Gas Turbine Association

December 17, 2021

To National Science and Technology Council, Committee on Technology, Subcommittee on Advanced Manufacturing, and White House Office of Science and Technology Policy
1600 Pennsylvania Avenue NW
Washington, DC 20500

Re: Gas Turbine Association (GTA) Response to National Strategic Plan for Advanced Manufacturing Request for Information

The Gas Turbine Association is pleased to offer the following responses to the questions posed by OSTP's National Science and Technology Council, Committee on Technology, Subcommittee on Advanced Manufacturing regarding input toward development of a National Strategic Plan for Advanced Manufacturing.

1. *Which emerging science and technology areas will be key to the next generation of advanced manufacturing for global competitiveness, sustainability and environmental challenges?*

Advanced Gas Turbine technologies are a strategically critical "Apex Technology" at the convergence of power generation, aviation, and aerospace. Advanced gas turbines are a major source of American industrial strength: the gas turbine sector accounts for over 500,000 direct and indirect high technology jobs across the U.S. The materials, technologies and manufacturing processes that underpin success in advanced gas turbines for power generation also support the United States' strength in aviation engines, military aircraft and weapons systems and even in commercial space applications. These represent tens of billions of high-value US exports each year, and help support a strong and vibrant advanced manufacturing industry across the United States.

As the U.S. National Academy of Sciences has highlighted in a recent report, Advanced Technologies for Gas Turbines: "the gas turbine industry will continue to play a critically important role in the generation of electric power, industrial applications, and aircraft propulsion…for decades to come, both domestically and globally."[1] Likewise, a separate National Academies study on Commercial Aircraft Propulsion and Energy Systems Research: Reducing Global Carbon Emissions highlighted advances in gas turbine engineering as critical to reducing overall carbon emissions from global transportation and advancing overall goals of decarbonizing the footprint of our current economy and transportation systems.[2] Advancing gas turbine technologies to decarbonize aviation is even

[1] Nat'l Academy of Sciences, "Advanced Technologies for Gas Turbines" Jan 2020 page 2 http://nap.edu/25630
[2] Nat'l Academy of Sciences: "Commercial Aircraft Propulsion and Energy Systems Research: Reducing Global Carbon Emissions" Aug 2016 https://www.nationalacademies.org/our-work/propulsion-and-energy-systems-to-reduce-commercial-aviation-carbon-emissions

more critical now. Under the auspices of the National Institute of Standards and Technology's Advanced Manufacturing Technology Consortium (AMTech) program, the Consortium for Advanced Production and Engineering of Gas Turbines (CAPE) also produced an industry-led technology roadmap regarding high-priority areas for research & development in relevant technology disciplines.[3] Improved turbine efficiency through advances in manufacturing benefits all applications: power generation, industrial applications, and aviation propulsion.

Together, all three reports identify high-priority goals and research areas that the U.S. government, industry, and academia should pursue in order to improve and develop advanced technologies for gas turbines. Many of these encompass emerging technology areas in cutting-edge materials, computation, sensing, data analytics and real-time feedback into complex manufacturing processes.

The Gas Turbine Association respectfully recommends that OSTP review the work and recommendations outlined in each of the reports highlighted in this response for additional information and details to inform the National Strategy for Advanced Manufacturing. A brief outline of each study's recommendations are provided below, however the Association strongly encourages the OSTP to review the full list of recommendations provided by each study highlighted. Gas turbines are an extraordinarily important application set for many of the cross-cutting technologies envisioned through broader national initiatives in advanced manufacturing, including advanced high temperature materials, additive manufacturing, digital manufacturing (digital twins and digital threads), advanced modeling and simulation (including modeling and simulation/computational fluid dynamics of complex systems, combustion dynamics and heat transfer, as well as direct shop-floor applications in areas such as maintenance, repair, and overhaul operations), sensors and big-data analytics, robotics, high-precision and exotic material welding, and a host of other advanced manufacturing technologies.

> 2. *What should be the near-term and long-term technology development R&D priorities for advanced manufacturing, the anticipated timeframe for achieving the objectives, and the metrics in assessing progress toward the objectives?*

<u>Recommendations on technology development goals and technology areas from the National Academies study on Advanced Gas Turbine Technologies (2020)</u>
Investment in advanced gas turbines provides a number of key benefits to the U.S. economy, which are highlighted in the National Academies study's High Priority Goals for Power Generation Gas Turbine R&D investments:

> *Improved Efficiency*. Increase combined cycle efficiency to 70 percent and simple cycle efficiency to more than 50 percent.

Technologies for ultra-high gas turbine combined cycle (GTCC) efficiency (67% and higher) will enable natural gas power generation to reduce emissions while maintaining the reliability and resiliency necessary to complement renewable energy sources. Current thresholds for combined cycle efficiency are approaching 63% and simple cycle efficiencies are approximately 40%. Each percentage

[3] NIST AMTech CAPE Advanced Gas Turbine Manufacturing Technology Roadmap, Dec 2018

point increase in efficiency of the gas turbine combined cycle fleet results in emissions reductions equivalent to taking 2 million cars off the road, and equally as important, provides an economic benefit of more than $7 billion to the US economy due to reduced fuel costs. Meanwhile, a trend toward higher per-BTU fuel costs due to fuel-switching from natural gas to increasingly decarbonized fuels such as hydrogen, biogas, or biofuels could be partially offset by these higher efficiency gensets.

Funds provided through the U.S. Department of Energy's Advanced Turbines program (currently classified under DOE's Fossil Energy Research & Development activities) have contributed to advances in gas turbine technologies resulting in greater efficiencies, enhanced reliability, and broad-based decarbonization of the U.S. power sector, including improvements in performance of turbines operating with high proportions of hydrogen as fuelstock. Improvements through these programs have also led to substantial improvements in the performance and efficiency of aircraft engines, another prime mover of modern life that we will be hard-pressed to replace. Our nation needs to invest significantly in advanced turbine R&D to assist in technology and material development and demonstration across all segments of the gas turbine industry, encompassing aviation and industrial applications as well as power generation.

> *Compatibility with Renewable Energy Sources*. Reduce turbine start-up times and improve part load efficiency

Gas turbines are highly dispatchable, reliable power sources so they are a perfect complement for the increasing penetration of renewable resources such as wind and solar. As a higher proportion of intermittent renewable sources comes online to the grid, there is a need for rapidly dispatchable high-volume sources of power generation to offset unexpected or seasonal deficits in power production when renewable and energy storage resources are not available, or when demand spikes at inopportune times relative to other sources of generation capacity. It may also require power capacity to operate at loads far from baseload for extended periods of time. The cycles can vary hourly, daily or seasonally. Gas turbines are well-suited to provide sustained dispatchable power at volumes beyond the capacity of current power storage solutions, adding security to the grid while reducing capacity overbuild, and can quickly turn down to allow renewable penetration to be maximized when it comes available.

Enabling black-start capability to mitigate grid instability and quickly restore power in the event of an unexpected shutdown or the unexpected loss of significant renewable generation capacity (either due to weather or grid infrastructure issues) is another important function for gas turbines in the context of a broader transition and decarbonization of the world's electrical generation and distribution systems. Paired with reclaimed or renewable fuel sources, these capabilities can help gas turbines provide flexible and scalable dispatchable power for a broad range of applications, with minimal or net-zero carbon footprint.

Research and development targeted toward these newly emerging operational cycles and modalities will help reduce turbine start-up times, improving the ability to provide demand response more quickly, efficiently and effectively. R&D to help optimize turbine design and components for rapid and repeated "ramp up" and "ramp down" cycles as operators provide active response to fluctuations in the supply and demand of electricity on the grid will reduce operational wear and tear on parts that were optimized for baseload operations, minimize downtime for maintenance purposes, and improve overall efficiency and cost-effectiveness of our nation's electric generation fleet.

Low to no CO2 Emissions

Natural gas-fired turbines produce less than half the amount of CO2 emissions per kilowatt-hour of power produced relative to coal-fired power facilities. Other air pollutants such as nitrogen oxide (NOx) and sulphur dioxide (SO2) are also drastically reduced through the use of natural gas resources for power generation. Reducing CO2 emissions is directly related to increasing turbine efficiencies.

According to IEA research, carbon dioxide emissions from power generation in the US fell by 27% between 2005 and 2017 while overall power generation increased, and the switch from coal to gas-fired power has provided 2/3rds of that reduction in emissions. Moreover, the switch from coal to gas has enabled CO2 emissions from US power generation to be lower than CO2 emissions from the US transportation sector for the first time in history – a strong demonstration of the impact that improving efficiency can have for our economy and our environment.

Research and development to lower this emissions signature would be beneficial for multiple reasons, including that achieving this goal will increase compatibility with renewable energy sources and the future electrical grid by enabling greater use of renewable fuels.

Improvements in Fuel Flexibility. Goal of enabling high proportions (up to 100 percent) of hydrogen and other renewable gas fuels

Gas turbines offer a high degree of fuel flexibility, including the opportunity to harness a carbon-free fuel in hydrogen and other renewable gas fuels, including sustainable alternative fuels. Instead of "dumping" excess power generated by renewable energy sources during periods of relatively low demand, hydrogen can be produced through harnessing excess power from renewable sources such as wind or solar to drive hydrolysis and then "storing" that resource for use as a highly efficient on-demand fuel source. In this model, the hydrogen can then be combusted via a gas turbine for on-demand zero-emission power generation. Certain fuels are ready to implement today in existing systems, while others (such as hydrogen at scale for power generation) need additional effort and development to address the issues necessary to bring them to effective fruition. Additional research can help to optimize and improve the efficiency and resiliency of turbine systems to utilize different fuels, which will assist broader headline environmental goals as well as provide substantial performance improvements with significant economic benefits for the broader U.S. economy.

Lower levelized Cost of Electricity improving life cycle costs and energy affordability

<u>High-Priority Technology Areas for Gas Turbine R&D Investment</u>
In order to achieve these goals, the 2020 National Academies study on Advanced Technologies for Gas Turbines identified ten high-priority technology areas to focus attention for turbine technology R&D activities. In the study committee's perspective, investment in these technology areas offer the greatest likelihood of enabling the goals for turbine technology advances that will enhance

decarbonization and overall efficiency of the nation's electricity generation, industrial and transportation sectors.

Disciplines

1. Combustion (including Emissions Control)
2. Structural Materials and Coatings
3. Additive Manufacturing for Gas Turbines
4. Thermal Management
5. High-Fidelity Integrated Simulations and Validation Experiments

Systems

6. Unconventional Thermodynamic Cycles
7. System Integration
8. Condition-Based Operations and Maintenance
9. Digital Twins and Their Supporting Infrastructure
10. Gas Turbines in Pipeline Applications (including Hydrogen distribution infrastructure)

<u>Recommendations of the National Academies study on Commercial Aircraft Propulsion and Energy Systems Research (2016)</u>

Likewise, the National Academies study on Commercial Aircraft Propulsion and Energy Systems Research in 2016 highlighted research to support advances in:

- Aircraft-Propulsion Integration Research
- Gas Turbine Engine Research
- Turboelectric Propulsion Research, and
- Sustainable Alternative Fuels Research.

Specifically within the area of Gas Turbine Engine Research, the National Academies study highlighted three high-priority research projects to support advances in gas turbine engines:

- Low pressure–ratio fan propulsors,
- [High Temperature] Engine materials and coatings, and
- Small engine cores

The National Academies study on aircraft propulsion also noted that: "Gas turbine engines have considerable room for improvement, with a potential to reach overall efficiencies 30 percent greater than the best engines in service today. This magnitude of gain requires investment in a host of technologies such as developing advanced materials to reduce weight and improve engine performance and designing smaller, more efficient engine cores."[4]

Likewise in the area of Turboelectric Propulsion Research, the National Academies committee noted that "Turboelectric systems … are probably the only approach for developing electric propulsion systems for a large passenger aircraft that can be feasibly achieved in the next 30 years. Combined with other technologies, turboelectric systems could potentially reduce fuel burn by up to 20 percent

[4] NAS *Commercial Aircraft Propulsion and Energy Systems Research: Reducing Global Carbon Emissions*, page 2

or more compared to aircraft in service today. These projects would include research to better understand the benefits and design trade-offs related to key aircraft systems and the creation of system research facilities to better develop the core megawatt-class technologies for turboelectric aircraft propulsion systems."[5]

NIST AMTech CAPE Advanced Gas Turbine Manufacturing Roadmap recommendations

The NIST AMTech CAPE Advanced Gas Turbine Manufacturing Roadmap compiled industry input though an extensive set of interviews with gas turbine industry partners, and completed widespread market research to identify technical areas of interest for the acceleration of gas turbine technology advancement. The industry input led to the selection of a number of technology areas as being identified to have the highest impact on technology advancement, and in which collaborative, precompetitive technology development efforts are possible due to the high cross-cutting impact on the entire gas turbine industry and related sectors of the broader economy.

These topics covered within the NIST AMTech CAPE roadmap were organized into five technical focus areas:

- Materials for Hostile Environments & Extreme Conditions (MHEEC)
    - Existing Materials, Hybrid Materials & Refractory Metals
    - High Entropy Alloys
    - Ceramic Matrix Composites
    - Thermal Barrier Coatings
- Additive Manufacturing that Enables New Design(s) and Engineering for Advanced Gas Turbines
    - Thermo-mechanical models
    - Process Standards
    - Feedstock materials
    - Design & Engineering for Gas Turbines Enabled by New Processes & Materials
- Non-destructive Evaluation (NDE), Digital Thread & Digital Twins
- Maintenance Repair and Overhaul (MRO)
    - Additive Repair & (Re-)Certification
    - Advanced Material Repair Methodologies
    - On-Demand Legacy Parts & Data Resources
    - Optimizing & Customizing Repair
- Workforce Development & Safety

Examples of specific high-priority items include development of hybrid/multi-material components, refinement of thermomechanical models for additive manufacturing materials and processes, mixed-material processing through additive manufacturing, development and deployment of real-time sensors in areas critical to process monitoring and control (across multiple advanced manufacturing process categories including additive), joining of disparate materials (different alloys,

[5] Ibid. The National Academies describe turboelectric systems in this context as: "electric propulsion systems that use gas turbines to drive the electrical generators that power electric motors, which in turn drive propulsors (fans or propellers)."

metals/ceramics), and developing repair techniques and maintenance reference standards for newer/more exotic materials.

Each of these initiatives highlighted research that should be pursued in the next several years (by 2025) with a goal toward having an impact in the 2030-2040 timeframe. Specific timelines and metrics for achieving progress in each area are covered in the details provided with each study.

3. *What are examples of technological, market or business challenges that may best be addressed by public-private partnerships, and are likely to attract both participation and primary funding from industry?*

The Gas Turbine Association would like to highlight turbine component development as an area of critical need for significant investment and collaboration in advanced manufacturing research that would address major challenge(s) associated with this technology and improve yield(s), lead time, and throughput for existing and prospective production and repair techniques. Turbine components include blades, vanes, nozzles, and a variety of other components distributed throughout these systems, which are subjected to extremely high temperatures, stresses or corrosive environments, often in combination, and which need to work flawlessly over thousands of hours of operation time.

Advanced turbine blade (and overall component) design, engineering and production is a competitive advantage for the United States. There are more countries who can produce nuclear weapons than have mastered this particular technology – high-quality, consistent production of advanced turbine components.

As a critical technology with applications across multiple sectors (energy, industrial, aviation and defense) the United States must continue to invest in advanced technical research and manufacturing techniques to retain our technical edge in this suite of technologies in the face of significant pressure from other economies that seek their own advantage in these technologies.

Many of the advanced manufacturing processes and research areas outlined earlier by the National Academies studies and NIST AMTech technology roadmap are relevant to advanced turbine component development and testing. Among them, additive manufacturing and digital technologies (digital twins, digital thread and advanced modeling) have direct application in this specific context (turbine component development, manufacturing, inspection and repair). Many of the specialized materials used or considered for use in advanced gas turbines stretch the limits of current knowledge and practice in metallurgical and material property research and characterization, as well as need further work to ensure consistent manufacturability.

Multiple industry partners are actively pursuing investment in advancing these technologies and would welcome and support public-private collaboration and targeted funding of pre-competitive research in these technical issues. These types of strategic investments would then enable future generations of technological advancement and ensure that the strong industrial base the U.S. in the gas turbine industry, with hundreds of thousands of high-wage, high-skill manufacturing and maintenance jobs across the country are maintained and enhanced for decades to come.

4. *How can federal agencies and federally funded R&D centers supporting advanced manufacturing R&D facilitate the transfer of research results, intellectual property and technology into commercialization and manufacturing for the benefit of society and ensure sustainability, national security and economic security?*

5. *How would you assess the state of the domestic advanced manufacturing workforce in the U.S.? How can federal agencies and federally funded R&D centers develop, align and strengthen all levels of advanced manufacturing education, training and certification programs to ensure a high-quality, equitable, diverse and inclusive workforce that meets the needs of the sector and drives new advanced manufacturing jobs into the future?*

6. *How can the federal government assist in the development of regional public-private partnerships to achieve greater distribution of advanced manufacturing clusters or technology hubs, particularly in underserved regions of the country? What outreach and engagement strategies are most useful in promoting development in underserved regions of the country?*

7. *How do we assess the adequacy of the domestic advanced manufacturing supply chain and industrial base? How can federal agencies assist small and medium-sized manufacturing companies to adopt advanced technologies and to develop a robust and resilient manufacturing supply chain? What steps can these agencies take to promote the development and diffusion of technology that augments worker skills (rather than substituting for them), and ensures that manufacturing jobs are good jobs?*

8. *Are there useful models (at the international, national, state and/or local level) that should be expanded?*

The Gas Turbine Association recommends that the OSTP review the success of the US Department of Energy's University Turbine Systems Research (UTSR) program as a potential model for expansion and/or application to other sectors of US advanced manufacturing. The University Turbine Systems Research program is a long-standing initiative with significant engagement and participation from both universities and the industry community which has been sustained over the course of more than 20 years. The program provides grants to university engineering research labs who work in close partnership with private-sector industry partners to address and solve specific technical challenges and improve performance of advanced turbine systems. The UTSR program promotes extraordinarily strong collaborative partnerships between industry and academic research institutions, providing input and expertise to the universities and a steady stream of specialized talent and new innovations for use by industry. The UTSR program is a real model for how to structure US applied research and development funding programs to support the advanced manufacturing industry across the country, with strong collaboration between industry and academia "baked into" the criteria of the program and the culture of these efforts resulting in truly impactful applied research relative to advanced manufacturing, and the strong emphasis on working closely with industry partners to support and contribute to research activities is a model that should be considered across many other facets of the US advanced manufacturing research enterprise. The structure and emphasis of the UTSR program enables and incentivizes companies and academic institutions across the country to broaden and deepen their networks and collaboration for mutual benefit.

In addition to the strong partnerships between research universities and private industry in the UTSR research program, there is also a UTSR technical internship program that enables engineering students (particularly upper-level undergraduates and selected graduate students) the opportunity for hands-on real world internship and work experience with leading companies across the gas turbine design, engineering, manufacturing and maintenance community. The UTSR internship program has been very beneficial to the development and enhancement of the U.S. gas turbine research community, and it provides significant value-added to our organizations and to the turbine manufacturing industry overall. The vast majority of costs associated with the UTSR internship program are absorbed by industry partners and academic institutions involved, with a coordinating role provided and supported with a nominal amount of federal funding.

Using this model, the UTSR program has leveraged significant resources from the private sector to support early-stage research leading to development and adoption of technologies that underpin the efficiency of gas turbines today and will continue to improve and optimize their efficiency in the future, as well as providing an important and ongoing pipeline of talent and expertise from our leading research institutions to the gas turbine manufacturing industry across the country.

In addition to the UTSR program mentioned above, there are also active programs to support collaboration between national laboratories and private-sector partners to advance the "state of the art” in advanced manufacturing technologies and industrial applications. The High Performance Computing for Manufacturing (HPC4Mfg) and High Performance Computing for Materials (HPC4Materials) programs sponsored by the US Department of Energy have been very beneficial to US industry, particularly in the advanced turbine and propulsion community, as resources and expertise provided through these collaborative research projects have enabled US firms to make significant advances in modeling complex combustion dynamics in advanced turbines for power generation and propulsion, as well as supported big-data analysis of performance of the US power generation fleet, enabling new types of analytics to highlight opportunities for operational improvements and predictive maintenance to reduce downtimes and unexpected generation outages across the US power generation system as well as reduce carbon emissions and improve overall system reliability and efficiency.

The Materials for Extreme Environments (eXtremeMAT) program at the US Department of Energy is another program that has successfully brought together industry, academia and the national laboratories to accelerate the development of materials for service in extreme environments.
This research initiative, a collaboration across seven national laboratories with participation from academic and industry partners, seeks to address material integrity challenges inherent in highly efficient advanced energy systems. Specifically, the eXtremeMAT initiative aims to improve both heat-resistant alloys and models for predicting long-term material performance. Collaborations such as the eXtremeMAT program are essential in order for industry to make progress in addressing pressing challenges in identifying and adapting candidate materials and associated manufacturing techniques for applications in extreme operating conditions, whether extreme temperatures, high-stress applications, highly corrosive or chemically caustic environments, high radiation or other

situations (such as hydrogen embrittlement) that can cause significant challenges as they test the limits of current material systems and manufacturing processes.

The resources and information provided through these partnerships have been invaluable to US advanced manufacturing companies in the power generation, propulsion and maintenance and repair industry, supporting thousands of US jobs and millions of dollars in economic activity. The GTA respectfully suggests that programs that incentivize collaboration between national labs, academic research institutions and private companies toward broader national goals in advanced manufacturing (such as the UTSR, HPC and eXtremeMAT programs) are areas for further expansion in order to enable further collaboration among the world-class resources of our national laboratories and relevant members of the US advanced manufacturing community, especially in advanced gas turbines.

9. *The current Strategy for American Leadership in Advanced Manufacturing has three top-level goals, each with objectives and priorities:*

   - *Develop and transition new manufacturing technologies*
   - *Educate, train and connect the manufacturing workforce*
   - *Expand the capabilities of the domestic manufacturing supply chains*

   Are these goals appropriate for the next 4-5 years? Are there additional top-level goals to consider?

10. *Is there any additional information related to advanced manufacturing in the United States, not requested above, that you believe should be considered?*

References:

National Academies of Sciences, Engineering, and Medicine. 2020. *Advanced Technologies for Gas Turbines*. Washington, DC: The National Academies Press. https://doi.org/10.17226/25630
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NIST AMTech CAPE Advanced Gas Turbine Manufacturing Technology Roadmap, Dec 2018 (Executive Summary available under the GTA Today page at https://www.gasturbine.org)

Sincerely,

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