

# GLOBAL GAS TURBINE NEWS

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his inaugural 2-day symposium, now in its second edition, surpassed expectations in bringing together engineers, designers, repair professionals and business leaders at companies that design, manufacture, repair and own gas turbines.

Over 130 attendees from 11 countries (Afghanistan, Canada, Egypt, Ghana, India, Japan, South Africa, Sweden, Switzerland, United Kingdom, and the United States) and 59 different companies were able to network and exchange industry knowledge and best practices for advanced manufacturing and repair for gas turbines!

We would like to thank our platinum sponsor, Liburdi Turbine Services, our bronze OAM and Penn State, and our lanyard sponsor, ANSYS, for supporting this conference. We also recognize the AMRGT Organizing Committee for the wholehearted and selfless volunteer hours that they collectively dedicated toward the successful technical program of the conference.



# AS THE TURBINE TURNS...

#42 / MAY 2020 — THE DECARBONIZATION OF GAS TURBINE POWER

T

he gas turbine industry is facing the prospects of meeting proposed national and international targets for reducing carbon dioxide emissions and for the promotion of sustainable energy.

The evolving role of gas turbines to decarbonize the world's energy conversion systems has been the theme of articles in the Global Gas Turbine News (GGTN) in the last three issues, in September 2019, December 2019, and March 2020.

At the request of the GGTN Editorial Board, I have been asked to briefly summarize some of the highlights of the five articles that dealt with this critical issue of decarbonization of gas turbine electrical power.

## Decarbonization Highlights

In GGTN's September issue, Wegel and Baron [1] of EUTurbines considered that the bulk of future European electricity will be generated with variable wind and sun, requiring a growing need for system flexibility. That flexibility could be based on dispatchable decarbonized gas turbine power. Decarbonization would be achieved using gas

turbine technology with renewable gases, focusing strongly on hydrogen, either stored or blended into natural gas as a fuel. Financial support will be needed for this conversion to renewable gases.

GGTN's December issue featured an article by Bothien and Ciani [2] of Ansaldo Energia in Switzerland. They present experimental results and data showing that an existing gas turbine combustion system can handle mixtures of natural gas and hydrogen over a wide range. They show how the full range of 0 – 100 percent hydrogen can be burned in a low-NO<sub>x</sub> premix system without implementing any changes to standard hardware in their GT36 and GT26 gas turbines.

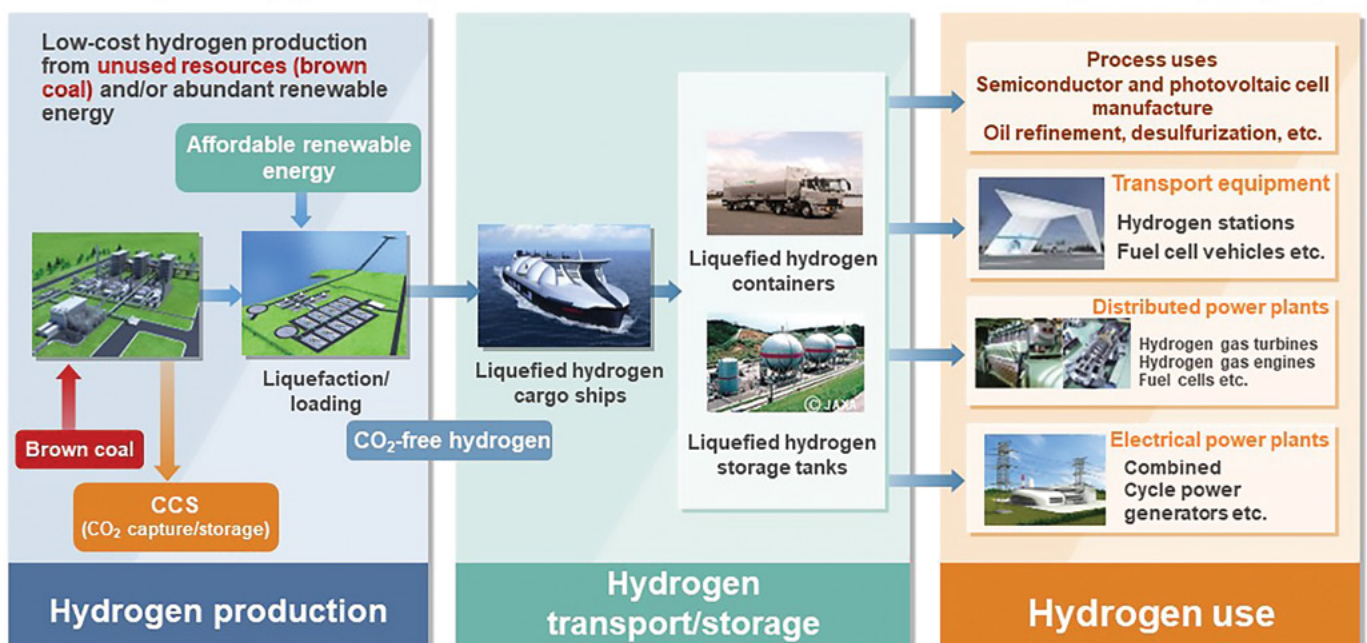
While [1] and [2] highlight European decarbonization activities involving hydrogen-fueled gas turbines, [3] and [4] deal with the extensive work going on in Japan on this topic.

Reporting on Mitsubishi Hitachi Power Systems (MHI) hydrogen-fired gas turbine development in GGTN's March issue, Nakamura [3] describes a new combustor that was developed to minimize the occurrence of flashback, that can typically be induced during hydrogen co-firing. MHI successfully passed a firing test using 30 percent hydrogen

## Hydrogen chain with near zero CO<sub>2</sub> emission

### Resourcing country (Australia)

### Utilizing country (Japan)



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mix in volume, resulting in a 10 percent reduction in CO<sub>2</sub> emissions. European and Japanese decarbonization efforts are being combined, with MHI converting a 440 MW natural gas fired combined cycle gas turbine plant in the Netherlands, to 100 percent hydrogen by 2025.

Also included in the GGTN March issue was an article by Nishimura [4] of Kawasaki Heavy Industries on Japan's hydrogen energy supply chain for decarbonization. Japan, the world's third largest economy, has few domestic sources of primary energy. In 2011-2014 the Hydrogen Society Plan was developed by the government, resulting in the world's first hydrogen energy supply chain pilot project between Australia and Japan.

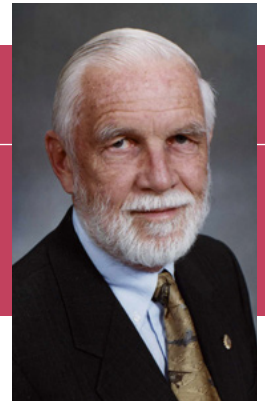
Nishimura [4] points out that half of the world's total coal resources are in the form of brown coal (lignite). It's limited to on-site applications, since it can ignite spontaneously on contact with air. Victoria, Australia has extensive brown coal resources in its Latrobe Valley. Work has started on an A\$500 million pilot project there to turn this brown coal into hydrogen for liquefaction, to be shipped from Port Hastings, Victoria, 9000 km, to the Port of Kobe, Japan, in Kawasaki LH2 tankers. The CO<sub>2</sub> resulting from the brown coal used to produce the hydrogen will be sequestered in deep underground offshore storage sites in the Bass Strait, separating Australia and Tasmania.

Kawasaki has developed a pure hydrogen fueled Dry Low NO<sub>x</sub> combustor for their 1 MW electric power gas turbines. These will be used in a cogeneration plant on Kobe Port Island.

Finally, in GGTN's December issue, Allison [5] reports on the need for grid-scale energy storage technologies to cost-effectively store energy during periods of high renewable generation and discharge power when wind and solar renewables drop off. He points out that the success of machinery-based energy storage systems require the development of application-specific turbomachinery to meet transient response requirements with high round-trip efficiency at low cost.

*By Lee S. Langston*

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## *Summary*

The five GGTN articles highlighted here present state-of-the-art information on the evolving role of gas turbines to decarbonize energy conversion systems. It is apparent that efforts in Europe and Japan to use hydrogen as a renewable, CO<sub>2</sub>-free fuel for gas turbines are well advanced. (History shows that hydrogen was first used as the fuel for Hans von Ohain's very first jet engine in Germany in 1937 [6].) Gas turbines should play a key role in decarbonization through their use in grid storage technologies. One expert in this area has recently written me that new gas turbine heat storage concepts are multiplying like rabbits, and we should see all sorts of combinations being proposed in the next five years. Stay tuned! ♦

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# HYBRID ELECTRIC PROPULSION

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RESEARCH CENTER

*This article is part of an ongoing decarbonization series (see the Sept 2019 issue for details).*

## Architectural Design Space and Potential Benefits

### ABSTRACT

Electrified propulsion holds the promise of reducing aviation's CO<sub>2</sub> emissions footprint through three means: access to green grid electric energy, improvements in aircraft performance through new airframe and propulsion system architectures and enabling further optimization of the gas turbine cycle. Charging an aircraft battery pack with green electric energy and using this energy to drive electric propulsors results in a zero emissions vehicle. This is practical for light aircraft and short missions. Boosting a Jet-A burning gas turbine with green electric energy (again stored in a ground charged battery), in either a parallel or series turbo-electric architecture can yield a net reduction in CO<sub>2</sub> emissions, as long as the fuel burn required to carry the weight of a discharged battery pack does not overcome the reduction in fuel burn afforded by the ground charged battery. Several studies have indicated that a net savings is possible with cell level energy densities approach ~ 500 whr/kg, a reasonable target for the 2030 time frame. Electrified propulsion can also enable unique aircraft configurations, employing a very high efficiency prime mover (gas turbine) designed for running only a generator at peak efficiency, and/or distributing the propulsors throughout the aircraft, for improvement in L/D and propulsive efficiency.

Airliners (aircraft of > 100 pax), consume over 90 percent of aviation fuel [1]. Absent a major shift from the hub and spoke system, efforts to reduced aviation's emissions footprint must focus on airliners. Carbon-neutral liquid fuels (CNLF [2]) are clearly one pathway to lowering emissions, thus efforts to develop CNLF production methods should clearly continue. Improvement in aircraft performance, both airframe and propulsion system represent the other major pathway to reduced emission. Further advancements in gas turbine (GT) technology will continue to provide GT performance improvements. In addition, with recent improvements in electric machine performance (weight and efficiency), propulsion system electrification could provide aircraft performance improvements beyond what is possible with conventional GT technology.

Airliner propulsion electrification architectures have been extensively studied within the aviation research community. Figure 1 provides the continuum from

the conventional gas turbine (GT) to the battery all-electric. Between these two extremes lies the series turbo-electric, the partial turbo-electric and the parallel hybrid. In the series turbo-electric, a prime mover converts fuel energy to electric power to drive a set of electric propulsors. A battery may be included for peak shaving or access to green grid energy. With the partial turbo-electric, the GTs provide propulsive thrust and electric power to drive a set of auxiliary electric propulsors. A battery may also be included. Finally the parallel hybrid integrates an electric machine onto the GT fan drive shaft with the electric power sourced by a battery charged with (green) grid energy.

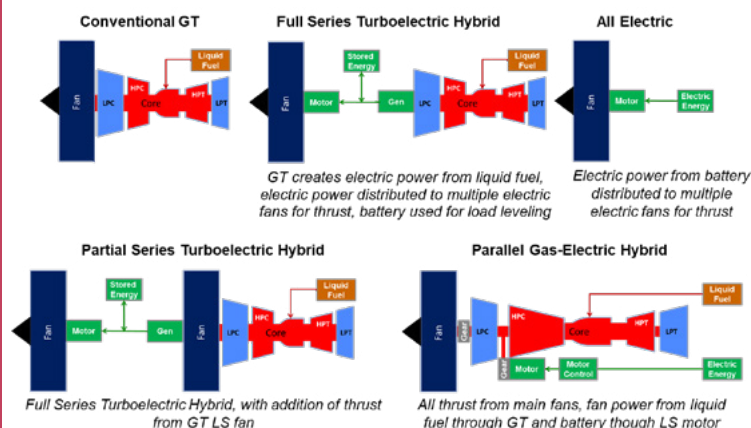


Figure 1. Electrified Propulsion Architectures

Some aircraft concepts that have emerged based on these propulsion system architectures are provided in Figure 2. The upper left Boeing SUGAR-VOLT employs a parallel hybrid propulsion system, injecting battery energy during cruise to decrease Jet-A consumption. The upper right Airbus E-Thrust employs six distributed over-wing electric propulsors, sourced by a turbo-generator and battery pack, that ingest the aircraft boundary layer for improved aircraft performance. The bottom left partial series turbo-electric NASA STARC-ABL leverages a tail boundary layer-ingesting electric fan, driven by electric generators on the two main underwing GT propulsors. Finally the bottom right battery electric NASA X57 employs distributed blown-wing electric propellers enabling a smaller wing and maximum power reduction.

### Battery All-Electric

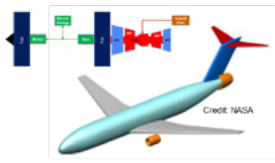
The X57 offers a battery electric configuration example. Small, low passenger-count aircraft have been shown to



Parallel Gas-Electric Hybrid



Full Series Turboelectric Hybrid



Partial Series Turboelectric Hybrid



Electric

be feasible at short range with battery energy densities achievable in the next five years (~ 300 whr/kg, packaged) [3]. However, multiple studies have shown that all-battery electric flight for airliner aircraft is not feasible [4] at current battery energy density. At 500 to 1000 whr/kg an airliner may be able to reach ranges of ~ 300 nm, but the demand for such a range-limited aircraft is unclear. Improvements in battery cell and pack specific energy will help. Current packaged battery energy density is approaching ~ 250 whr/kg, there is general agreement that 400 whr/kg (packaged) is possible in 5-10 years, and while the theoretical energy density of some chemistries reaches almost 3000 whr/kg, the path to a practical battery at > 500 whr/kg [5] is challenging.

## Parallel Hybrid

Green grid energy can be accessed, without full electrification, through the parallel hybrid, where battery energy is used to inject power into a GT during some operating points. With power coming from an alternate source, less Jet-A is needed to make the same thrust. However the parallel architecture adds electric component weight to the system, thus more thrust is required at any given mission point. The parallel hybrid architecture may provide an energy decrease or increase depending on these two opposing effects. Four single aisle aircraft studies illustrate the range of results. The Boeing SUGAR study [6] of augmented takeoff and cruise operation predicts a 20 percent Jet-A reduction but a 17 percent energy consumption increase. UTRC explored a core sized for cruise [7], predicting a 6 percent Jet-A reduction and a 2 percent energy consumption increase. A Rolls Royce study [8]

considering fleet operations, showed a 20 percent Jet-A and 10 percent energy reduction for the short (<300 nm) missions. Finally, NASA has studied use of electric machines for GT stability control [9], showing significant efficiency improvements could be realized.

## Series Turboelectric

As described above, even with unknown battery technology approaching 1000 whr/kg, batteries can't provide the energy density necessary to enable an all-electric airliner with meaningful range. A GT based turbo-generator burning Jet-A however, easily achieving > 1500 whr/kg (2-hour cruise) to 3000 whr/kg (5-hour cruise), could feasibly provide the electric power for an electric propulsion system. However, with an electric drive train (EDT) of generators, distribution cable, motor drives and motors between the GT and the propulsors, such a propulsion system would be heavier and less efficient than a conventional underwing GT propulsion system and thus result in increased fuel burn and CO<sub>2</sub> emissions. The series electric propulsion system cannot provide a benefit by simply replacing conventional GTs on a conventional tube and wing aircraft with a conventional GT driving an EDT with two underwing electric propulsors. The prime mover thermal efficiency must be improved through cycle improvements and/or the electric propulsors must enable an aircraft level performance benefit through propulsion airframe integration that overcomes the EDT weight increase and efficiency decrease. A parametric analysis of EDT specific power and efficiency required to provide a fuel burn reduction with assumed benefits of propulsion airframe integration has been conducted by NASA [11, 12]. This study shows a partial series turboelectric like the NASA STAC-ABL could provide a fuel burn benefit with near term realizable EDT efficiency of 80 percent at 4 kW/kg specific power.

## Conclusion

There is potential for reducing airliner emissions through aircraft electrification, with the parallel hybrid showing the most mid-term promise and the partial turboelectric incorporated on an advanced airframe showing longer term promise. However, there is a large design space that has only been cursorily described above. A survey study executed Isikveren [12] provides a good review of the design space, and introduces the degree of energy and degree of power electrification parameters in describing this design space.

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## *ASME IGTI Dilip R. Ballal Early Career Award*

Nomination packets are due to ASME on or before August 1. Send complete nomination to: [igtiawards@asme.org](mailto:igtiawards@asme.org)

A nomination package should include the following:

- A. A paragraph (less than 50 words) from the nominator highlighting nominee's contributions
- B. Nomination letter
- C. Two supporting letters
- D. Current resume of the nominee

## *ASME IGTI Aircraft Engine Technology Award*

Nominating and supporting letters for the Aircraft Engine Technology Award should be sent by October 15 to: [igtiawards@asme.org](mailto:igtiawards@asme.org)

Nominating letters should contain all information on the nominee's relevant qualifications. The Award Committee will not solicit or consider materials other than those described below. The selection committee will hold nominations active for a period of three years. A minimum of two supporting letters from individuals, other than the nominator, must accompany the nominating letter. Supporting letters should reflect peer recognition of the nominee's breadth of experience with various aspects of industrial gas turbine technology.

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The nomination must be complete and accompanied by three to five Letters of Recommendation from individuals who are well acquainted with the nominees' qualifications. Candidate nominations remain in effect for three years and are automatically carried over. The completed reference form from a minimum of 3 people will need to be sent in with the nomination package. It is up to the "Nominator" to submit all required information.

## *ASME IGTI Industrial Gas Turbine Technology Award*

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