ASME
SETTING THE STANDARD

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In this Issue...

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ASME

TURBO EXPO 2020 GOES VIRTUAL

His Royal Highness The Prince of Wales gave the opening address where he set out a challenge to accelerate the decarbonization of flight and power generation. His Royal Highness outlined **10 specific actions** that could be advanced by the Turbo Expo Community.

In the message His Royal Highness said, "As we emerge from this crisis, the need to decarbonize flight must remain at the top of the agenda. While many are calling for net zero flight by 2050 I would like to challenge you all to think about **halving that time frame to 2035**." To achieve this target, he said "we must acknowledge that the decarbonization of flight is technically possible. However, more focus is required if it is to be achieved in the necessary time scale."

Ten Actions by His Royal Highness to Accelerate the Decarbonization of Flight

1. We must accelerate the production and adoption of sustainable aviation fuels.
2. We must accelerate research and development into hydrogen-powered flight and the development of lightweight electrical power systems for hybrid and battery-powered flight.
3. We must develop credible independent roadmaps which accelerate the delivery, scaleup, infrastructure, investment, and policy necessary to decarbonize aviation.
4. We need to cut dramatically the time required to develop and deploy new technologies just as we do during war time, moving from decades to years, and preferably months.
5. We must invest at scale in practical projects to demonstrate the feasibility of new technologies. It is only when projects are tangible that investors and consumers can generate the demand for their use.
6. We need to optimise aircraft operations to minimize both carbon dioxide emissions and the non-carbon dioxide climate forcing impacts of aviation.
7. We need to invest in climate science to better understand the impact of a non-CO_2 effective aviation on global warming.
8. We must set up co-located multidisciplinary teams made up of industry academia and government.
9. We need to educate consumers about the technologies that are emerging so they can help fuel the demand for decarbonized flight.
10. We must acknowledge the decarbonization of flight is technically possible. However, more focus is required if it is to be achieved within the necessary time scale.

See the video at *event.asme.org/turbo-expo-2020*.

Thank you to our volunteers!

Turbo Expo 2020 Conference Committee

Turbo Expo 2020 Local Liaison Committee

Point Contacts & Vanguard Chairs, Session Chairs and Co-Chairs, Reviewers, Authors and Speakers

Glenn Llewellyn chose Turbo Expo to announce Airbus's plans to produce a zero-emissions aircraft. He explained three concepts for the world's first zero-emission commercial aircraft which could enter service by 2035 all codenamed "ZEROe."

THE FULL VIDEO CAN BE SEEN AT EVENT.ASME.ORG/TURBO-EXPO-2020

ASME TURBO EXPO 2020 VIRTUAL STATISTICS

1,588 attendees from 41 different countries convened at the first virtual Turbo Expo conference where they participated in 289 technical sessions. In these sessions, authors presented close to 1,000 final papers!

The virtual event site will be available until December 24, 2020.

Post conference registration is available until November 24, 2020.

- Technical sessions
- Student poster sessions
- Network with authors, exhibitors, and sponsors!

Tutorials of Basics

Complimentary for Turbo Expo 2020 attendees!

Visit the conference site to view the schedule: *event.asme.org/Turbo-Expo-2020*

ASME TURBO EXPO 2021 VIRTUAL CONFERENCE

Virtual Event Dates

June 7 – 11, 2021

Student Poster Competition

One major event organized by the ASME IGTI Student Advisory Committee is the Student Poster Competition. Presenting a poster is an excellent opportunity to display research outside of a paper while still contributing to the continuing advancements in the turbomachinery community. To be eligible to present a poster, the presenting author must have completed the research presented on the poster while seeking a degree at a university at an undergraduate (Bachelor's) or graduate level (Master's or PhD). Submit your research and contribute to the continuing conversation on advancements in gas and wind turbine technology.

Abstracts are due on January 31, 2021.
event.asme.org/Turbo-Expo

As the Turbine Turns...

PIPED GAS FUELS GT POWER PLANT GROWTH

#44 - December 2020

By Lee S. Langston,
Professor Emeritus,
University of Connecticut

In the last 10 years the growth of America's natural gas fueled, gas turbine power plants have flourished in its lower 48 states. They are replacing older coal-fueled steam turbine power plants, ending a century's-old dominance of King Coal, for the nation's electricity production.

The first simple cycle gas turbine (GT) electrical power plant, rated at 4 MW output, ran in Switzerland in 1938. Subsequently, in the relatively short span of 80 years, gas turbines are now a dominant means of electrical power production in the United States. Fueled by clean burning, low-carbon natural gas and aided by technology adopted from aviation jet engine advances, gas turbine power plants now have low capital costs and by far, the highest thermal efficiencies ever recorded.

In the form of gas turbine combined cycle plants (CCGTs), they are approaching thermal efficiencies of 65%. In a CCGT, which are generally in the 100 to 800 MW range, the hot exhaust of the Brayton cycle electric power gas turbine is used to produce steam to drive a Rankine cycle electric power steam turbine. Thus, a CCGT uses one unit of fuel (generally natural gas) to supply two sources of electric power.

Sustainment by Natural Gas

Underlying their introduction and operation, simple cycle GT and CCGT plants in the U.S. have been fueled by the world's most extensive natural gas pipeline system, a network of some 300,000 miles of interstate and intrastate gas pipelines. This network has an ample supply of domestic natural gas, recently supplemented by the development of fracking, which has created America's shale gas industry.

Ten years ago, when I started writing this column [1], Energy Information Administration (EIA) data [2], showed that 23% of the U.S. electrical power in 2009 was generated by natural gas as a fuel. In 2019, that number has almost doubled to 38%, with coal (formerly dominant in 2009 at 44%) dropping to 23%, nuclear at 20%, wind and solar at 9%, hydro at 7% and biomass and geothermal at the remaining 3%.

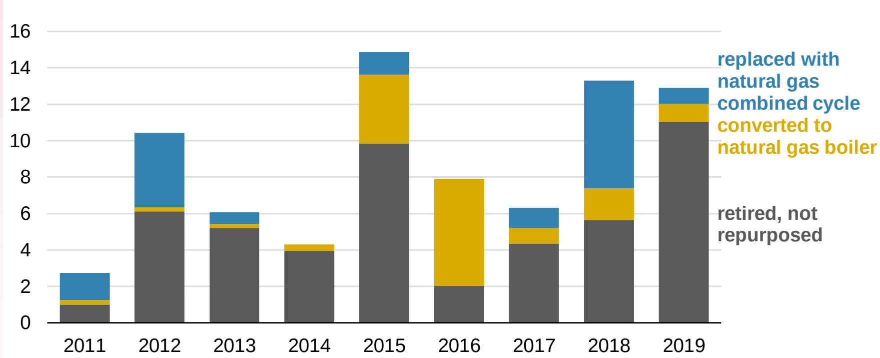
For the leading 38%, most of the natural gas was fuel for new Brayton cycle gas turbine power plants (either simple cycle or combined cycle) replacing coal plants, with the remainder used in existing, Rankine coal plants converted to natural gas. All told, EIA data [3] shows that more than 100 U.S. coal-fired power plants had been replaced by gas turbine plants or converted to natural gas since 2011.

This recent replacement of coal-fueled plants in the U.S. has been by far, the quickest route to lower the world's carbon emissions. The combined effects of halving the fuel's content through the use of natural gas, and the higher record-breaking CCGT thermal efficiency (~60%) cuts carbon emissions per unit of electricity by potentially as much as 75%. In 2018, which had a same level of total annual net electricity as 2005, carbon dioxide power plant emissions in the U.S. dropped by 27% from 2005. This is a record-breaking reduction, nearly equal to the total CO_2 2017 emissions of Germany, the world's fourth largest economy [4].

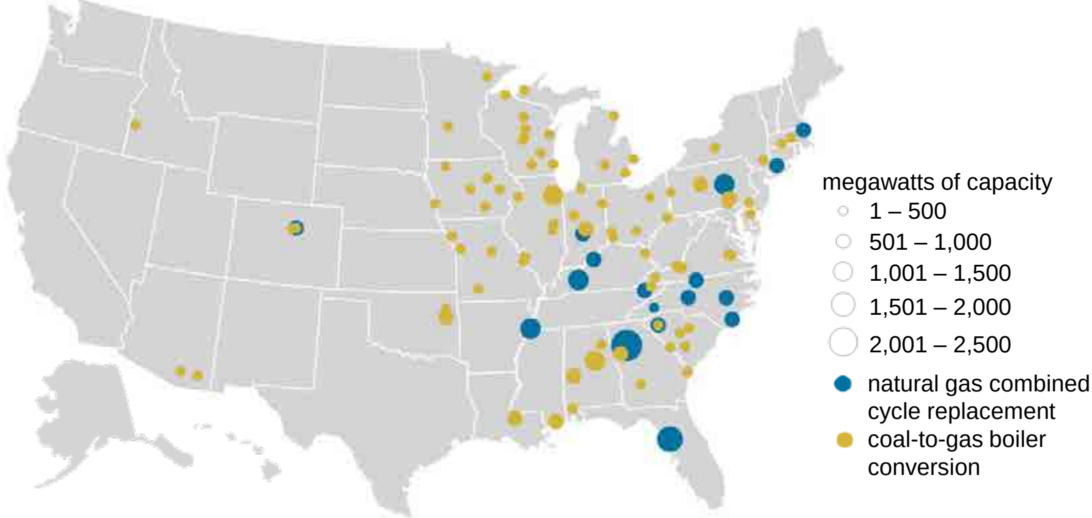
The Pipeline is the Lifeline

Let me highlight how a natural gas pipeline system is a key element in the operation of a gas turbine power plant, by giving

U.S. coal-fired capacity retired or repurposed to natural gas by conversion type (2011-2019) [3]
gigawatts



U.S. coal-to-natural gas plant conversions by conversion type and capacity (2011-2019) [3]



an account of our own GT power plant, here on the Storrs campus of the University of Connecticut (UCONN) [5].

We have a 25 MW cogeneration, combined cycle power plant that has served our 20,000-student campus since 2006. It has three 7 MW Solar Taurus gas turbines burning natural gas, with 300,000 gallons of fuel oil as a backup fuel. The Solar units drive water-cooled generators for campus electrical power, and supply exhaust gas heat to generate steam for campus heating, for a 4.6 MW steam turbine electric generator set, and for steam turbine driven chilled water refrigerator units for campus building air conditioning.

The UCONN power plant natural gas fuel comes from the nearby interstate 1129 mile, 3.2 billion cubic feet of gas per day, Algonquin Gas Transmission pipeline. Such major large diameter pipelines (typically 26-42 inch) are typically buried unobtrusively underground, immune to natural disasters, such as winter storms or hurricanes. They are the most efficient means of bringing fuel to gas turbine power plants. As Smil [6] notes, gas pipelines can have power transmission capacities of up to 10-25 GW (electrical transmission lines leading away from power plants are at least an order of magnitude lower). The heart of the Algonquin pipeline in Connecticut are three compression stations (gas turbine powered) along its length, that maintain high gas pressurization and adequate gas flow rate.

The UCONN power plant is connected to the Algonquin pipeline with a 2.5-mile 8-inch diameter 500 psig rated pipeline, owned by the University. Safe fuel supply is critical for this underground high-pressure pipeline running through the heart of the campus. The pipeline is pressure tested every five years, and is cathodically protected against corrosion, with thermal soil sensors in place where it is in proximity to underground steam piping.

The UCONN pipeline operates at a 380 psig delivery pressure from the higher-pressure Algonquin pipeline. From a pressure standpoint, it is advantageous to have a gas turbine power plant located close to a major pipeline, which usually has a nominal operating line pressure of about 1000 psig. Compressor pressure ratios (and combustion pressures) for gas turbines used for electrical generation can range from 16:1 (235 psia) for our Solar Taurus units to 44:1 (647 psia) for General Electric's 100 MWLMS100 units.

Thus, the high-pressure natural gas supplied by a major pipeline allows fuel to be injected directly into a gas turbine combustor, without the need of a fuel gas boosting compressor unit. For instance, if UCONN was just supplied by a city natural gas pipeline (typically at 15 psig) it would require a separate fuel gas boosting unit, along with an expensive safety system to prevent and deal with a possible fire (or explosion). I estimate that such a compression unit would consume about 1 MW to boost city gas pressure fuel for injection into the Solar combustors, representing about a 4% reduction (from 25 MW) in available power for the campus. Connection to major natural gas pipelines is a definite advantage for a gas turbine power plant.

Natural gas, transported by pipelines, is being used to fuel record-breaking, thermally efficient gas turbine plants in the United States. The current result is more efficient electricity production and a significant reduction in the nation's carbon dioxide emissions.

1. Langston, Lee S., 2010, "A Bright Natural Gas Future", *Global Gas Turbine News, Mechanical Engineering Magazine*, February, p. 3.
2. U.S. Energy Information Administration, https://www.eia.gov/energyexplained/electricity/electricity-in-the-us.php
3. Ibid., https://www.eia.gov/todayinenergy/detail.php?id=44636.
4. Langston, Lee S., 2020, "Hits and Errors", *Mechanical Engineering Magazine*, June, pp. 46-51.
5. Langston, Lee S., 2019, "Gas Turbine Powered Campus Update", *Global Gas Turbine News, Mechanical Engineering Magazine*, May, pp. 46-48.
6. Smil, Vaclav, 2015, *Natural Gas: Fuel for the 21st Century*, Wiley, p.5.

Correction to GGTN September 2020's ATTT #43

Error in Equation (2) on page 55. The corrected equation is:

$$\eta = 1 - \frac{1}{\left(1 + ((\gamma - 1)/2)(M_o^2)\right)(PR)^{(\gamma-1)/\gamma}}$$

Another Gas Turbine Decarbonization Path:

ADDING ENERGY STORAGE TO THE COMBINED CYCLE

By William M. Conlon, *P.E. Ph.D., President, Pintail Power LLC*
and Milton J. Venetos, *Vice President, Pintail Power LLC*

The efficient natural gas Combined Cycle Power Plant (CCPP) has driven a substantial reduction in Greenhouse Gas (GHG) emissions, while gas turbine peaking plants also provide backup for variable renewable resources. As more wind and solar generation is added to grids around the world, there is a need for more flexible CCPPs with faster startup and ramping capability, storage of increasingly over-abundant renewable energy, and lower GHG emissions from dispatchable power plants. Novel integration of energy storage with the CCPP can meet these needs at lower cost than alternatives like batteries.

Renewable resources are so abundant in some places that after displacing fossil generation, the renewables must also be curtailed. For example, on April 21, 2019, before COVID related load reductions, the California Independent System Operator (CAISO) curtailed almost 32GWh of solar energy because generation exceeded demand. For both economic and environmental reasons, it is essential to store this otherwise curtailed energy for use when the natural variability of renewable resources demands backup from dispatchable generation. Each day, as solar production begins, the CAISO grid experiences a large and rapid drop in net load that forces combined cycle plants off-line. And as solar production wanes in the late afternoon, these plants must rapidly come back online. These two related grid operational issues – over-generation and renewable curtailment, and steep ramps in the load served by CAISO are phenomena that create the now famous "Duck Curve" [1] shown in Figure 1.

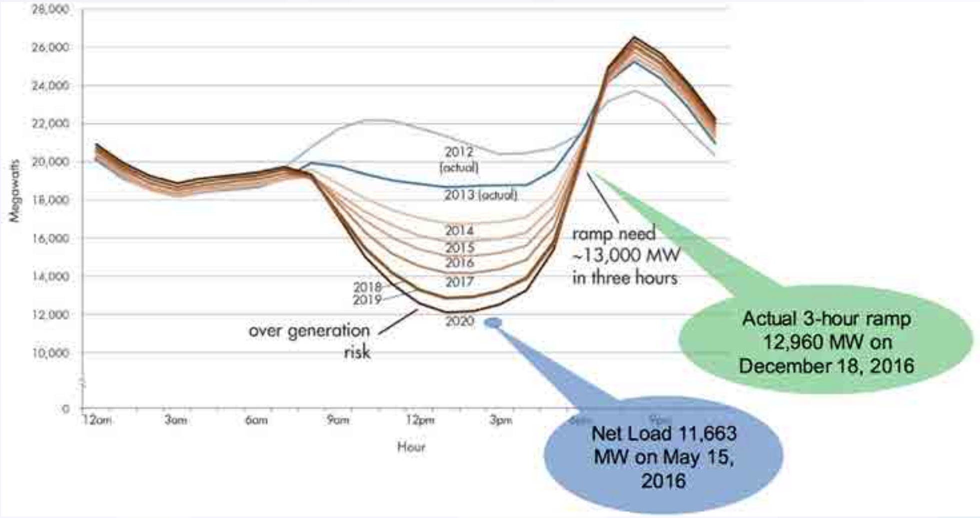
Two paths to the challenge of storing excess renewable energy for subsequent power generation were summarized by Dr. Lee Langston in the May 2020 issue of Global Gas Turbine News (GGTN) [2]:

- Using renewable energy to produce Hydrogen for use in modified gas turbine combustion systems, with technology development and demonstrations underway.
- Developing non-combustion energy storage systems with novel cycles and turbomachinery. Several R&D approaches use turbo-compressors for conversion of renewable to thermal energy for storage in various media, such as cryogenic liquids, hot molten salt, or packed beds.

GGTN readers know that development of novel turbomachinery is time-consuming, often entails new materials and manufacturing capabilities, and requires a large market to justify the substantial investment. Moreover, the novel cycles require development of heat transfer equipment with their own performance, materials, manufacturing, and cost challenges.

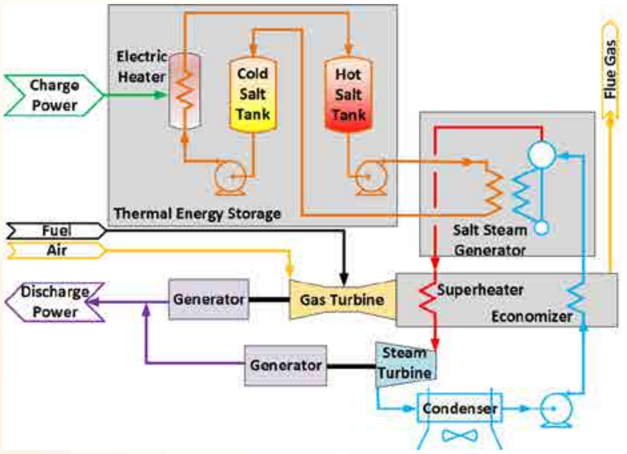
A third path avoids the cost, risk and time needed to develop new turbomachinery and heat transfer equipment:

Figure 1. CAISO Duck Curve Showing Changes in Net Load with Solar PV Energy Additions



modifying the familiar CCPP to incorporate proven two-tank molten salt thermal energy storage. This approach bridges renewable and conventional power, uses excess renewables to improve fuel efficiency and reduce emissions, is based on existing components at customary operating conditions, and leverages proven engineering, procurement and construction methods to deliver superior cost and performance.

Figure 2. Liquid Salt Combined Cycle Flow Diagram



The Liquid Salt Combined Cycle (LSCC) shown in Figure 2 integrates thermal energy storage with gas and steam turbines in a novel system that enables faster startup and improved plant fuel efficiency. By moving evaporative heating duty outside the exhaust heat recovery steam generator, this patented [3] arrangement removes heat transfer constraints to increase steam flow without increasing fuel flow. Steam is evaporated using energy stored in molten salt, while the gas turbine exhaust is used to preheat and then superheat the steam in a single pressure, non-reheat steam cycle. LSCC can be used with any gas turbine, including industrial, frame, and aeroderivatives, to boost output, reduce fuel heat rate and make efficient use of stored thermal energy [4].

Table 1

Net Ratings	**GE 7FA.04 Gas Turbine**		
	Simple Cycle	**Combined Cycle**	**Liquid Salt Combined Cycle**
Power *(kW)*	198,000	305,000	398,874
Fuel Heat Rate *(kJ/kWh)*	9324	6030	4364
Stored Energy Rate *(kJ/kWh)*	0	0	2396
Thermal Efficiency	38.6%	59.7%	53.25%

Table 1 compares the performance of a General Electric 7FA.04 gas turbine in simple cycle, combined cycle and LSCC configurations. By using stored energy, LSCC allows much higher steam flow and steam turbine power than in a triple-pressure reheat combined cycle. The stored energy reduces fuel consumption and GHGs per unit of electricity, as reflected in Fuel Heat Rate and Stored Energy Rate. Using stored energy to displace fuel is an effective GHG reduction strategy, even though overall LSCC thermal efficiency is somewhat lower than combined cycle.

To appreciate the LSCC steam cycle, it is important to realize that high steam temperature is needed primarily for managing moisture content at the steam turbine exhaust, rather than to improve efficiency as in gas turbines. By reserving high temperature exhaust for superheating, LSCC can use lower-temperature molten salt, compatible with carbon steel tanks and piping, to reduce cost. Integration of the gas turbine and its exhaust heat reduces the mass and volume of salt needed per MWh by 80% compared to parabolic trough or tower Concentrating Solar Power (CSP) plants.

Instead of heating salt with solar energy, LSCC uses inexpensive and flexible electric heaters, with >99% electric to thermal efficiency, to store low-cost or otherwise curtailed renewable energy. As loss rates are <1% per day, this energy can remain stored in the LSCC tank(s) for many days until needed. The salt is also non-toxic, non-flammable, and does not degrade with use, no matter how often the system is cycled, or how fast it is charged or discharged.

Stored energy can bring the LSCC steam cycle to readiness without using fuel, so startup and ramping to full power is rapid and fuel efficient with lower startup emissions. Flexibility is also provided by the charging system, which can rapidly add or drop load to compensate for variable wind and solar, and even provide frequency regulation using solid-state controls with sub-cycle response. Likewise, the LSCC generator could provide voltage regulation as a synchronous condenser by inserting an SSS clutch on the steam turbine shaft.

Gas turbines have been an integral part of decarbonization, facilitating the shift from coal to natural gas and providing the fast ramping required to back up variable renewables. By integrating energy storage into power plants, gas turbines will continue to perform an essential role in renewable integration and decarbonization. And as vendors develop combustion systems to fuel gas turbines with expensive hydrogen, the exceptionally low fuel Heat Rate afforded by LSCC will be appreciated by power plant operators and electricity customers.

1. CAISO 2016, "What the Duck Curve tells us about managing a green grid", http://www.caiso.com/Documents/UsingRenewablesToOperateLow-CarbonGrid.pdf
2. Langston, Lee, 2020, "As the Turbine Turns…the Decarbonization of Gas Turbine Power", *Global Gas Turbine News*, *Mechanical Engineering Magazine*. May pp 52-53.
3. Conlon, William, 2018, "Dispatchable Combined Cycle Power Plant," U.S. Patent 10,113,535.
4. Conlon, William, 2019, "Decarbonizing with Energy Storage Combined Cycles," *POWER Magazine*, December, pp 36-39.

ASME Gas Turbine Segment Appoints

NEW SEGMENT LEADER & WELCOMES NEW MEMBERS

Gas Turbine Segment Leadership Team

ASME Gas Turbine Segment is pleased to announce the appointment of **Mark Zelesky** (Pratt & Whitney) as the Gas Turbine Segment Leader for 2020-2021. In addition, the Gas Turbine Segment welcomes three new Segment Leadership Team members: **Nateri Madavan**, NASA; **Susan Scofield**, Siemens; and **Charles Soothill**, Sulzer.

Mark Zelesky
Senior Fellow Discipline Lead, *Thermal and Fluids Disciplines, Pratt & Whitney Aero*

Nateri Madavan
Deputy Director (acting) of the Integrated Aviation Systems Program, *NASA Aeronautics Research Mission Directorate (ARMD)*

Susan Scofield
Director of Project Management for New Business, *Siemens Energy, Inc.*

Charles Soothill
Head of Technology, *Sulzer Rotating Equipment Services*

ASME Gas Turbine Segment would like to thank the outgoing Segment Leadership Team Members for their participation and contribution to the organization.

Thank you to Segment Leader, **Nicole Key**, Purdue University, who will continue as a member on the SLT; Segment Members **Paul Garbett**, Siemens; **Eisaku Ito**, MHS; **Jaroslaw Szwedowicz**, Siemens; and advisors **Richard Dennis**, NETL, DOE; and **Ruben Del Rosario**, Crown Consulting.

Your dedication to the industry is greatly appreciated.

IGTI Executive Committee

ASME Gas Turbine Segment is also pleased to announce the members of the 2020-2021 IGTI Executive Committee led by the Executive Committee Chair, **Prof. Ricardo Martinez-Botas**, FREng, Imperial College London.

Ricardo Martinez-Botas, FREng
Professor of Turbomachinery, *Imperial College London, Mechanical Engineering*

Akin Keskin, PhD
Eng. Associate Fellow, *Design Systems, Rolls-Royce Civil Aerospace*

Damian Vogt, PhD MSc
Director, *Institute of Thermal Turbomachinery and Machinery Laboratory, University of Stuttgart*

Douglas Hofer, PhD
Senior Principal Engineer, *Aero Thermal Systems, GE Global Research*

Kenneth L. Suder, PhD
Senior Technologist, *Airbreathing Propulsion, Propulsion Division, Research and Engineering Directorate, NASA Glenn Research Center*

SUPPORTING THE IGTI COMMUNITY

The ASME IGTI Executive Committee and the ASME Gas Turbine Segment Leadership Team decided to establish a relief fund for TURBO EXPO organizers who were financially impacted by the COVID-19 pandemic. It was our intention to take care our "ASME Family" in a time that has challenged all of us globally. This resulted in 90 organizers being able to attend the virtual event at the special subsidized rate, and five organizers who faced unemployment or furlough who received complimentary subsidized registration.

We are thankful for all conference organizers who served as valued volunteers. **YOU are critical to the success of the ASME TURBO EXPO!** Our thoughts are with you, your families, and your colleagues during these difficult times. Please stay safe and healthy.