APR '25 / MAY '25

VOL. 66 NO. 1

GLOBAL GAS TURBINE NEWS

IN THIS ISSUE...

AMERICAN SOCIETY OF MECHANICAL ENGINEERS (ASME)

ASME Gas Turbine Technology Group / 11757 Katy Frwy, Suite 1500 Houston, Texas 77079 / go.asme.org/igti

Sun Machines and Gas Turbines

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Solar photovoltaic (PV) cells were developed by AT&T's Bell Telephone Laboratories in 1954, for turning sunlight directly into electrical power. Over the ensuing 70 plus years, commercial PV cell thermal efficiency has been markedly increased to the current low 20% range, and their manufacture continues to become increasing cheaper.

Currently, world annual production (mostly in China) is of the order of 70 billion solar PV cells. Each PV cell is about human hand-sized (half a foot or 15 cm square), usually composed of a layer of semiconductor silicon, sandwiched between two panes of glass. These raw materials are readily available. Silicon is the Earth's second most abundant material, and the glass is made from sand. This is in sharp contrast to the vast host of materials (some hard to get, like rhenium for single crystal turbine blades) necessary to produce a gas turbine.

Most of us are increasingly aware that sunward-facing panels composed of PV cells are being installed in many locations in the world. The US Energy Information Administration (EIA) reports that in 2023, about 4% of the US electricity generated was from PV cell installations, such as shown in Figure 1. According to recent published literature, that amount is going to increase drastically in the very near future.

RECENT SOLAR PV CELL LITERATURE

In 2022, Rupert Way, et al. [1] of Oxford University's Joule Program published a paper, seeking to see what could happen if the costs of PV solar cells and other renewable electrical sources continue to fall with increased development, follow-

Figure 1. A 20 MW capacity "Sun Machine" solar farm is shown in foreground, associated with the background 585 MW gas turbine combined cycle power plant at the Silverhawk Generating Station, in Las Vegas, Nevada [5].

ing their past demonstrative performance. Under their “fast transition scenario” a key finding is that a swift transition to renewables is likely to lead to substantial net economic savings, even when compared to a scenario where fossil fuels remain dominant.

In 2024, The Economist [2] featured and added to Oxford’s Joule study in a June 22nd cover essay, focusing on PV solar power, and stating that PV solar cells eventually will most likely become the largest source of electricity on our planet.

Figure 2, taken from the essay [2], shows how market forces can drive global adoption of energy systems, such as PV solar power, to decarbonize electrical production. The Economist [2] reports that the extraordinary growth stems from three simple factors: “When industries make more of something, they make it more cheaply. When things get cheaper, demand for them grows. When demand grows, more is made. In the case of solar power, demand was created and sustained by subsidies early this century for long enough that falling prices became noteworthy and, soon afterwards, predictable. The positive feedback that drives exponential growth took off on a global scale.”

The Economist continues: “And it shows no signs of stopping, or even slowing down. Buying and installing solar panels is currently the largest single category of investment in electricity generation, according to the International Energy Agency (IEA), an intergovernmental think-tank: it expects $500 billion this year, not far short of the sum being put into upstream oil and gas. Installed capacity is doubling every three years. According to the International Solar Energy Society, solar power is on track to generate more electricity than all the world’s nuclear power plants in 2026, than its wind turbines in 2027, than its dams in 2028, its gas-fired power plants in 2030 and its coal-fired ones in 2032. In an IEA scenario which provides net-zero carbon-dioxide emissions by the middle of the century, solar energy becomes humankind’s largest source of primary energy—not just electricity—by the 2040s.” [2].

The predictions of PV solar dominance seem to be gaining confirmational momentum. The New York Times [3] reported that Texas, the US’s biggest oil-producing state has turned to solar power and battery storage. In the summer of 2023, Texas’s independent and isolated electric power grid (ERCOT) reached a record level of demand. It successfully met it, largely through the substantial expansion of new solar PV cell panel fields. Texas, which has already surpassed California in the amount of electrical power coming from large scale solar farms, is expected to gain on its West Coast rival in battery storage as well.

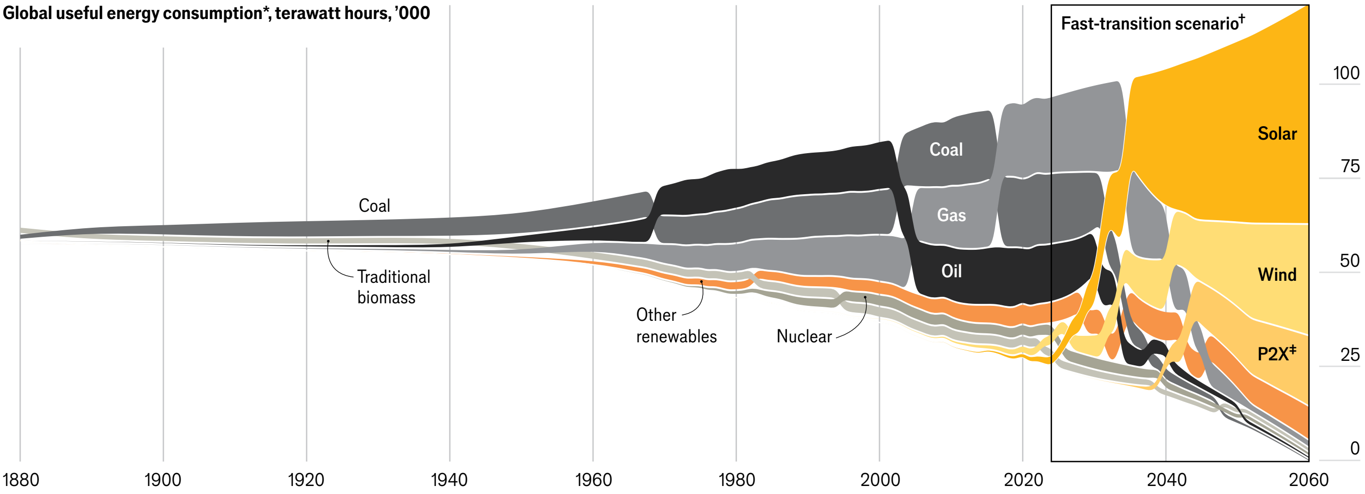
WHERE DO GAS TURBINES FIT IN?

Where do electric power gas turbines fit into the predicted energy future, dominated by solar PV cell electricity? The answer is, of course, obvious: When the daily sun doesn’t shine on solar cells, demanded electric power could come from the storage of surplus solar generated electricity (e.g., batteries), hydropower plants, wind turbines (when the wind blows), not easily turn-on-able nuclear power plants, and from the most readily available and easily turn-on-able electric power plants, those having gas turbines as their prime mover.

Gas turbine electrical power plants (including the highly thermally efficient combined cycle plants (see one in the background of Figure 1), which currently reach as high as 64% [4]) already exist in great numbers. In the US, the EIA reports that in 2023, 43% of the electricity was generated from natural gas, mostly in just over 2000 gas turbine driven power plants.

As the authoritative current Gas Turbine World Handbook [4] points out, existing and future electric power gas turbine can be modified to combust hydrogen, resulting in a carbon free exhaust. As part of an energy transition to eliminate greenhouse

↓ **HERE COMES THE SUN** *the past and a possible future*



Sources: Rupert Way; Our World in Data *Primary energy adjusted for waste-heat losses †From Way et al. (2022) ‡Electricity-conversion technologies (eg, green hydrogen)

Figure 2. Global Energy Consumption as a Function of Calendar Year, from Various Energy Sources [2].

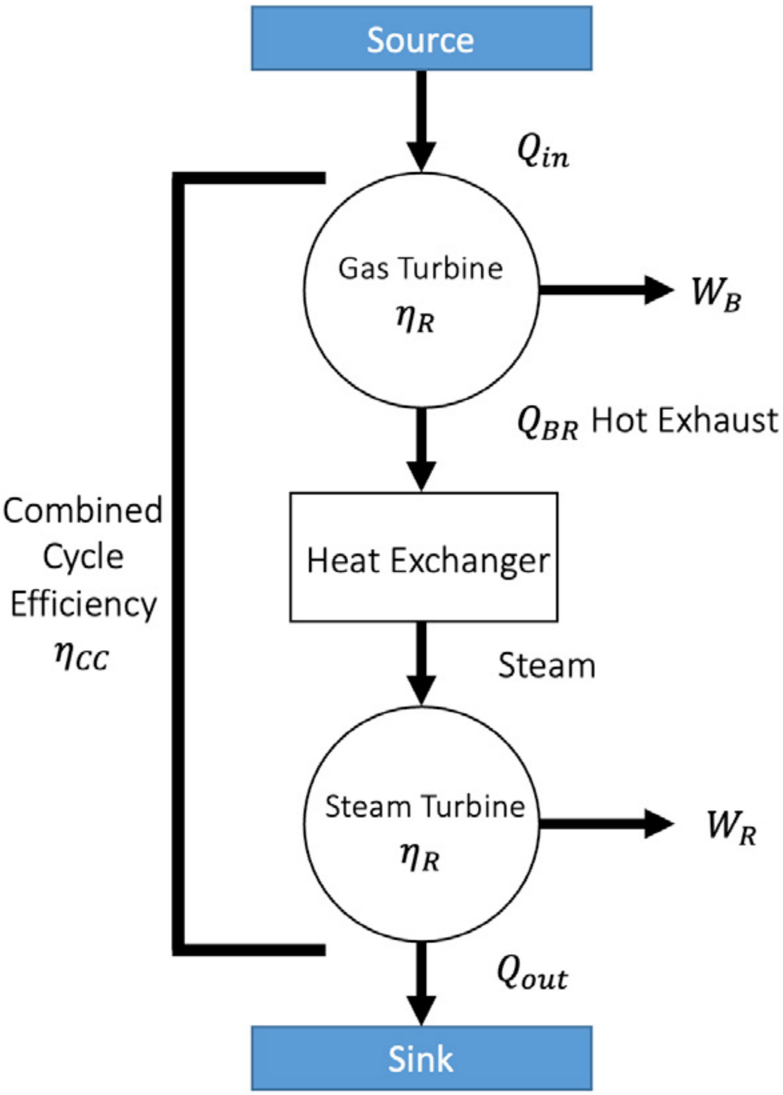


Figure 3. Schematic for a combined cycle gas turbine Powerplant.

exhaust gases, many gas turbine designs have been modified to operate on natural gas blends of up to 50% hydrogen (by volume) to reduce carbon emissions. In anticipation of large-scale hydrogen production (say, from electrolysis of water from surplus solar PV electricity), almost every gas turbine OEM in the industry is working on advanced combustion technology that by 2030 can burn 100% hydrogen for carbon-free electric power generation.

At the same time, GTW [4] reports that gas turbine OEMs and electric utilities, with government support, are developing and demonstrating post-combustion carbon capture and storage technology for retrofit and new natural gas burning gas turbine power plant application.

A BRIGHT SUNLIT FUTURE

The “sun machines”, world-wide installations of PV solar cell panels, look to be major contributors to the world’s increasing demand for electrical power. When the sun doesn’t shine, gas turbines should continue to provide a major part of the planet’s need for that electrical power. ◆

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Ecological Evaluation of Turbomachinery Component Manufacturing

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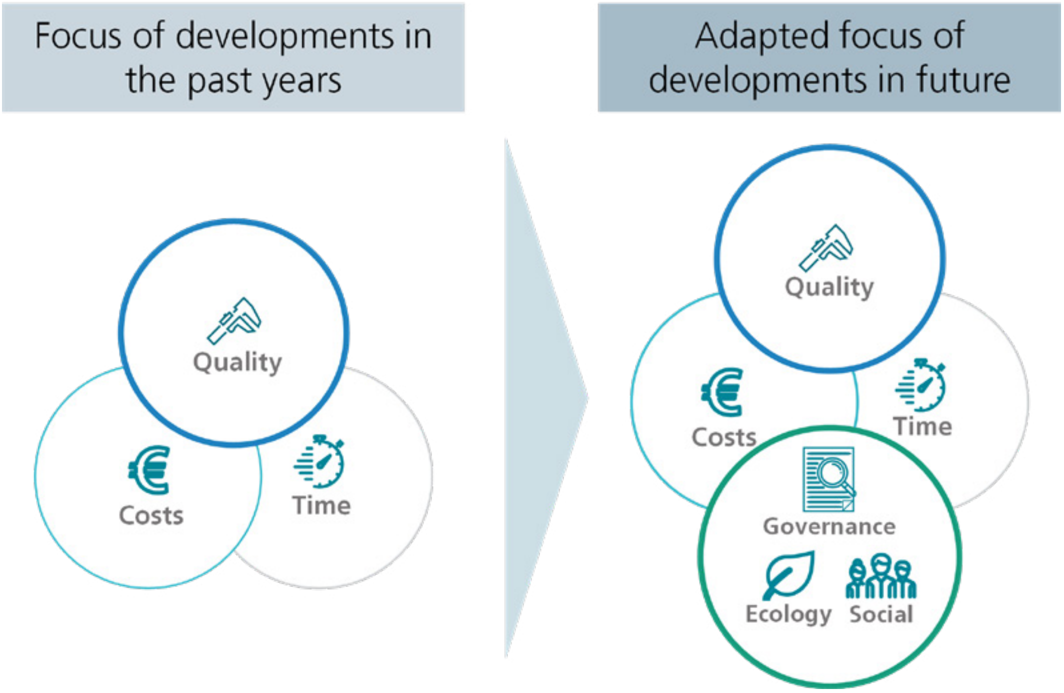

Figure 1. "Adapted" approach of taking decisions in manufacturing.

The demand for sustainable solutions in turbomachinery has significantly increased in recent years, focusing on the use phase, with developments in alternative combustion gases or fuels like hydrogen and sustainable aviation fuels (SAFs), as well as on more sustainable manufacturing of turbomachinery components [1; 2]. The energy consumption and emissions in production initially seem low compared to the high consumption during engine operation. However, the non-linear interactions of production on the user cycle should not be neglected. In addition, upstream and downstream processes of production, such as the manufacture of tools and machines, must be considered for a holistic picture [3]. The Paris Climate Agreement of 2015, the Green New Deal of 2019 and the European Climate Pact of 2020 are major initiatives that are advancing sustainability in society and industry. These frameworks set standards that aim to significantly reduce global resource consumption and emissions, thereby promoting more sustainable products and production processes [4]. The objectives of Flightpath 2050 relative to a reference engine from the year 2000 are: 75 % reduction of CO_2 emissions per passenger kilometer, 90 % reduction of NOx emissions per passenger kilometer and 65 % reduction of noise emissions [5].

Manufacturing is one of the keys for enabling aircraft engines and stationary turbomachinery to be more efficient. The above addressed requirements, combined with a shortage and lack of availability of certain goods such as materials (e.g. Nickel), have led to a shift in thinking and decision-making away from the "traditional" way primarily based on quality, cost, and time towards an "adapted" approach (see Figure 1) to highly sustainability-related decisions and developments, which leads to a turning point and opens new fields of solutions.

Today, new developments not only have to exhibit a better trade off in terms of costs and time but also need to contribute to reduce resource demands or emissions. Of course, in all cases “quality” is not negotiable within turbomachinery manufacturing and especially in aircraft engine manufacturing as safety is of highest priority.

In the turbomachinery industry, a comprehensive understanding of environmental impacts throughout the lifecycle, including materials, processes, and manufacturing, is crucial. Increasing the efficiency of turbomachinery is key to improving the sustainability of future aircraft engines, but this also significantly increases the complexity of manufacturing solutions. The manufacture of future aircraft engine components faces new challenges due to higher technological requirements, such as increased component complexity and use of more difficult-to-process materials, while at the same time meeting stringent sustainability requirements. One key to overcoming these challenges is the consistent digitalization of the entire value chain, from raw material extraction to recycling. Transparency in terms of resource consumption, emissions, and Global Warming Potential (GWP) can be achieved by collecting data in the digital twin. The digital twin structures use data over the entire life cycle of a product, making an important contribution to sustainable production and strengthening a company’s resilience[3; 6].

To improve the sustainability in turbomachinery, areas where energy or resources are used inefficiently and where production waste can be reduced or material recycling improved need to be identified and addressed. Immediate opportunities for energy savings include eliminating inefficiencies such as unnecessary standby times of machine tools or leaks in the compressed air supply. Beyond these simple improvements, there is further potential in the manufacturing processes themselves. Key factors such as tool materials, cooling lubricant composition, tool maintenance intervals and process design should be thoroughly evaluated. For example, improving process stability can make a significant contribution to conserving tool resources[3].

The main objective is to identify and exploit these opportunities across the entire value and production chain. Life Cycle Assessment (LCA) is an effective method for recording energy consumption and emissions[7]. The DIN EN ISO 14040/14044[8; 9] is the recognized standard for assessing the environmental impacts of product systems[10]. This standard describes a methodology for “recording and evaluating the inputs, outputs and potential environmental impacts of a product system throughout its entire life cycle”[9]. An LCA based on ISO 14040/44 consists of the following phases: target and scope definition, life cycle inventory, life cycle impact assessment and interpretation. It provides a transparent representation of the entire life cycle of a product or component and offers a comprehensive perspective on resource consumption and emissions by quantifying key figures such as Global Warming Potential, ecotoxicity, land use and water consumption. Therefore, the LCA goes far beyond the simple determination of the CO_2 footprint[3].

The Life Cycle Inventory (LCI) is essential for conducting a valid life cycle assessment. Combined with data collection to create a digital twin, it provides transparency over the entire product life cycle, even across company boundaries. The quality of the LCI data, which includes the inputs and outputs of each process step, including mass and energy flows, is critical, especially if the data is not captured internally[11]. Current databases lack the necessary granularity for accurate LCA in production environments, making the integration of production related LCI data an important task. In addition, the data must be up to date, as the recycling rates of materials such as aluminum

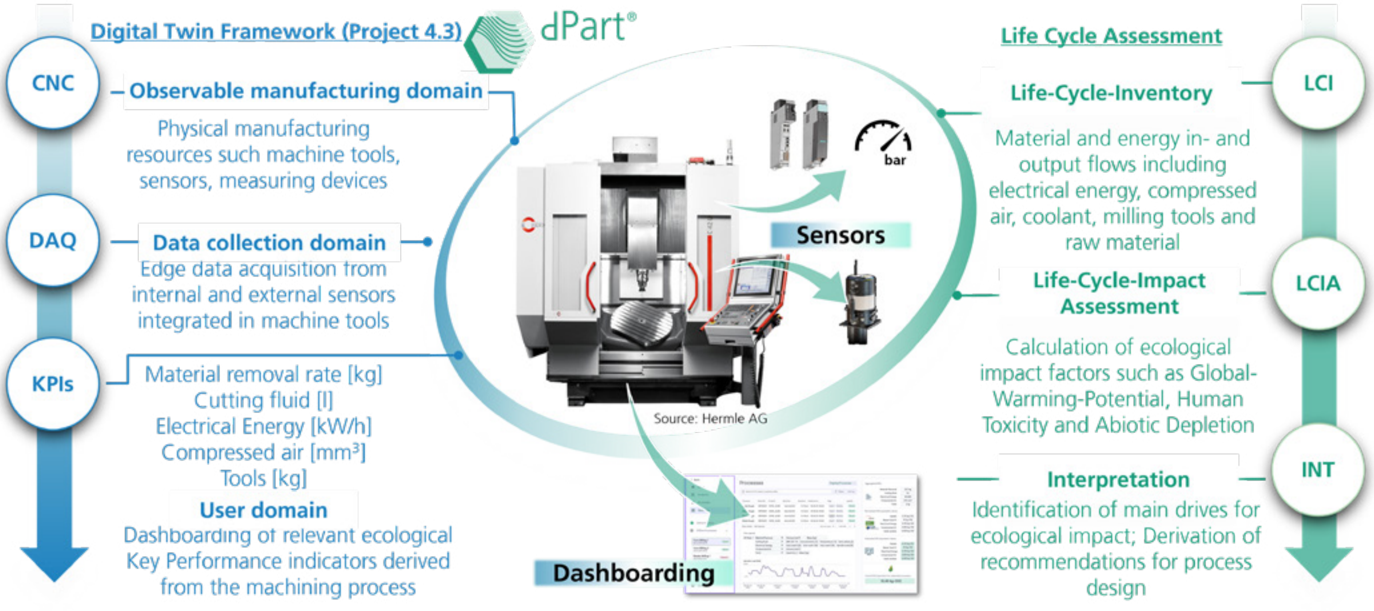

Figure 2. Life Cycle Assessment (LCA) Steps combined with Digital Twin Framework.

can fluctuate significantly over time. The digital twin as a virtual representative of the physical component enables an ecologically balanced objective and transparent representation of the life cycle [3].

In initiatives like Clean Sky 2 and the ICTM International Center for Turbomachinery Manufacturing in Aachen, the Fraunhofer Institute for Production Technology (IPT) conducts research on the manufacturing of various aircraft engine components using different materials and machining methods. The investigations focus amongst others on evaluating the environmental impact and efficiency of these advanced manufacturing techniques.

In addition, the dPart framework, developed at Fraunhofer IPT, enables to design a comprehensive LCI-data dashboard concept for machining processes. It offers a digital twin framework tailored for the machining domain, representing a domain-specific implementation of a big data lambda architecture [12]. Initially, the basic input and output flows for general manufacturing processes and the corresponding sensor environment were established. The proposed LCI data acquisition method evaluates multiple material and energy flows for each machining operation, based on the acquired process data and material removal simulations, such as the amount of material removed from the workpiece and electrical energy consumption. Figure 2 illustrates the overall process, the sensor environment, and the integration with the digital twin framework.

One of the objectives of the Clean Sky 2 initiative was to improve sustainability during production phase. This included comparing the resource consumption and environmental impact of different machining strategies and production processes. The use of ceramic milling tools and bondless PCBN (polycrystalline cubic boron nitride) tools reduced the environmental footprint by around 20% compared to conventional tools for the investigated use case, as they are more durable and efficient and therefore consume less energy and produce less waste. In addition, studies on additive manufacturing have shown that the ecological footprint can be reduced by up to 30 % compared to conventional processes, as less material waste is generated, and the production techniques are more precise.

Overall, the Fraunhofer IPT's research underscores the significant environmental benefits achievable through advanced machining strategies in the turbomachinery industry. These findings contribute to more sustainable and efficient production practices in the manufacturing of aircraft engine components. ◆

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The Case for Hydrogen for High-Volume Air Travel

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Dr. Simon Evans, Advanced Concepts, *Pratt & Whitney*

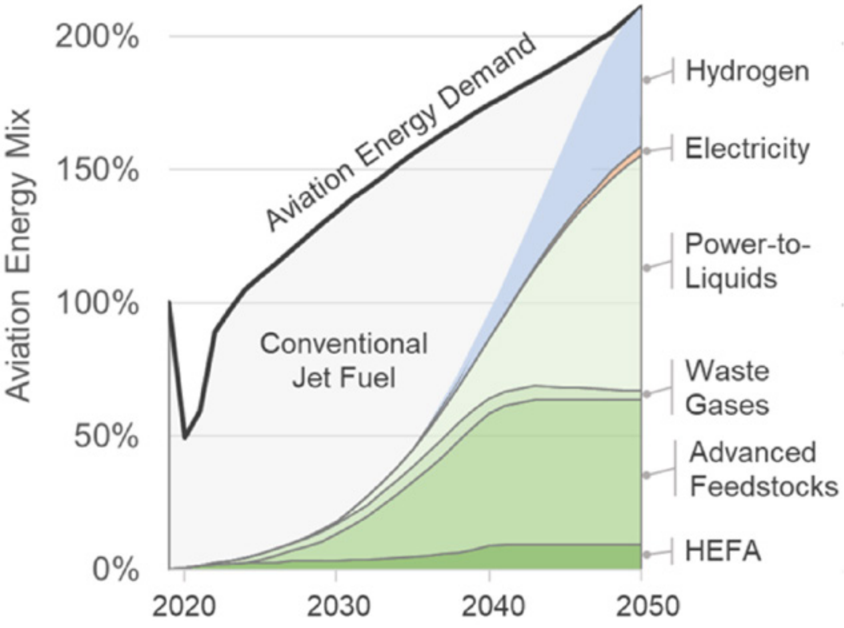

Figure 1. Aviation energy mix with anticipated aviation growth[1].

The aviation industry accounts for approximately 2.5% of global CO_2 emissions today but could contribute a greater fraction by 2050 due, in part, to the estimated increase in customer demand for global air travel [1]. Current and near-term aircraft that will remain in the skies for decades are designed around the combustion of kerosene. Conventional jet fuels contain fossil-based carbon that is released during the aircraft engine combustion process and through the extraction, refining, and delivery of these fuels. However, synthetic aviation fuels (SAF) offer great potential as near carbon-neutral sources of energy over their life cycle. Widespread production, distribution, and uptake of SAFs that are drop-in compatible with existing aircraft technology and fueling infrastructure would accelerate aviation decarbonization. However, the worldwide demand for jet fuel is likely to exceed the scalable production of SAFs derived from waste oils, fats, and greases via the Hydro-processed Esters & Fatty Acids (HEFA) technology pathway, as shown in Figure 1. Additional energy carriers combined with bio-derived SAFs from advanced feedstocks, such as agricultural waste and municipal solid waste, will be needed to fully offset the use of petroleum-derived jet fuels by 2050.

Alternatives to bio-derived jet fuel pathways include electro-fuels, also known as Power-to-Liquid (PtL) fuels. They are produced by extracting CO_2 from the air using direct air capture, separating hydrogen from oxygen in water using electrolysis powered by green electricity, and combining the carbon and hydrogen atoms via a Fischer-Tropsch process to create a liquid hydrocarbon fuel. However, the electro-fuel production process is energy-intensive, with 2050 estimates suggesting the need for 1.9 kJ of electrical energy input to generate 1 kJ of fuel energy [2]. The need for hydrogen as a precursor begs the question as to whether burning that hydrogen in an aircraft engine would be more efficient from an energy use perspective.

THE ATTRACTION

Key players in the commercial aviation industry have been investing in technology to enable hydrogen as an aviation energy carrier since at least 2020. With no carbon atom, combustion of hydrogen produces no CO_2, nor does it produce any particulates at the ground, which are known to affect the health of people living around airports. Hydrogen also carries approximately 75% more energy per kg than kerosene, making it an attractive fuel. However, due to the low density of gaseous hydrogen, it needs to be carried in its liquid form (LH2). Hydrogen condenses at -423°F (20K) at atmospheric pressure, making it energy intensive to liquify. However, to generate LH2 with 1 kJ of chemical energy, the electrolysis and liquefaction process requires 21% less energy than it takes to produce 1kJ of PtL SAF.

THE CHALLENGE

Due to the low boiling point of hydrogen, it must be stored in insulated or refrigerated tanks with a system in place to limit boil off. These constraints limit storage on an aircraft to cylindrical or near-cylindrical tanks in the fuselage rather than the wing. For a fixed range and passenger load, this incurs a weight and drag penalty compared with the traditional wet wings used for kerosene and SAF. Even assuming aggressive tank technology that might be mature by the time hydrogen enters the single-aisle market, that penalty is unlikely to be lower than a 15% thrust penalty. Although gaseous hydrogen is operational in trains in Germany today [4], LH2 introduces specific challenges to the fuel system and refueling operations. Outside the aircraft, additional challenges exist in the infrastructure needed to make a second fuel available at airports, on top of the specific challenges associated with LH2. These challenges are being worked by various organizations.

The vast quantity of green hydrogen production needed to support the anticipated growth in aviation demand, even assuming bio-derived SAFs are produced at scale, is a further challenge. However, in the head-to-head comparison between LH2 and PtL SAF, it must be recognized that this hydrogen must be produced either way, whether it is turned into PtL SAF or liquified and burned directly. The key research question then becomes: in which scenario is less hydrogen needed? The desire is that this hydrogen is green hydrogen, i.e. hydrogen generated from electrolysis using green electricity. This is in contrast to most hydrogen produced today, which is either grey, produced by steam methane reforming of natural gas; or brown, produced using coal or lignite. Assuming green hydrogen, the research question changes slightly: in which scenario is less green electricity needed? The energy use comparison therefore drives the economics of the decision. Based on the increased energy content and reduced energy cost to generate 1 kJ of chemical energy in LH2, and accounting for the penalty to the aircraft, a fleet of aircraft powered by advanced engines with the same efficiency as an advanced SAF engine, would require 15% less green energy from “well-to-wake”. Although the H_2-combustion solution requires technology maturation in the fuel system and its integration into the aircraft, modifications to the engine are largely limited to the combustor.

LEVERAGING HYDROGEN RATHER THAN ACCOMMODATING IT

Hydrogen, however, brings additional characteristics that can be leveraged to further reduce the amount of the fuel needed for a specific mission, and therefore the well-to-wake energy use associated with that mission. This is the goal of the HySIITE concept, developed by Pratt & Whitney with support from the U.S. Department of Energy’s ARPA-E s [5]. The engine is shown schematically in Figure 2. The Hydrogen Steam Injected, Intercooled Turbine Engine concept is a modified Cheng cycle, combining Rankine and Brayton cycles. Water is boiled in the exhaust for waste heat recovery into the fuel and then injected into the combustor with the hydrogen fuel. The specific heat capacity of steam increases power density in the turbine relative to a cycle without steam. This characteristic of water has long been used to increase takeoff thrust on a hot day. However, in this case, the water does not come from a tank, but is recovered from the exhaust. This is enabled by another characteristic of hydrogen leveraged by the cycle – the product of

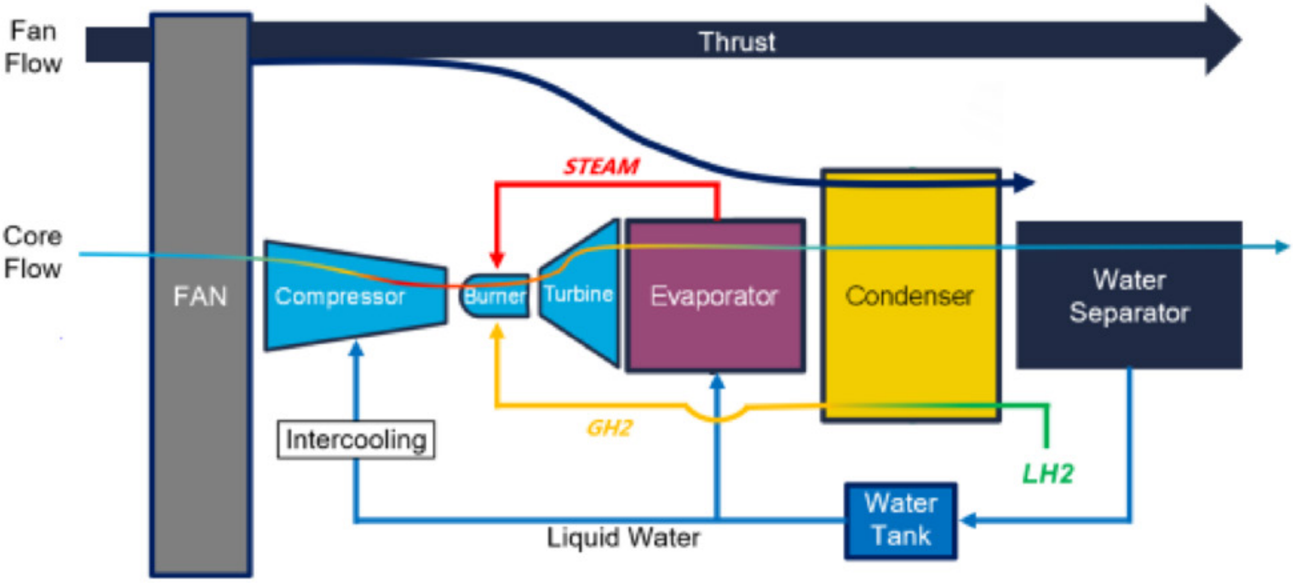

Figure 2. Schematic of the HySIITE concept.

its combustion is water. A further characteristic of LH2 is its low storage temperature. While a challenge for the fuel system, this cold sink can facilitate condensation of water from the exhaust.

By designing a cycle to fully-leverage the characteristics of hydrogen, the "well-to-wake" energy use may be further reduced to 26% less than for an advanced SAF-burning engine. This translates to an equivalent reduction in green grid loading, potentially making hydrogen the minimum energy solution for future generation aircraft.

THE WAY FORWARD

Leveraging hydrogen as an aviation energy carrier in advanced propulsion systems has the potential to reduce net CO_2 emissions. This future state would strongly depend on the presence of a global infrastructure for low-carbon intensity hydrogen production, distribution, storage, and handling; extensive scientific research to improve the understanding of the impacts of hydrogen engine emissions on contrail properties; and advanced, low NOx hydrogen combustor research & development.

Investment continues in hydrogen aircraft technology, with a late-2030s/early-2040s entry-into-service envisioned in Europe, for a regional aircraft. Furthermore, investment continues in hydrogen infrastructure development to support a possible hydrogen economy that anticipates use cases beyond aviation. Moreover, hydrogen will be a key feedstock for electro-fuel production. While a single-aisle aircraft application is further away, progress in both integration of hydrogen fuel into a regional aircraft and hydrogen production will only serve to pull the date of potential single-aisle hydrogen entry-into-service to the left. We, as an aviation community, need to be ready to fully leverage the potential of hydrogen to transform aviation. ◆

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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. Including a CV would be appreciated. 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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CELEBRATING WOMEN IN TURBOMACHINERY

Wednesday Evening

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