Renewable Energy Storage Alternatives and the Hydrogen Generation Gas Turbine

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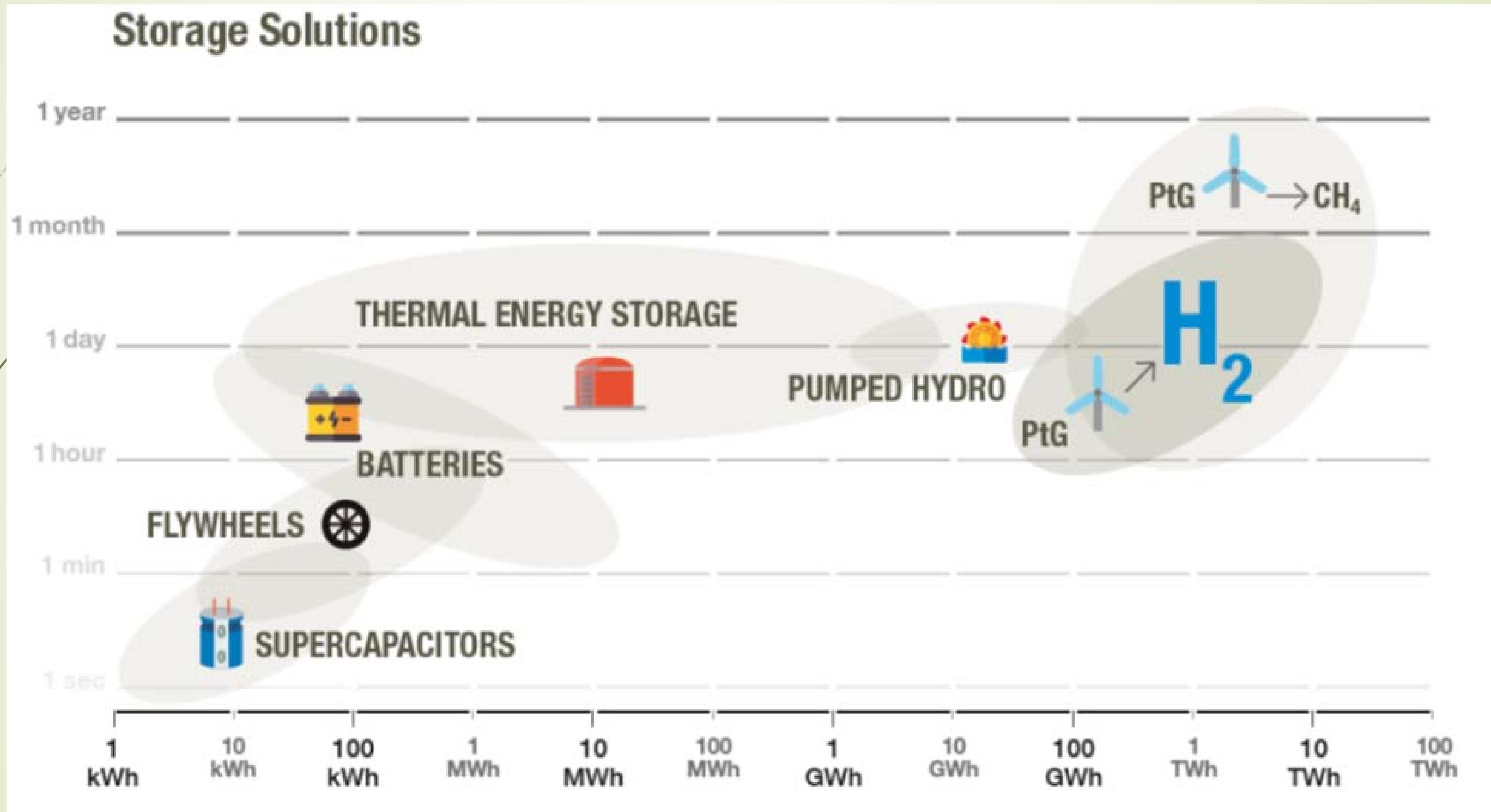
Renewable Energy Storage Solutions



Hydrogen Production

- Hydrogen can be generated from a variety of feedstocks and chemical processes, as photosynthesis using algae, steam methane reforming (SMR) of natural gas, crude oil partial oxidation, and coal gasification. CO_2 is often a by product of these H_2 production streams.
- Hydrogen is present in the coke oven gas and blast furnace gas that are by-products of the steelmaking process, as well as in the waste gases of an oil refinery.
- Electrolysis is a promising green option for hydrogen production from renewable resources as it produces clean H_2 (i.e.without CO_2 by product).

Hydrogen is being considered the missing link in the energy transition as key technologies to produce it using renewable electricity, such as proton exchange membrane electrolyzers and fuel cells, reach technical maturity and economies of scale.

Hydrogen Energy Storage (HES)

Hydrogen can be stored using different methods and phenomena:

- Compressed Gas: High-pressure gas cylinders (up to 800 bar).
- Cryogenic Liquid: in tanks (at 21 K and ambient pressure).
- Metal Hydride & Chemical Hydrides materials : In these cases, the hydrogen is bonded to a solid material and can be liberated upon demand.
- Chemicals : such as liquid organic hydrogen carriers and ammonia, that can act as molecular hydrogen carriers for long distance transportation.
- Hydrogen storage systems can be very safe, provided that good design and safety practices have been followed.

HES allows for integration with the gas grid via pipeline injection in small percentages, which directly leverages existing infrastructure.

Hydrogen as a Fuel – Take 1

- Hydrogen is a colorless, odorless, tasteless, and nonpoisonous gas under normal conditions.
- It has a high energy content per weight (nearly 3 times as much as gasoline), but the energy density per volume is quite low at standard temperature and pressure
- Hydrogen is a clean-burning fuel—it doesn't carry any carbon with it—when it burns, it produces only water & heat (i.e. no CO2).
- The energy industry and environmentalists alike are excited about hydrogen's potential as a clean fuel alternative for generating electricity.
- Among all combustible gases, hydrogen stands out as an almost perfect combination of storability for long periods and reliability.

Hydrogen as a Fuel – Take 2

- Hydrogen is a substance that is difficult to handle. It's easy flammability and unparalleled lightness makes it burn violently, so the idea of hydrogen use is often accompanied by the fear of explosions.

- Hydrogen is highly combustible; it only needs energy equivalent to static electricity to ignite & has a broad combustion range.

- Hydrogen burns hotter than methane or other hydrocarbons, and since NOx is a function of flame temperature, while you can get lower CO2 emissions, you actually get higher NOx emissions.

Being able to burn hydrogen alone or in combination with other natural gases, and to do it safely and efficiently, could therefore make all the difference.

Hydrogen as a Gas Turbine Fuel – General Considerations

- Hydrogen having physically a smaller molecule than natural gas, hydrogen leaks occur where normal fittings and seals wouldn't leak with natural gas.
- A hydrogen leak, is far more dangerous than a natural gas leak. Hydrogen being odorless, colorless and highly flammable, flames that may occur are harder to see with the naked eye than a flame with a traditional hydrocarbon. **Thereby we have a fundamental safety issue when running hydrogen on a gas turbine.**
- Many balance of plant systems become also critical like safety systems, accessories, ventilation, gas detection systems, explosion proof systems etc. basically anything that the fuel may touch, any auxiliary systems could potentially be impacted.

Hydrogen as a Gas Turbine Fuel – Combustion Challenges

- High Combustion Temperatures: Hydrogen-containing gases lead to combustion temperatures that are too high for conventional gas turbines. Temperatures inside the combustor reach 1,600℃ resulting in combustion pressure fluctuation or oscillation.

- Flashback: H2 increased reactivity as compared to natural gas, is such that during H2 combustion the flame position moves upstream, thus increasing the risk of flashback.

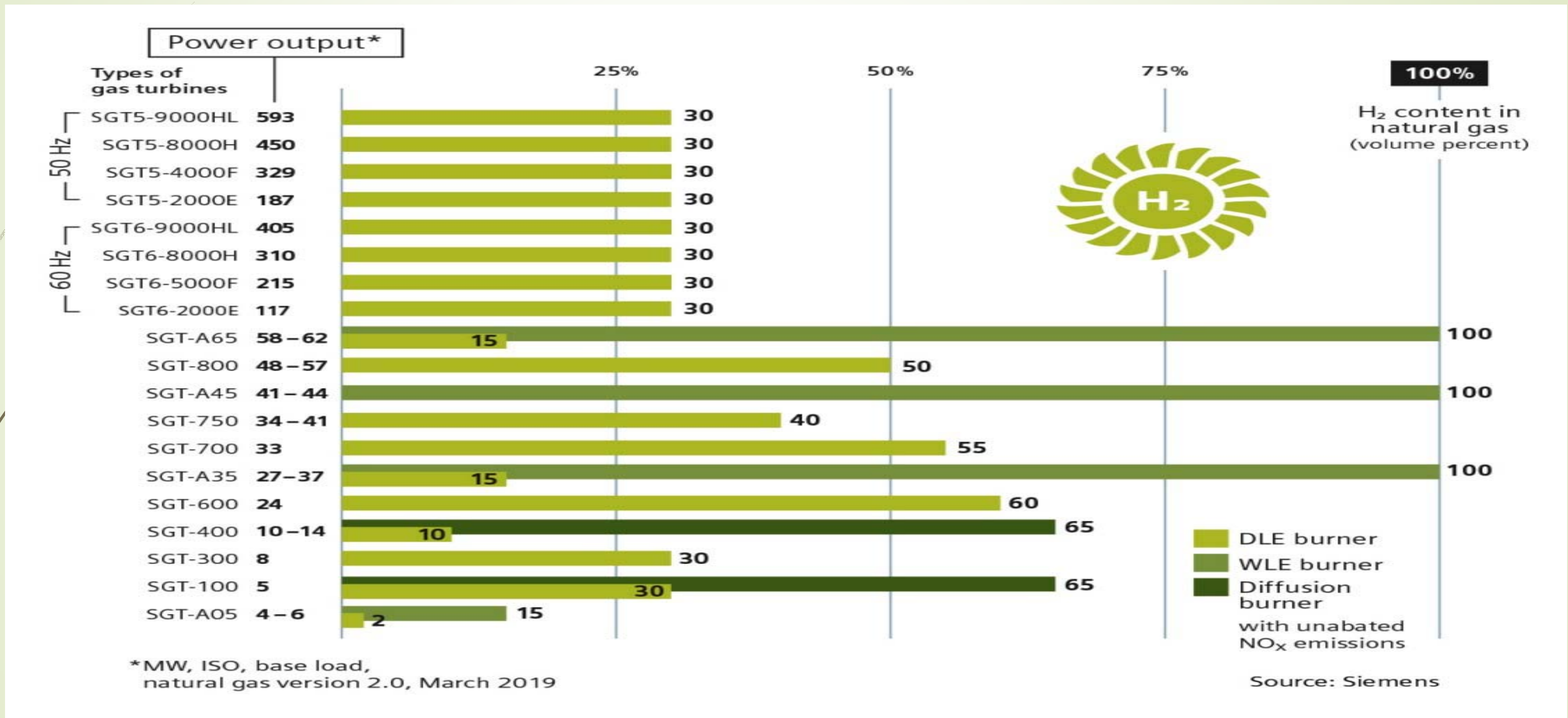
- Nox Emissions: H2 combustion in gas turbines tends to be unstable due to the fast combustion speed of H2. Combined with high flame temperatures, this results in NOx emissions that are nearly double the amount emitted when combusting natural gas.

- Additional Flow Requirements: H2 carries about 1/3 of the heating value on a volumetric basis, which means in order to give the gas turbine the same kind of energy input, you got to flow more H2—which impacts the configuration of the accessory system.

Capability of Gas Turbines to burn Hydrogen

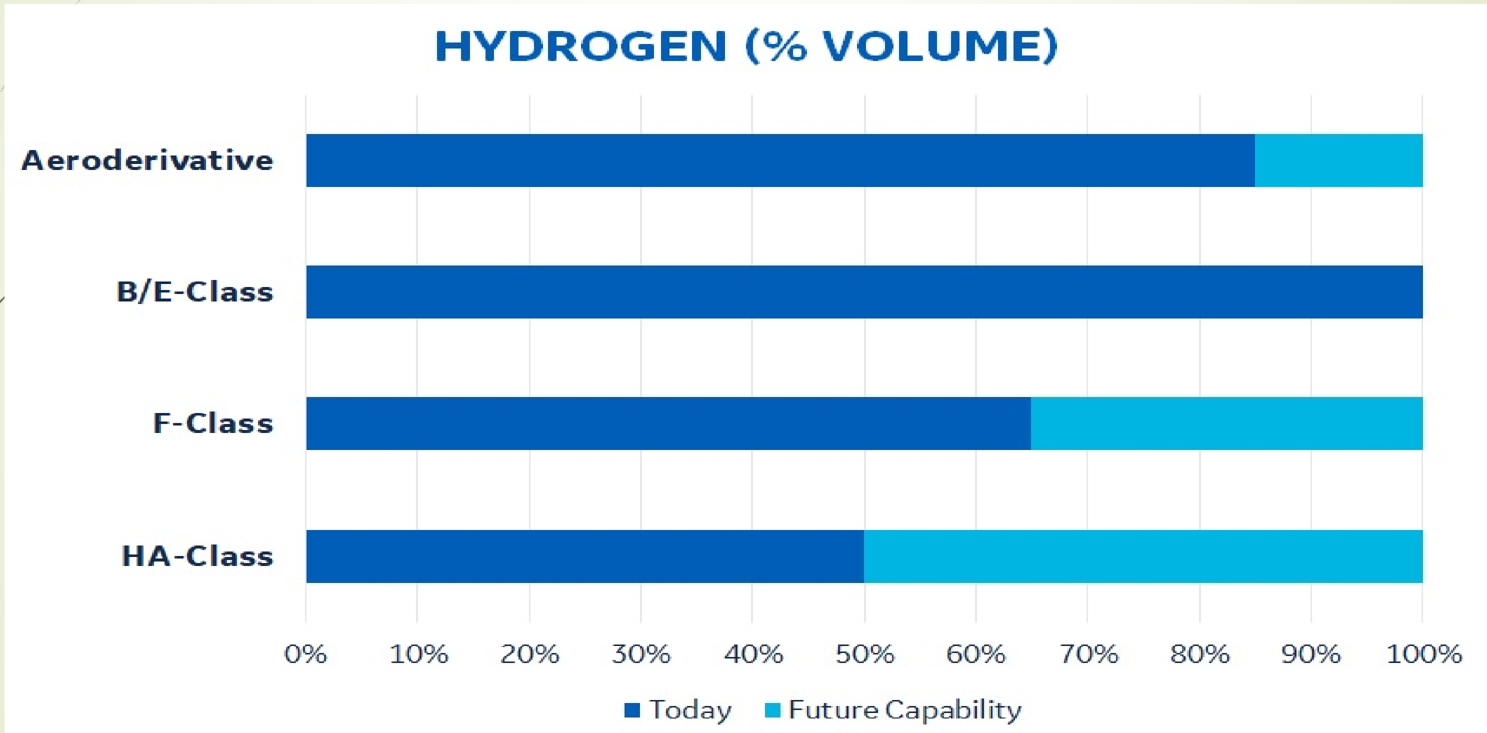
- Most Gas Turbines manufacturers can accommodate the use of up to 15 % to 20% hydrogen fuel mix on their standard Gas Turbine combustion system.
- According to several experts, efforts by companies like Mitsubishi Hitachi Power Systems (MHPS), GE Power, Siemens Energy, and Ansaldo Energia to develop 100% hydrogen-fueled gas turbines have recently shifted into high gear, owing in part to new carbon reduction policies worldwide that have accelerated renewables capacity.
- Along with Japan, members of EUTurbines—an association of the entire gas and steam turbine sector in the European Union (EU)—in January 2019 **committed to provide gas turbines that can handle 20% hydrogen by 2020, and 100% hydrogen by 2030.**

Siemens Gas Turbines H2 Capabilities



https://new.siemens.com/global/en/company/stories/energy/hydrogen-capable-gas-turbine.html

GE Gas Turbines H2 Capabilities



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Ansaldo Energia Gas Turbines H2 Capabilities

ANSALDO ENERGIA SOLUTIONS FOR BURNING H_2 AT HIGH EFFICIENCY

Ansaldo Energia H_2 solutions for new equipment and service feature leading edge, unmatched technological characteristics in terms of:

- amount of H_2 volume mixed with natural gas;
- no or only slight derating compared to 100% natural gas;
- NOx emissions at 15 ppm or less;
- very broad load range (wider than 100% natural gas).

Technology	Application	Max H_2 vol. %	Derating	Emissions NOx [ppm]	Load range
Sequential combustion	**GT26 New and service**	30	<1%	NOx @ 15ppm	20-100%
Sequential combustion	**GT36 New**	50	<1%		
FlameSheet™	Service Retrofits Solutions for: **GE Frame 6F, 7F, 9F** **MHPS 501F/G, 701F/G** **Siemens-Westinghouse 501F/G**	40	<1%	NOx @ 9ppm	30-100%

https://www.ansaldoenergia.com/business-lines/hydrogen-technology

MHPS Gas Turbines H2 Capabilities

- Since 1970, MHPS has fired 29 gas turbine units with hydrogen content ranging between 30% and 90%, tests that have spanned over 3.5 million operating hours.
- MHPS developed a large-scale hydrogen gas turbine combustor that uses a mix of LNG & 30% hydrogen. It burns hydrogen while allowing suppression of NOx emissions to the level of gas-fired thermal power. The technology is compatible with an output equivalent to 700MW (with temperature at turbine inlet at 1600℃) &offers a reduction of about 10% in CO2 emissions compared with GTCC.

https://www.mhps.com/special/hydrogen/index.html

So, if Renewable Energies can produce Hydrogen & all GT Manufacturers can burn hydrogen why it’s use is still limited ?

H2 Electrolysis Production requires lots of H_2O

Table 3: Electrolysis requirements supporting 100% hydrogen operation.

Gas Turbine	Output† MW	Heat Input† GJ/hour (MMBTU/hour)	100% H_2 Flow Rate m^3/hour (ft^3/hour)	Water Required to Generate H_2 m^3/hour (gallons/hour)	Electrolysis Power Required†† GWh
GE-10	11.2	129 (122)	~11,700 (~446,000)	~10 (~3,700)	~500
TM2500	34.3	350 (332)	~31,800 (~1,210,800)	~27 (~7,300)	~1,500
6B.03	44.0	473 (448)	~ 43,000 (~1,635,900)	~37 (~9,900)	~2,000
6F.03	87	857 (813)	~78,000 (2,970,000)	~68 (~17,950)	~3,600
7F.05	243	2,197 (2,083)	~200,000 (~7,600,000)	~174 (~46,000)	~9,400
9F.04	288	2,677 (2,537)	~243,500 (~9,266,900)	~212 (~56,000)	~11,400
9HA.02	557	4,560 (4,322)	~415,000 (~15,786,400)	~361 (~95,500)	~19,500

† ISO conditions operating on natural gas

†† Power required for electrolysis to supply H_2 flow for gas turbine to operate on 100% H_2 for 8000 hours

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- Supplying hydrogen for a GE 9F.04 with capacity (288 MW) would use an Olympic pool of water (2500 m3 of water) every 12 hours.

- Water being a resource that is already extensively solicited for Potable, Domestic, Agricultural & Industrial use , the large-scale use of Hydrogen produced from water as fuel has to be carefully analyzed.

Hydrogen is still more expensive than Natural Gas

Power to hydrogen: fuel price forecasts and impact to cost of electricity

There are multiple studies evaluating the cost of hydrogen generated via electrolysis and renewable power. The table below summarizes some of the published price forecast.

Report & Forecast Period	Forecast Period	Forecasted Cost Range ($/MMBTU)
Hydrogen for Australia's future [13]	2018	30.4 – 46.8
2018 EIA World Energy Outlook [17]	2018	35.2 – 52.8
METI Basic Hydrogen Strategy [14]	2030	27.2 (30 Yen/Nm^3)
METI Basic Hydrogen Strategy [14]	Beyond 2030	18.2 (20 Yen/Nm^3)
Hydrogen for Australia's future [13]	2050	14.6 – 19.6

As a reference, Henry Hub natural gas spot prices in the US are in in the range of $3-4/MMBTU, and estimated landed LNG prices today range from $9.39/MMBTU – $10.95/MMBTU in Europe, and $10.86/MMBTU in Asia [18]. ($ are USD)

Operating a power plant on a fuel whose cost ranges from 3x to 10x the current cost of natural gas will increase the cost of electricity (LCoE) by similar factors.

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Gas Turbines Performances on Hydrogen are still limited

- Most suppliers still have limitations on the percentage of Hydrogen that can be mixed with the natural gas and the type of units that can be used for hydrogen combustion (i.e. higher hydrogen % are found on small size units whereas there are still limitations on large units).

- The high Nox emissions accompanied with hydrogen combustion are often compensated for by water or steam injection which a significant penalty on efficiency.

Conclusion

- Hydrogen is a promising fuel as it can be produced with renewable energy and can be burned without CO2 emissions.
- Gas Turbines with 100% Hydrogen capability are already a reality and the technology will be more mature within 2030.
- Technology improvements for producing the hydrogen more efficiently via the electrolysis and thereby using less water + sorting out the Hydrogen Gas Turbines Nox emissions in an efficient way will be instrumental in making the cost of H2 electricity more competitive.
- The trigger to a large-scale use of H2 as a fuel will be the capability to produce hydrogen at a competitive price through technology improvements on the production & storage chain and a decrease in the renewable energy costs.

References

- The POWER Interview: GE Unleashing a Hydrogen Gas Power Future – Power Magazine, By Sonal Patel, May 30, 2019
- High-Volume Hydrogen Gas Turbines Take Shape – Power Magazine, By Sonal Patel, May 1st, 2019
- Power to Gas – Hydrogen for Power Generation - GEA33861, Feb 2019
- Fuel Switching – International Turbomachinery Magazine, By Drew Robb, September 5, 2018
- Hydrogen Power Generation Handbook – MHPS
- https://new.siemens.com/global/en/company/stories/energy/hydrogen-capable-gas-turbine.html
- https://www.ansaldoenergia.com/business-lines/hydrogen-technology
- https://www.mhps.com/special/hydrogen/index.html
- https://www.ge.com/power/gas/fuel-capability/hydrogen-fueled-gas-turbines

Thank you for your kind attention

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