# GLOBAL GAS TURBINE NEWS

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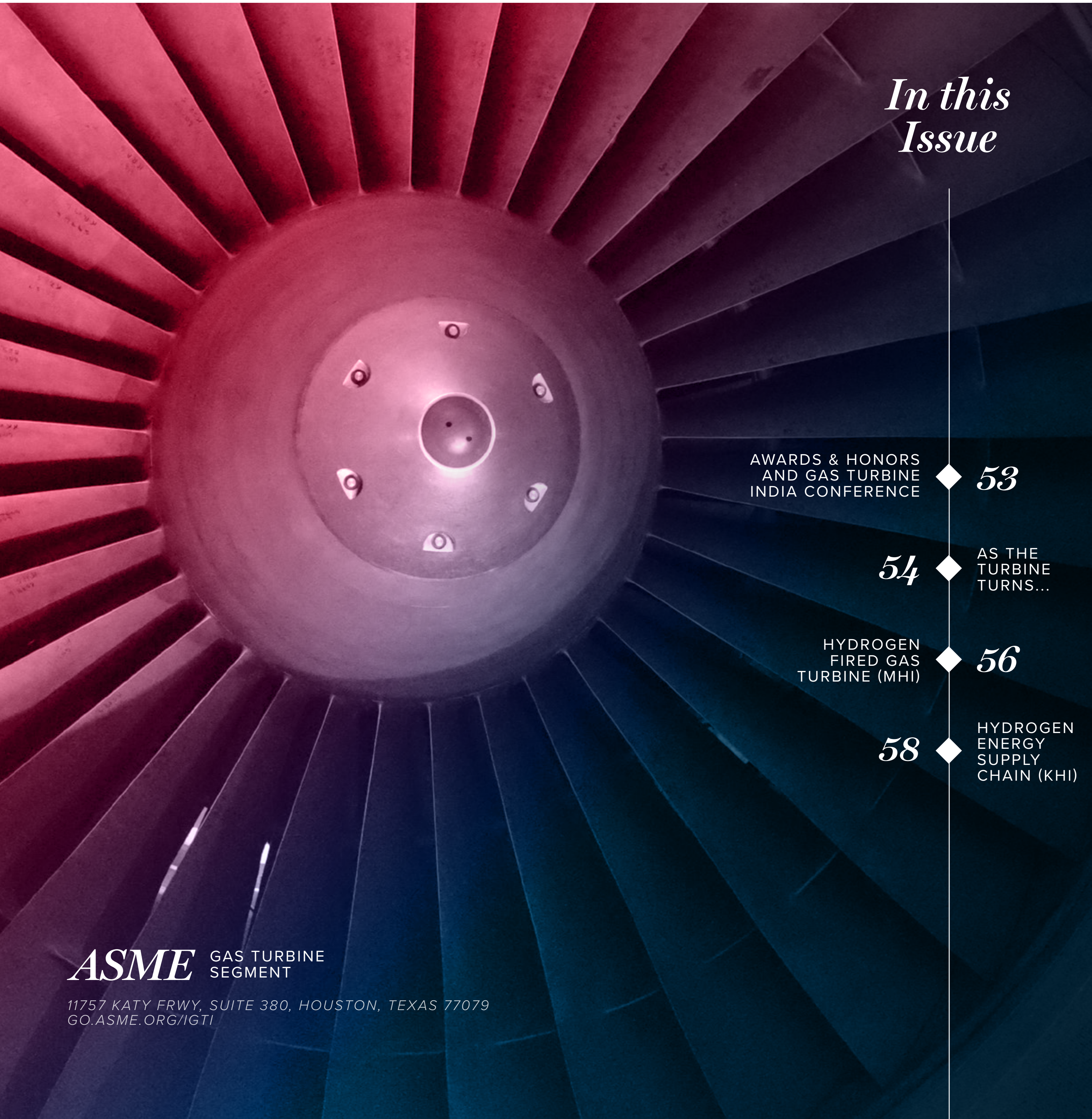
ASME INTERNATIONAL GAS TURBINE INSTITUTE

ASME SETTING THE STANDARD



## In this Issue



ASME GAS TURBINE SEGMENT

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## *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.

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.

# ASME 2019 GAS TURBINE INDIA CONFERENCE

This 2-day biennial event, now in its sixth edition, surpassed expectations in bringing together gas turbine professionals from academia, industry, government, and practitioners, including engineering students in the turbomachinery industry covering different application areas such as aviation, energy, and many more.

Close to 400 attendees from 16 countries shared latest technology knowledge and best practices in the turbomachinery domain. The Indian Institute of Technology Madras, conference host, is one of the premier engineering institutions in India and boasts in research & development in the turbomachinery space.

We would like to thank our platinum sponsors, GE and Siemens, our silver sponsors, GAIL (India) Limited and Oil India Limited, our Gala Dinner Sponsor, RWG, our bronze sponsor, COMSOL, and our badge/lanyard sponsor, QuEST, for supporting this conference. We also recognize the Gas Turbine India Conference Committee for the wholehearted and selfless volunteer hours that they collectively dedicated toward the successful technical program of the conference.

## *ASME IGTI Student Scholarship Program*

Student application deadline is **March 1** for the 2020-2021 Academic School Year. Scholarship winners will be notified between **June 15** and **July 15**.

For complete information on the scholarship program and application process, visit:

**asme.org/career-education/scholarships-and-grants/scholarship/asme-scholarships-how-to-apply**

## *ASME IGTI Industrial Gas Turbine Technology Award*

Nominating and supporting letters for the Industrial Gas Turbine Technology Award should be sent by **October 15** to: igtiawards@asme.org.

Nomination requirements are identical to the ASME IGTI Aircraft Engine Technology Award.

## *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.

The 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 R. Tom Sawyer Award*

Your nomination package should be received at the ASME Office no later than **August 15** to be considered.

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.

Email completed nomination package to: igtiawards@asme.org.

# AS THE TURBINE TURNS...

#41 / MARCH 2020

## GAS TURBINES — ROBUST AND ADAPTIVE!

Starting with the famous James Watt steam engine of the 1700s, inventors, technologists and engineers have provided society with a wide range of energy converters for mechanical, electrical and motive power. The brief historical itemization of energy converters given in Table 1 gives examples of those that have faded (the Brayton engine), have languished (the Fuel Cell), have prospered (the Otto and Diesel engines), and the youngest (the Gas Turbine).

Since its dual development in 1939 as a jet engine and its land use to generate electricity, the gas turbine has become a robust and adaptive prime mover for both aviation and non-aviation applications, worldwide. In a mere 81 years, it has come to dominate aircraft propulsion, and has in its role in combined cycle electric power plants, become the means of providing the most efficient heat engine (60 percent and increasing) yet produced by mankind.

### *Current Trends*

Current events have raised some questions about the future of gas turbines. Present day gas turbine OEMs are facing the prospects of meeting proposed national and international targets for reducing greenhouse gas emissions and for the promotion of sustainable energy.

In aviation, jet engine OEMs know that gas turbines are the only viable propulsion means for commercial aviation for the foreseeable future (e.g., see Epstein [1]).

In 2017, Aviation Week reported that the last three years generated more profit for the commercial airline industry than the previous 30 years combined. However, even though this has resulted in record jet engine orders, OEMs have work going on to look into battery-powered electric fan engines, and hybrid-electric power concepts are in early development, all aimed at reducing flight greenhouse gas emissions—and the use of jet engines.

Currently, there has been a downturn in the large electric power gas turbine market, caused by the increasingly cheap power from wind turbines and photovoltaic solar cell units, that are being put on line in record numbers. Recently, both GE and Siemens had to significantly reduce their workforces to address the disruptions in the gas turbine power business. This has caused some to raise the speculation that electric power gas turbines may be a transitional technology for the next 5-10 years, putting in question their long-term future.

*By Lee S. Langston*

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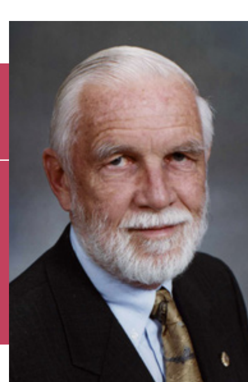

**Energy Converters**

Date of First Working Device

| | |
|---|---|
| Steam Engine | - 1769 |
| Fuel Cell | - 1839 |
| Brayton Engine | - 1872 |
| Otto Engine | - 1876 |
| Steam Turbine | - 1884 |
| Diesel Engine | - 1897 |
| Gas Turbine | - 1939 |

Table 1. Date of First Working Energy Converters.

### *The Gas Turbine Market*

The youthfulness of the gas turbine, highlighted in Table 1, seems to engender a notion of its early demise. I first encountered this in my first job. After finishing graduate work at Stanford in 1964, I joined the gas turbine OEM, Pratt & Whitney Aircraft in East Hartford, Connecticut. Founded in 1929, the East Hartford plant was just then phasing out its production of aircraft radial piston engines and was in full swing for jet engine production, which had commenced in the 1950s. I was assigned to a group called Advanced Power Systems (APS). The APS mission was to seek out other power systems, in the event that the gas turbine market would fade out, as its piston engine predecessor had done. (One APS outcome was the Gemini and Apollo mission fuel cells.)

So, in the intervening 56 years (1964-2020) how has the P&WA post-APS gas turbine market fared? In short, it has exploded, both for aviation and non-aviation applications. Each year (since 1999) I write an annual gas turbine industry overview article for *Mechanical Engineering* magazine, in which I include a plot of the world GT market size in terms of value of production dollars as a function of year.

As shown in Figure 1, the plot for 2018 [2] is based on data from Forecast International, or FI, a market research firm in Newtown, Conn. FI reports on the total gas turbine market, dealing with both aviation (commercial and military) and non-aviation (electrical power, mechanical and marine).

In 2018, using FI's computer models and extensive database, analyst Stuart Slade has provided the value of gas turbine manufacturing production from 1990 to 2017, and has projected values to 2032. FI considers value of production figures to be more accurate than reported sales figures.

As shown in Figure 1, Slade reports that the value of production for all gas turbines worldwide for 2017 was $84.3 billion. FI predicts that by 2032, production will reach $100.6 billion, representing a 19 percent growth in 15 years. Based on FI's value of production history and predictions, the worldwide gas turbine industry is and will be a global growth energy converter industry.

For 2017, FI data shows that the value of production of all aviation gas turbines was $71.6 billion or 85 percent of the total gas turbine market. (Of this, $63.4 billion was for commercial aviation with the remaining $8.2 billion for military.)

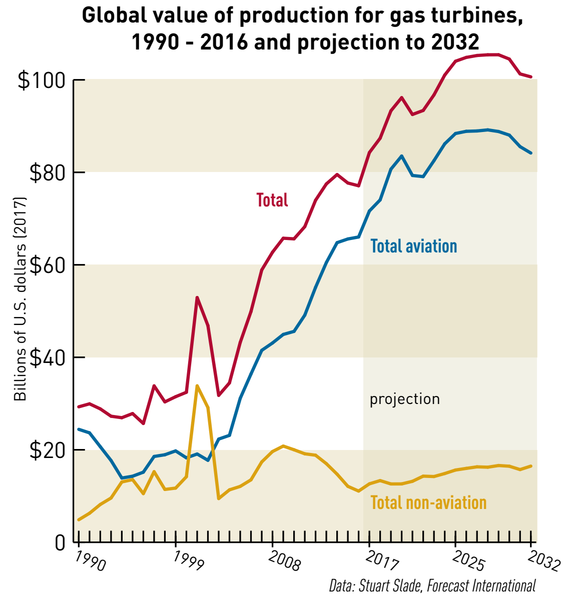


**Figure 1. Global Value of Production for Gas Turbines, 1990 - 2017 and Projection to 2032.**

The non-aviation market is not only considerably smaller than the aviation market, it's more fragmented. FI breaks out mechanical drive gas turbines, used extensively along natural gas pipelines to power compression stations, marine power gas turbines designed for ships, and gas turbines found in combined heat and electric power systems. The value of production for those three segments was $12.6 billion in 2017, with 80 percent accounting for electrical power. This segment of the gas turbine market can be volatile, as evidenced by a short-lived spike in the value of production of gas turbine electrical generating sets in 2001, caused by irrational market exuberance at the onset of electric utility deregulation.

## *Promises of an Adaptive Future*

Based on my own 50 years of experience in the gas turbine world and FI's market analysis given above, I feel it safe to say that the almost $90 billion annual gas turbine market is strong and it has a bright future.

As stated above, in aviation the jet engine appears to be the only viable propulsion means, especially for long distance and high speed flight. (Jet fuel has a gravimetric energy density of 44 MJ/kg and a volumetric energy density of 36 MJ/l [1]. Currently lithium-ion batteries have values as high as 0.88 MJ/kg and 2.4 MJ/l, which are both a factor of 50 and 15 respectively lower than jet fuel.)

Jet engines also have extensive safety and maintenance systems that have been built up and evolving over decades. For instance, quoting a short pithy description given in The Economist [3]:

"Manufacturers create a computer model of each engine they make, and then update it during or after every flight, using data collected by sensors on board the real thing. That way, the electronic simulacrum can keep an eye on its physical counterpart, flagging up potential problems and predicting better than an arbitrary maintenance schedule when parts need replacing."

A largely unsung benefit of natural gas fueled gas turbine combined cycle power plants, as they replace coal fired plants in the U.S., is they have largely contributed to a significant reduction of $CO_2$ emissions since 2005. The annual reduction in 2018 was about equal to the total $CO_2$ emissions of Germany in 2017[4]—with each plant at about one-sixth the cost of nuclear. These gas turbine plants are also adaptable to burn emission-free hydrogen, either mixed with natural gas or pure. Currently there are efforts to perhaps use surplus renewable wind turbine or solar electricity to electrolyze water to produce hydrogen.

Thus, by both their robustness and adaptiveness, gas turbines should continue to have a long and bright future as one of society's major energy converters. ◆

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*Hydrogen Fired Gas Turbine for*

# THE REALIZATION OF A $CO_2$-FREE SOCIETY

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

SOSUKE NAKAMURA / MITSUBISHI HITACHI POWER SYSTEMS, LTD.


## ABSTRACT

Gas turbine combined cycle power generation (GTCC) is clean and highly efficient and accounts for a large proportion of power generation today. Therefore, for the realization of a $CO_2$-free society, it is important to use hydrogen for large power generation gas turbines on a largescale. Mitsubishi heavy industries (MHI) group successfully passed a firing test using a 30 percent hydrogen mix in volume. This result achieved a 10 percent reduction in $CO_2$ emission. In addition, MHI group has announced a project in the Netherlands to convert a 440MW natural gas GTCC to 100 percent hydrogen combustion.

This article presents activities on the hydrogen gas turbine developing technologies for realizing a "hydrogen society".


Figure 1. A gas turbine.

## *Introduction*

The growth of renewable power supply, particularly wind and solar power, has meant that increasingly power supply has become variable as well, dependent upon climate variations. This has led to new wholesale services to be considered to maintain grid stability.

With an increasing portion of supply becoming variable and the historically variable demand, there is an increased need for energy storage to enable balancing of the network when generation exceeds demand. Hydrogen-fueled gas turbines provide a potential solution to this. Hydrogen is a good way of storing energy, and gas turbines using this hydrogen later can provide the necessary flexibility to balance the grid and minimize carbon generation. The hydrogen-fueled turbine is essentially the same as a conventional gas turbine shown in Figure 1.

The big difference lies in the combustors. Hydrogen and natural gas have different combustion characteristics. Hydrogen has a higher flame temperature and flame velocity than natural gas, as well as a lower density. Given the high flame velocity of hydrogen, there is associated risk of flashback occurring in the combustor. Therefore, for the development of hydrogen firing gas turbines, improvement of the combustor for prevention of flashback is important.

## *Combustor for Hydrogen Gas Turbine*

The development status of our combustors for hydrogen-fired gas turbines that can be used for co-firing and firing of hydrogen is described below. Figure 2 provides an overview.

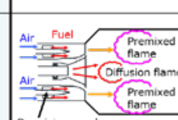
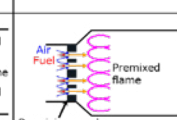
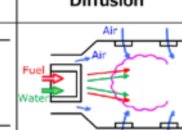
| | Multi-nozzle combustor | Multi-cluster combustor | Diffusion combustor |
|---|---|---|---|
| Combustor type | Premix | Premix | Diffusion |
| Structure |  |  |  |
| Dilution for low NOx | Not applicable (Dry) | Not applicable (Dry) | Water, Steam and N2 |
| Cycle efficiency | No efficiency drop because of no water injection | No efficiency drop because of no water injection | Efficiency drop occurs because water is injected to reduce NOx |
| Hydrogen co-firing ratio | Up to 30 vol% | Up to 100 vol% (under development) | Up to 100 vol% |

Figure 2. Comparison between combustor types.

### (a) Dry Low Nox (Dln) Multi-Nozzle Combustor For Hydrogen Co-Firing

Figure 2 gives newly developed combustor for hydrogen co-firing based on the conventional DLN combustor with the aim of preventing an increase in the occurrence risk of flashback. The air supplied from the compressor to the inside of the combustor passes through a swirler and forms a swirling flow. Fuel is supplied from a small hole provided on the wing surface of the swirler and mixed rapidly with the surrounding air due to the swirling flow effect. Combustion test with a 30 percent in volume hydrogen-natural gas mix were successfully performed. This achieved a reduction in carbon dioxide ($CO_2$) emissions of 10 percent compared to a purely natural-gas-fired power plant. The test was performed at a firing condition of 1600 degC using J-Series gas turbine with slightly increasing NOx as shown in Fig.3.

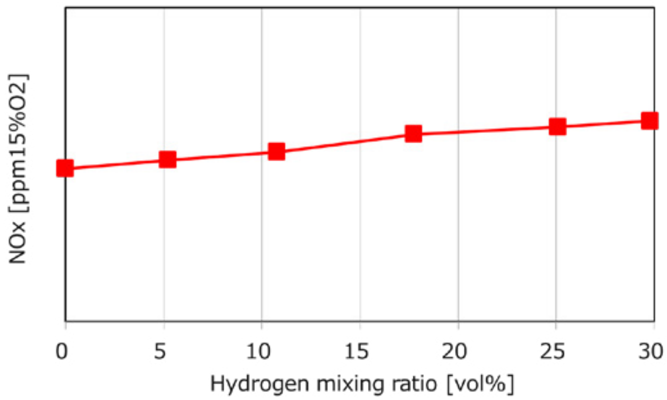



Figure 3. NOx with respect to hydrogen mixing ratio.

### (b) Multi-Cluster Combustor for Hydrogen Firing

Having tested mixtures of up to 30 percent hydrogen/natural gas ratio, the next stage is to continue up to 100 percent hydrogen. This will probably involve more development of the cluster combustor.

To mix fuel and air using swirling flow like a hydrogen co-firing DLN combustor, a relatively large space is necessary and the risk of flashback increases, so it is necessary to mix them in a short time in a narrow space. Therefore, we devised a mixing system that disperses the flame and blows the fuel smaller and more finely. Based on the multi-cluster combustor with a greater number of nozzles than the fuel supply nozzles (eight nozzles) of a DLN combustor, we adopted a system where the nozzle hole was made smaller, air was fed in, and hydrogen was blown in for mixing. It is possible to mix air and hydrogen at a smaller scale without using swirling flow, which may allow for the compatibility of high flashback resistance and low NOx combustion. Combustion characteristics with 80 percent in volume hydrogen co-firing have been confirmed in rig tests

### (c) Diffusion Combustor

As energy companies turn to hydrogen, MHI group has extensive hydrogen firing experience that dates back nearly 50 years and includes refineries, syngas and COG locations. Our network of 31 power plants uses fuel with up to 90 percent in volume hydrogen content and has been in operation for more than 3 million hours with diffusion combustor.

A diffusion combustor injects fuel to air into the combustor. Compared with a premixed combustion method, a region with a high flame temperature is likely to be formed, and the amount of NOx generated increases, so a measure for NOx reduction using steam or water injection is necessary. On the other hand, the stable combustion range is relatively wide, and the allowable range for the fluctuation of the fuel property is also large.

## *Efforts in Overseas Projects*

MHPS will participate in a hydrogen conversion project in the Netherlands. This project will convert one of the three 440MW GTCC at Vattenfall's Magnum Power plant. MHI group supplied the original three gas turbines at the plant, the project aims to complete the conversion by 2025. This will be the first commercial hydrogen-fired GTCC. The conversion will give a good idea how the hydrogen economy might develop. It could be one more step in the growth cycle of the hydrogen economy in the power industry.

## *Conclusions*

MHI Group is working on the development of a hydrogen and natural gas co-fired gas turbine to target reduced $CO_2$ emissions. A new combustor was developed in order to minimize the occurrence of flashback typically induced during hydrogen co-firing. The prospect for gas turbine operation up to 30 percent in volume hydrogen co-firing conditions was developed and tested. Development of plant operation technology for hydrogen co-firing is ongoing with a final target focusing on 100 vol% hydrogen firing in pursue of a hydrogen-based society. ◆

## REFERENCES

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# HYDROGEN ENERGY SUPPLY CHAIN FOR DECARBONIZATION

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

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In Japan, clean hydrogen energy has been gaining momentum since the endorsement of the Japanese Government's Strategic Energy Plan in 2014, which identified hydrogen as an important energy solution of the future. Kawasaki is developing world-leading technologies that will play an important role in realizing the hydrogen economy and global supply chains. These include liquefied hydrogen storage and supply systems for H-II space rocket base, liquefied hydrogen carrier ships, hydrogen gas turbines as well as electrolyzers. Our aim is to contribute to the realization of a decarbonized society relying on sustainable, affordable and stable energy. We will do this by promoting international hydrogen supply chains through our patented hydrogen-related technologies.

## *Hydrogen Supply Chain Pilot Project*

Together with our private and public sector partners, we have launched the world's first hydrogen energy supply chain pilot project between Australia and Japan. Under this flagship initiative, we will establish an integrated supply chain for sustainable hydrogen produced from Australian brown coal to be exported to Japan [1]. The Japanese, Australian and Victorian State Governments have invested in the project alongside a consortium of reputable private sector companies.

In 2020-2021, the pilot project will demonstrate brown coal gasification and hydrogen refining at Latrobe Valley in Australia, hydrogen liquefaction and storage of liquefied hydrogen at Hastings, marine transportation of liquefied hydrogen from Australia to Japan and unloading of liquefied hydrogen in Japan [2].

Approximately half of the world's total coal resources is brown coal. However, it is relatively heavy and bulky, but low calorie due to its extremely high moisture content. As it runs the risk of igniting spontaneously upon contact with air, it is not suitable for transportation and storage in its raw form. Thus, it is limited to on-site applications. The gasification process therefore needs to resolve various technological hurdles in order to realize mass production in the future. During the process of extracting hydrogen from syngas, it is possible to separate and capture carbon dioxide. The captured carbon dioxide will be sequestrated for commercial phase in cooperation with Australian national project "CarbonNet" [3]. An assessment on greenhouse gas emission from hydrogen production to refueling at a hydrogen gas station shows that the brown coal derived hydrogen connected to carbon dioxide capture and storage (CCS) has same emission level as renewable energy derived hydrogen [4]. This will reduce greenhouse gas emissions, despite the energy being derived from fossil fuels. Once you deploy hydrogen infrastructures with fossil derived hydrogen connected to CCS, called Blue Hydrogen, you can mix renewable energy derived hydrogen, called Green Hydrogen, and shift to it in the future along with its cost reduction. This may be one of the approaches to a sustainable energy society.

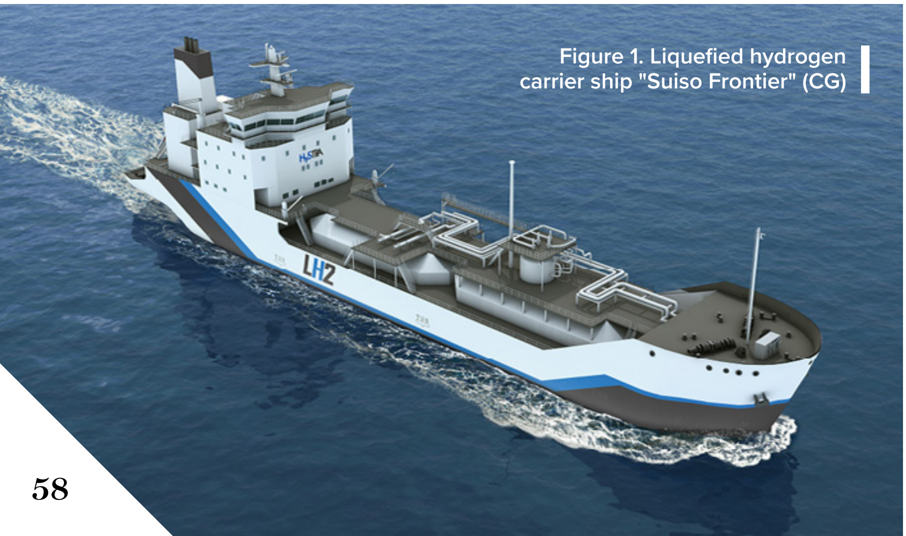


Figure 1. Liquefied hydrogen carrier ship "Suiso Frontier" (CG)

By cooling hydrogen down to a cryogenic level of -253°C, it is converted from gas into liquid and reduces in volume by 1/800. Such reduction in volume allows for more efficient transportation and distribution of more hydrogen.

Using existing technologies for construction of LNG marine carriers and for land transportation and storage of liquefied hydrogen, a new cargo containment system with cryogenic temperature and accumulated pressure to specifically transport liquefied hydrogen on a marine carrier has been developed [5]. We aim to establish technology for safe and efficient transportation of mass volumes of hydrogen. The liquefied hydrogen marine carrier arrives after a journey of around 9,000 km. A loading arm system unloads the hydrogen from the carrier into an on-land liquefied hydrogen storage tank, whilst maintaining a temperature of -253°C. This is the first new energy terminal in Japan. The pilot project site is located on a 10,000 $m^2$ area of land in the northeast section of Kobe Airport Island in the Port of Kobe, where the liquefied hydrogen storage tank and unloading facilities are built.

# HYDROGEN-FUELED GAS TURBINES

## *Demonstration in the City Area*

A difference between a conventional gas turbine and a hydrogen gas turbine lies in the combustor. Instead of designing it only for hydrogen, Kawasaki devised a technology so that natural gas, hydrogen, or mixture of them can be used as its fuel flexibly. However, a technology is required to resolve conflicting factors such as stable combustion and reducing NOx emission at the same time. Kawasaki succeeded to develop new burner achieving stable combustion with 0 to 100 percent hydrogen-natural gas mixture fuel. While NOx emission is suppressed by water spray injection that conforms to regulation limit. The developed technology has been applied to a demonstration project, shown next.

In Kobe Port Island, verification tests have been conducted on a cogeneration system using hydrogen gas turbines. The hydrogen energy converted into heat and electric power here in an urban location can be supplied to hospital and other public facilities – the first such attempt in the world. In September 2017, final adjustments were being made on a 1MW-gas turbine fueled by hydrogen and natural gas at the Kawasaki Heavy Industries Akashi Works. A cogeneration system with this 1MW-gas turbine as its core has been constructed on the site of a former waste treatment plant on Kobe Port Island.

After a construction period of around two months, a press announcement and opening ceremony were held in December 2017. We conducted numerous trial runs and safety inspections. Then, in April 2018, approximately four months after the start of testing, we succeeded in achieving a hydrogen blend rate of 100 percent. Generating heat and electric power in an urban location and providing it to nearby public facilities, this online experimental project is a world's first.

## *Dry Low NOx Emission Technology for Pure Hydrogen Combustion*

In response to the issue of increasing NOx emission with higher flame temperature, Kawasaki injects water to lower the flame temperature, but in fact, this worsens the fuel economy. So Kawasaki developed pure hydrogen-fueled Dry Low NOx combustor with a cutting edge technology to overcome this issue. The principle is to subdivide the fuel and eject it from tiny nozzles roughly the diameter of the core of a mechanical pencil, so that the fuel burns in a "micro-flame." Kawasaki call this technology "Micromix." With the Micromix combustor, it is possible to burn 100 percent pure hydrogen while suppressing NOx emission without water injection [6]. Results from combustion test rig under 100 percent load condition showed NOx emission is under 35 ppm ($O_2$-16 percent corrected values). As a result, the realization of $CO_2$ zero-emission power generation is now just around the corner. ◆

**Figure 2. Micromix combustor.**

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