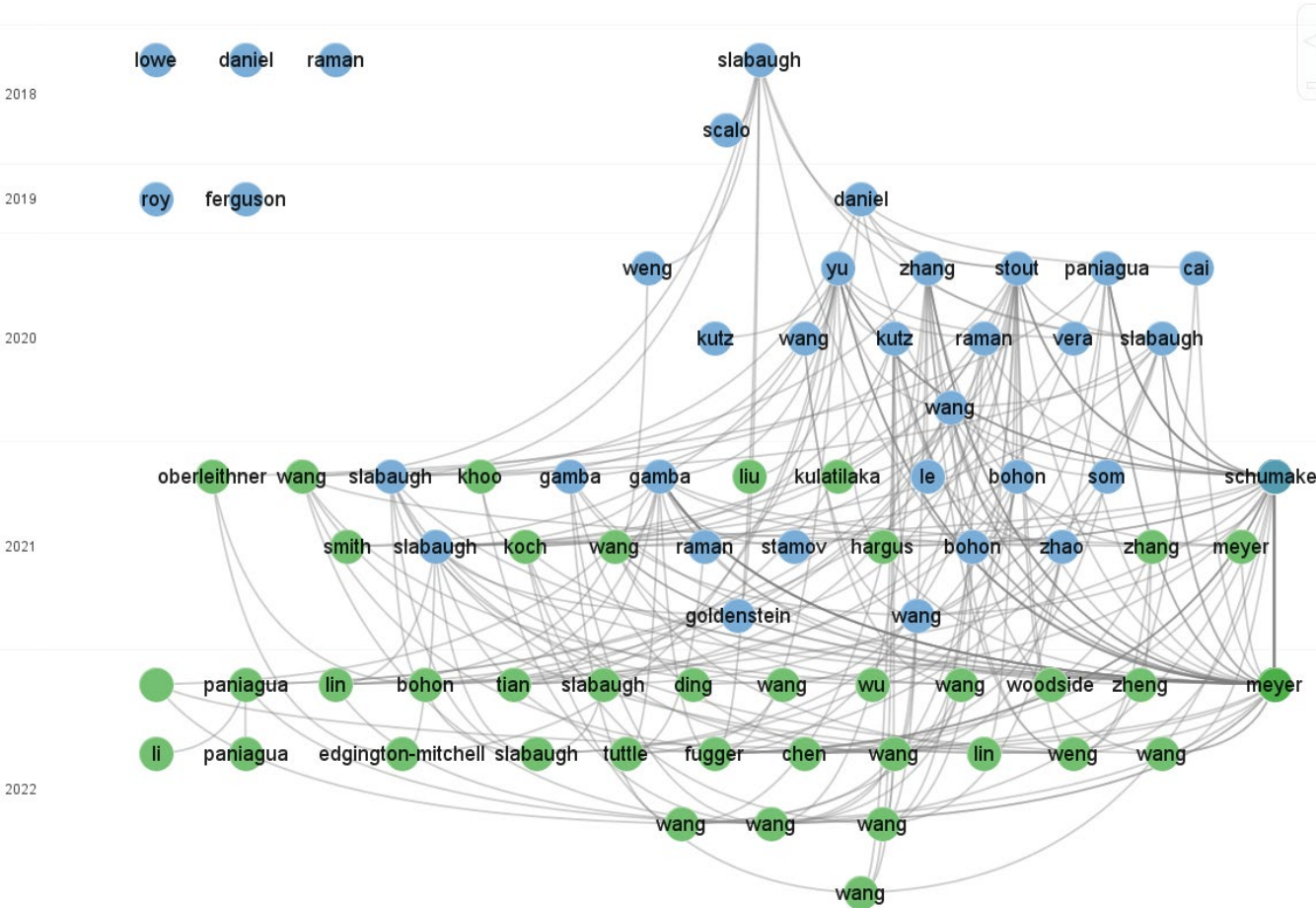


- Publication Keywords
Co-occurrence
Color: Average Date
- 2014 Thermal Barrier Coatings
 - Combustion Instabilities
 - Advanced Alloys & Lining
 - Staged Comb & Emissions
 - Hydrogen Combustion
 - Additive Mfg & Heat Trans
 - 2022 Rotating Detonation Engines



RDE Citation & Co-authorship

NETL Publications & Citations



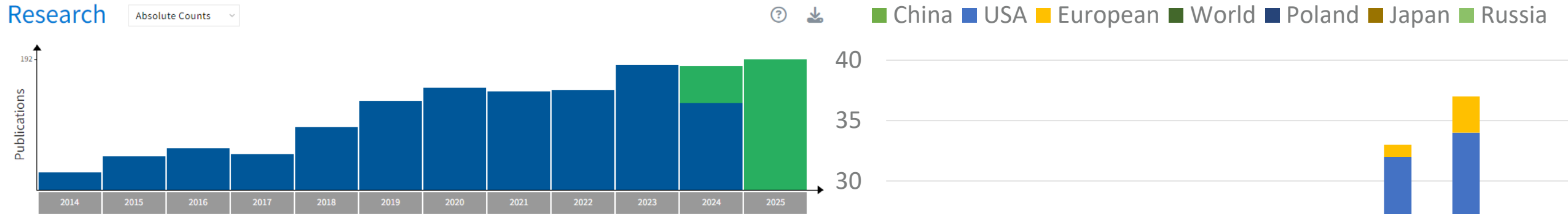
36 Advanced Turbines Publications → 234 Citations

No vertical segmentation → well-connected research areas

[VOSviewer Online](https://www.vosviewer.com/)

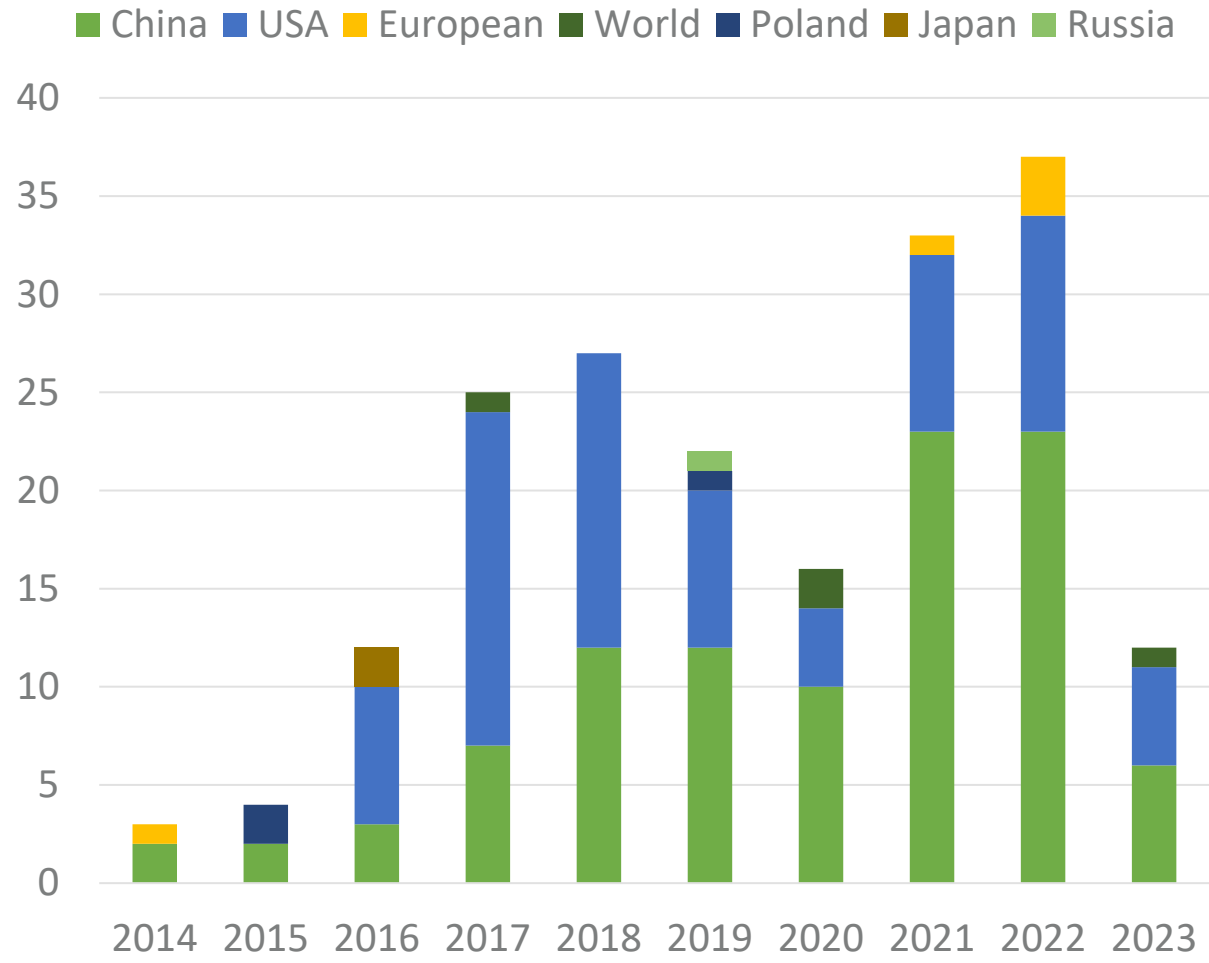
RDE Research & Patents

Mapegy Rotating Detonation Publications



Filter Fields! Integration Date Search in top 500 results

	Relevance	Published	Publisher
Effects of different physical properties of anthracite powder fuel on detonation characteristics of a rotating detonation engine	<div style="width: 20px; height: 10px; background-color: #007bff;"></div>	2023	AIP Publishing
Development of a Liquid-Propellant Rocket Powered by a Rotating Detonation Engine	<div style="width: 20px; height: 10px; background-color: #007bff;"></div>	2023	American Institute of Aeronautics and Astronautics (AIAA)
Thrust Performance of Converging Rotating Detonation Engine Compared with Steady Rocket Engine	<div style="width: 20px; height: 10px; background-color: #007bff;"></div>	2023	American Institute of Aeronautics and Astronautics (AIAA)
Study of the characteristics and combustion efficiency of liquid kerosene/oxygen-enriched air rotating detonation wave with different modes	<div style="width: 20px; height: 10px; background-color: #007bff;"></div>	2023	Elsevier BV
Investigation of counter-rotating shock wave and wave direction control of hollow rotating detonation engine with Laval nozzle	<div style="width: 20px; height: 10px; background-color: #007bff;"></div>	2022	AIP Publishing
Effects of blockage ratio on the propagation characteristics of hydrogen-rich gas rotating detonation	<div style="width: 20px; height: 10px; background-color: #007bff;"></div>	2023	AIP Publishing



RDE Research & Patents

Mapegy Rotating Detonation Publications



Indicator

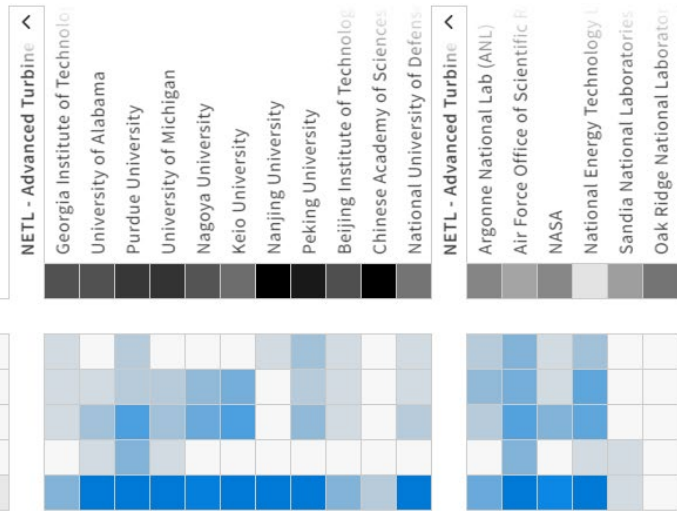
Research

Normalization ?

None

NETL - Advanced Turbine ^

hydrogen
combustion
performance
laser diagnostics
Rotating Detonation Publicat



Indicator

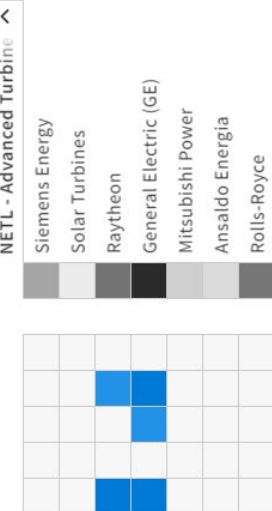
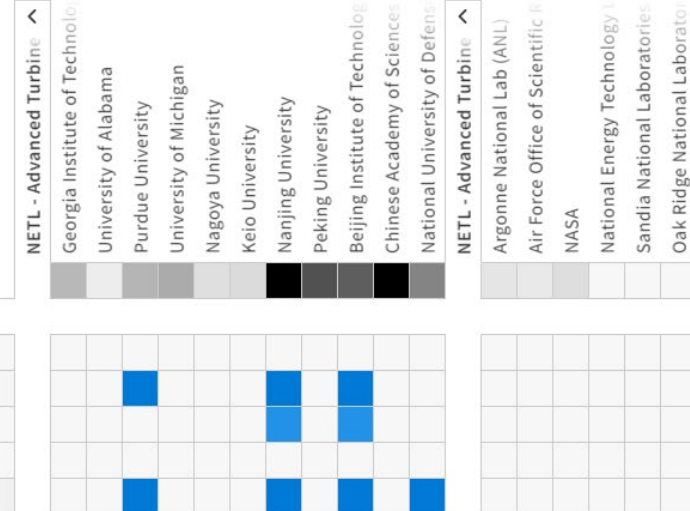
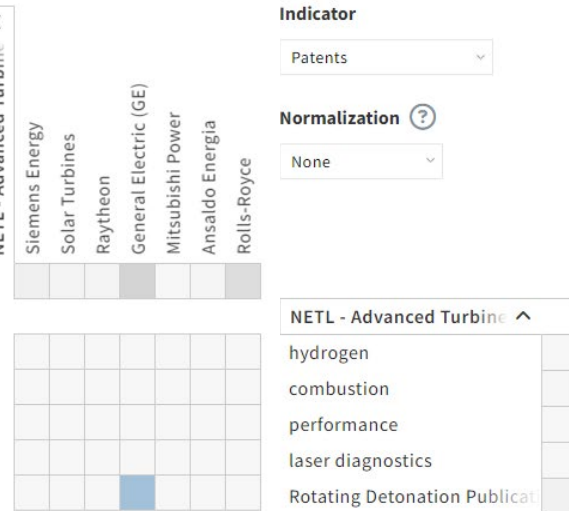
Patents

Normalization ?

None

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Questions?

Thank You!

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Additional information can be found at:

<https://netl.doe.gov/carbon-management/turbines>

