Nick Corbett

Education Background

Bachelor of Science – Mechanical Engineering

Fellow of The Institution of Mechanical Engineers

Rolls-Royce & Siemens Energy - Principal Key Expert

A graduate of Aston University in Birmingham UK, with a Batchelor of Science with Honours in Mechanical Engineering.

Recognised as a Principal Key Expert at Siemens Energy and Rolls-Royce

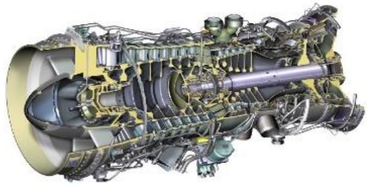
46½ years' experience in innovation and the development of technology for aeroderivative gas turbine solutions.

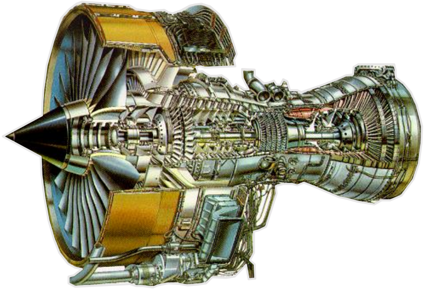
Appointed to leading roles in Controls automation, Performance Engineering, Condition Monitoring and Research & Technology

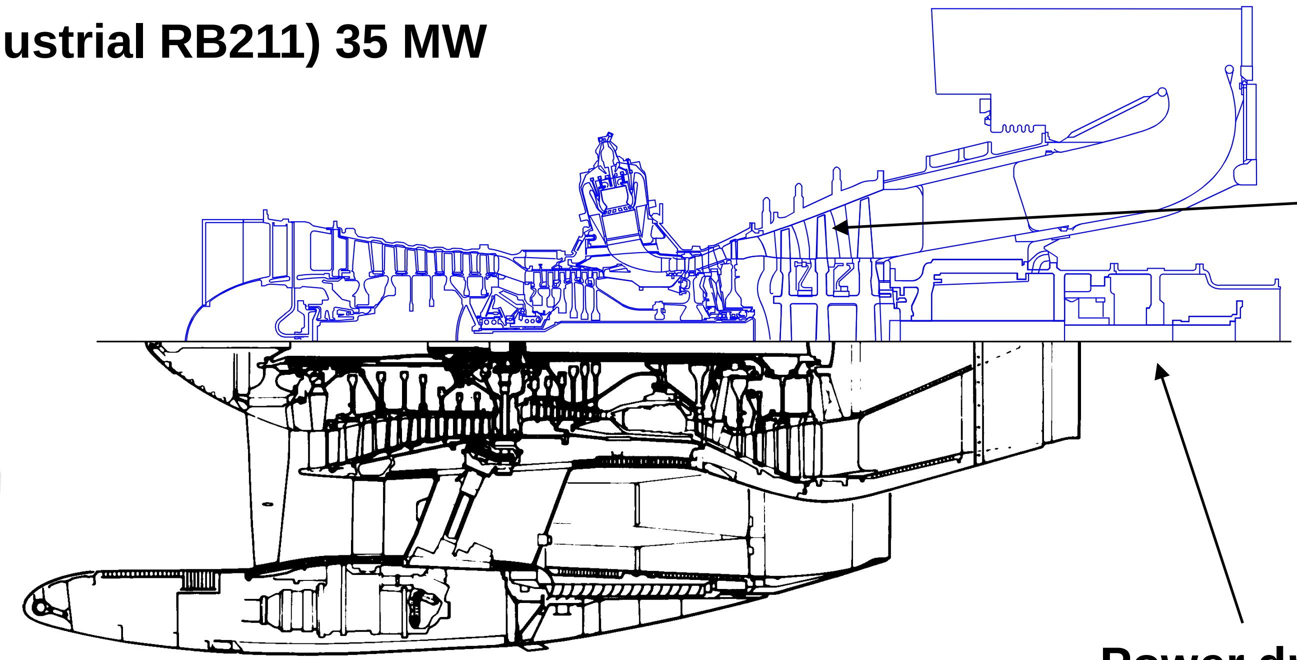
Became Chief Performance Engineer in 2017.

Industrial power from an aero engine

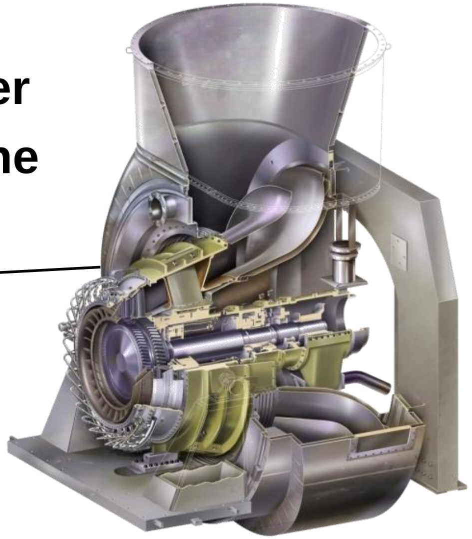
SGT-A35 (industrial RB211) 35 MW







Power turbine



Power drive

- **RB211-524 turbofan**
- **222.4kN thrust (50,000lb)**

Siemens Energy Aeroderivative Gas Turbines

- emergency and peak duty
- start up and accept full load rapidly preventing shutdown of grid
- Remote oil & gas production facilities
- Transportation of oil & gas across continents N America, Asia, Europe through pipelines to consumers

(Image: BP)

(Image: BP

(Image: TC Energy

SGT-A65

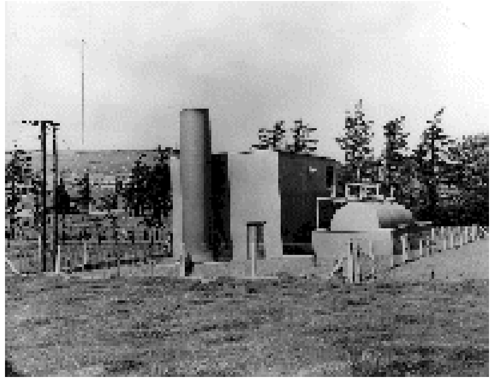
SGT-A35

SGT-A20

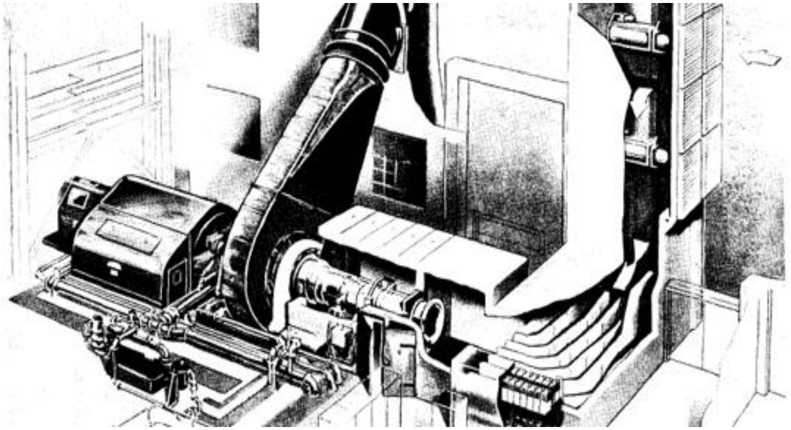
SGT-A05

Bristol Siddeley – Industrial Proteus & Olympus

“the world's first unmanned electricity generation stations”



"Pocket Power Stations“ South Western Electricity Board, at Princetown on Dartmoor, in 1959



Hams Hall Power Station

Image: www.ASME.org

https://creativecommons.org

Bulls Bridge Power Station

Image Andy Dingley

Internal Fire – Museum of Power

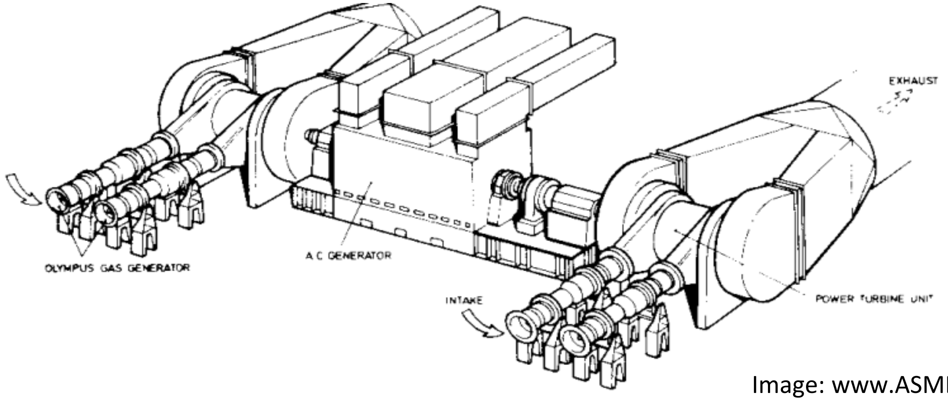


Image: www.ASME.org

Image Mark Pilbeam, CC BY-SA 2.0,

Kingston Power Station - Cowes

Full power in less than 4 mins from standing start

English Electric/AEI Industrial Avon

Supporting critical infrastructure with emergency power in less than 4 minutes

Image: www.tfl.gov.uk

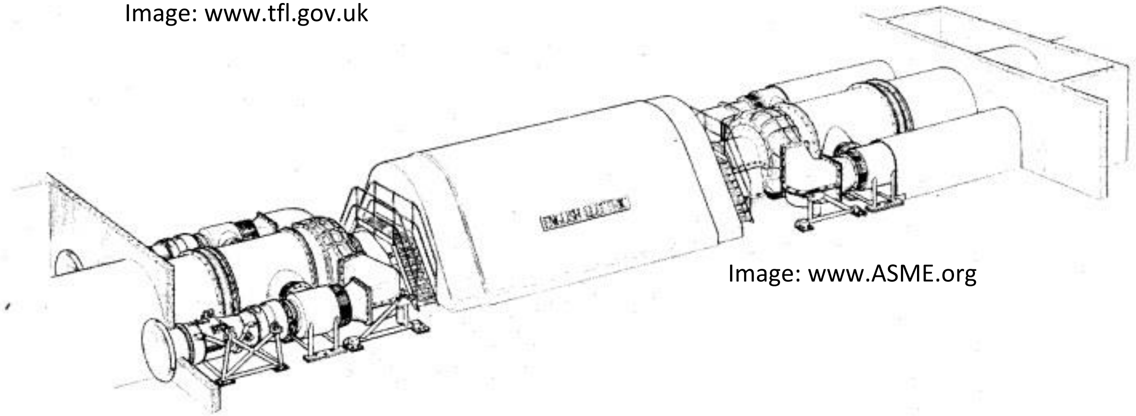


Image: www.ASME.org

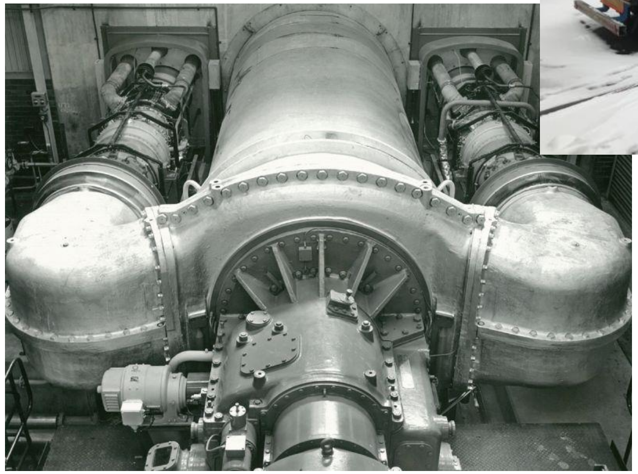


Image: Greenray Archive

Image: Siemens Energy AG

National Grid Gas Transmission

7660 km of pipeline

880 TWhr of gas energy

transported by turbo compressors

44 – SE Aero derivatives

8 – GE Aero derivatives

9 – Industrial gas turbines

7 – SE Electric motor drive

2018/ 2019 gas year:

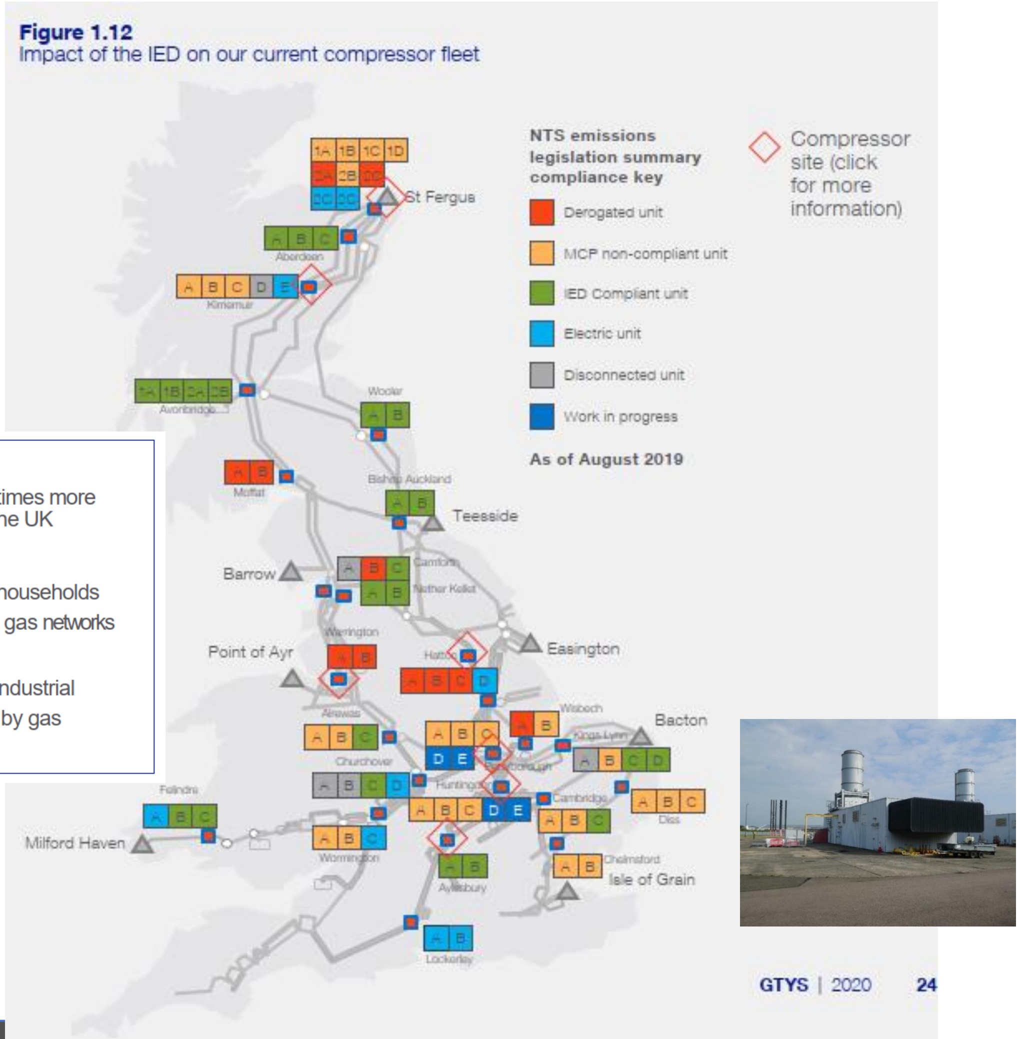
881TWh Gas delivered over three times more energy than electricity in the UK

23.2m gas customers

85% of households connected to gas networks

40% of power needs supplied by gas

38% of industrial demand met by gas

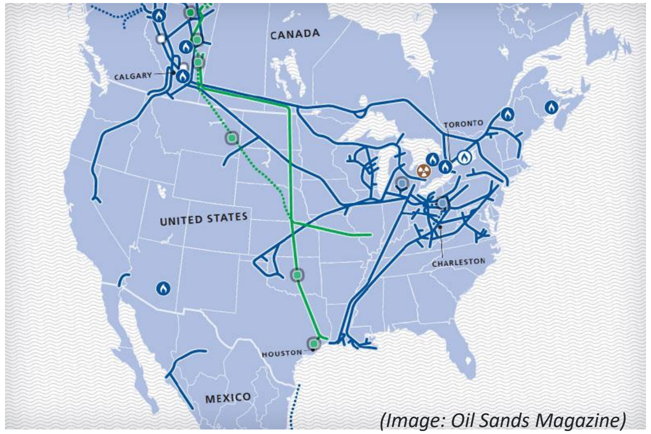


(Image: National Grid

Benefit of replacing 1% of UK Energy with Hydrogen fuel for domestic heating

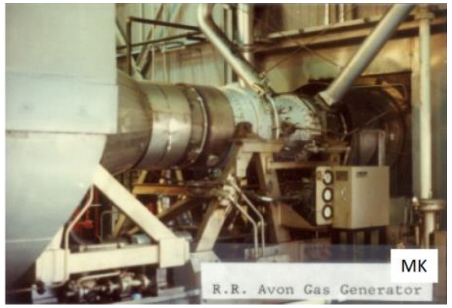
- 1.3 Million tonne of CO_2 pa less (€39M pa CO_2 Value @ €30 per tonne)

Siemens Energy Aero derivative Milestones



(Image: Oil Sands Magazine)

Industrial Proteus	**1959**	Princetown
Industrial Olympus	**1962**	Hams Hall
SGT-A05 (Industrial 501)	**1963**	
	2019	1st SGT-A05 KB7HE Mobile Package
SGT-A20 (Industrial Avon)	**1964**	1st SGT-A20 pipeline Saskatchewan
SGT-A35 (Industrial RB211)	**1973**	1st SGT-A35 Saskatchewan
	2002	1st SGT-A35GT Alberta
Industrial Spey	**1976**	1st Industrial Spey Winnipeg
SGT-A65 (Industrial Trent)	**1997**	1st SGT-A65 Ontario



(Photo M Klein)

(Image: TC Energy


(Image: TC Energy


(Image: Atlantic Packaging)

Carbon intensity

HydroCarbon Carbon Dioxide

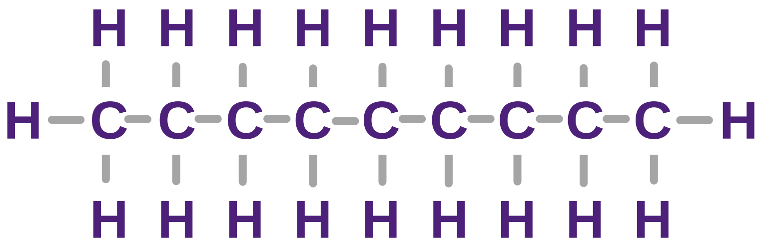
$$CH + O_2 \rightarrow CO_2 + H_2O$$

Oxygen Water

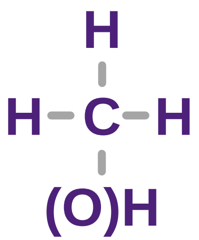
$$NH_3 + O_2 \rightarrow NO + H_2O$$

$$H_2 + O_2 \rightarrow H_2O$$

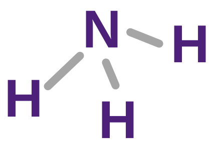
Diesel



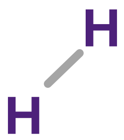
Methane



Ammonia

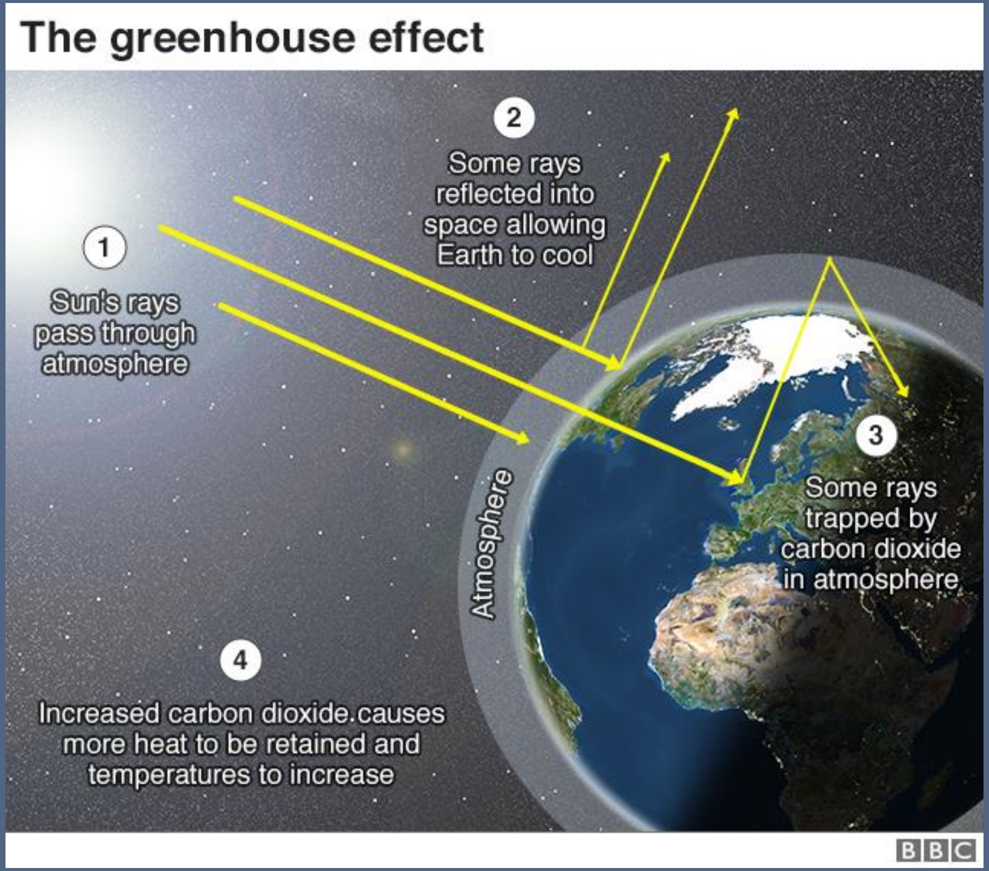


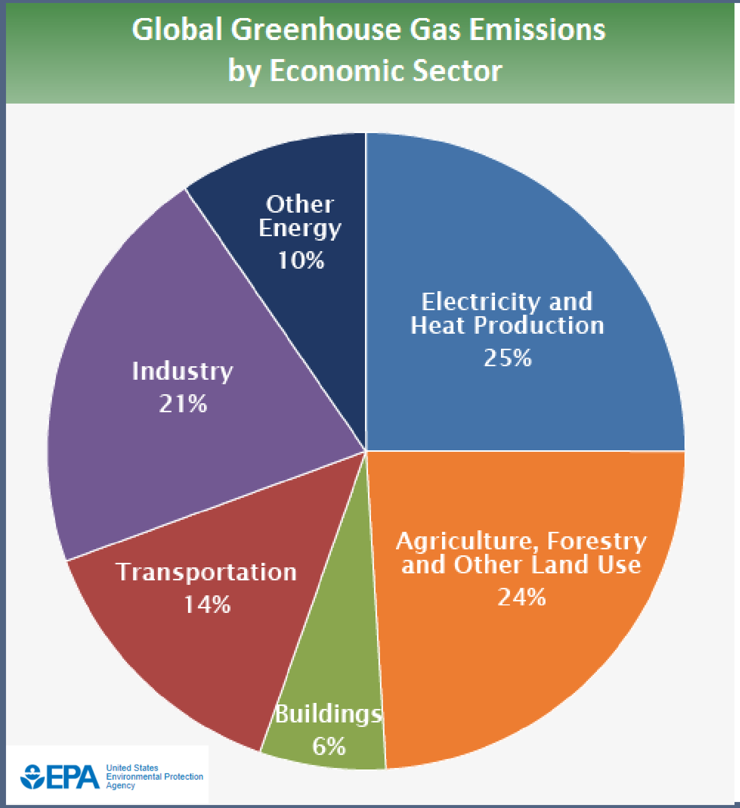
Hydrogen

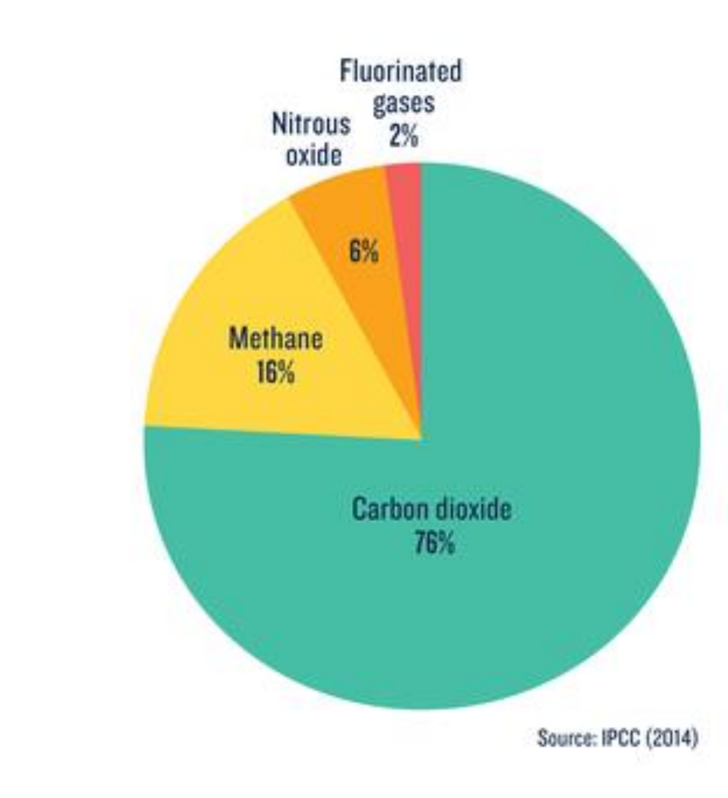


Fuel	MJ / kg	kg CO_2 / GJ Fuel
Coal	20	101
Diesel	46	68
Methanol	23	61
Methane	55	49
e-Ammonia	18	0
Hydrogen	143	70
e-Hydrogen	143	0
e-Methanol	23	Net Zero

Global Greenhouse Gas Emissions







Renewable Energy determined by the seasons & latitude

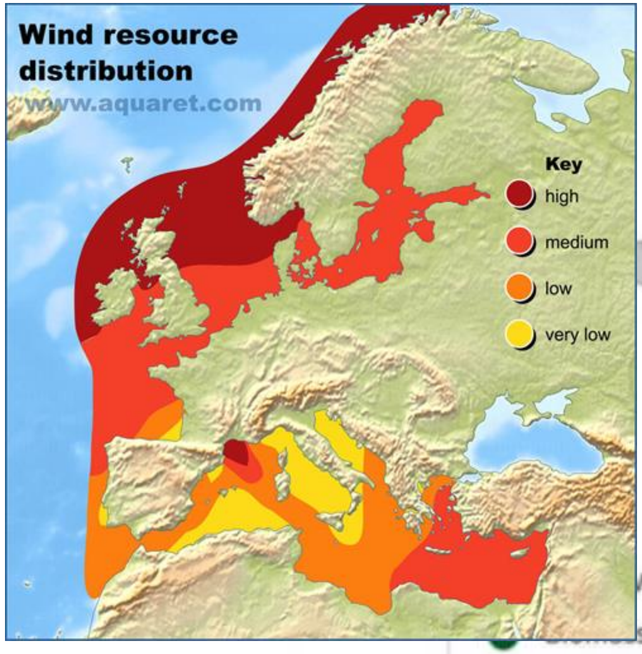



Image from Shutterstock

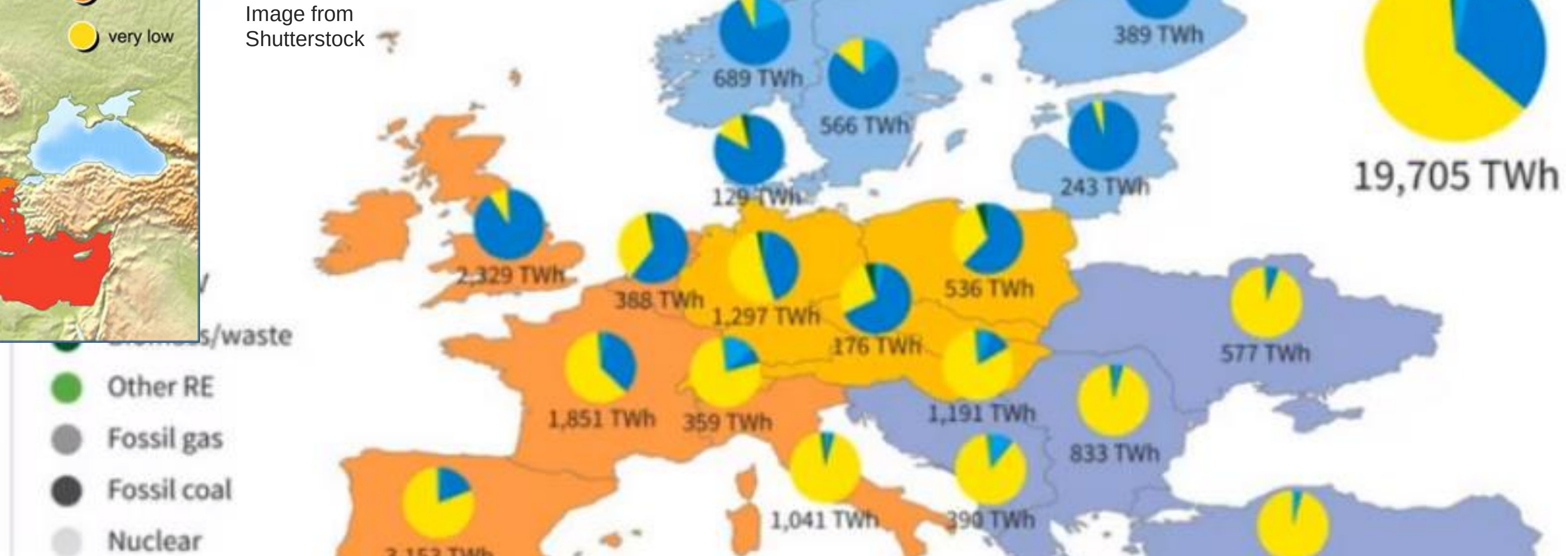
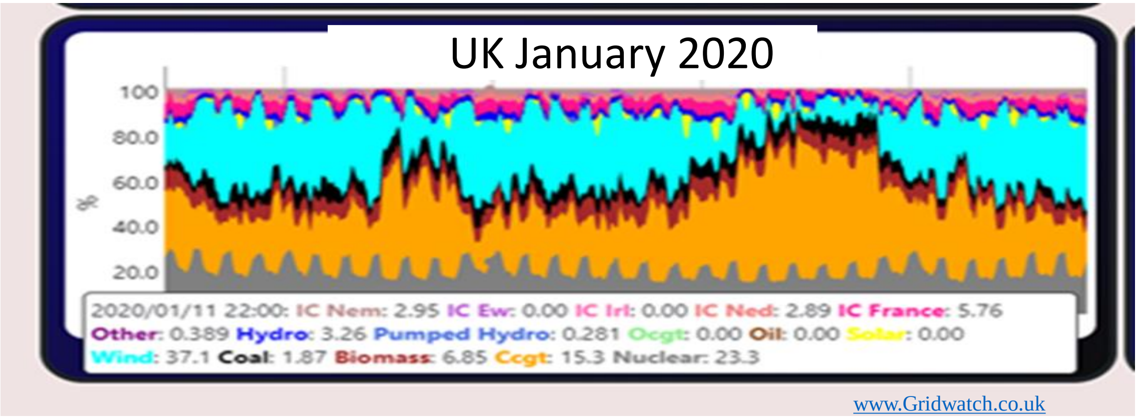


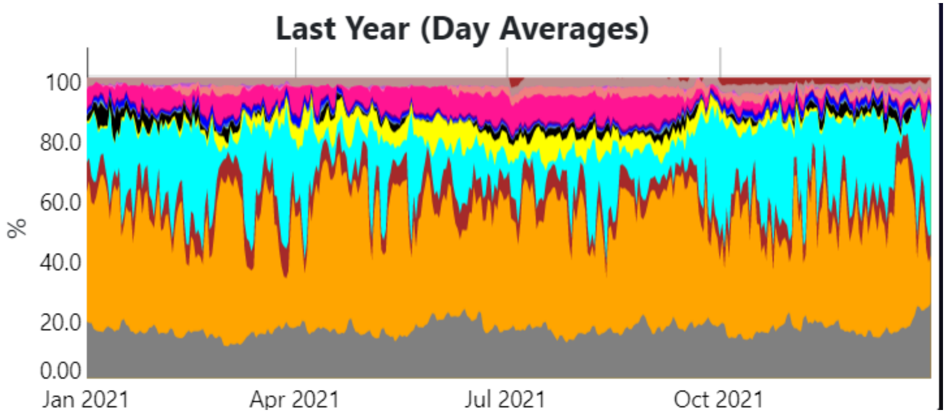

Image www.wikipedia.org

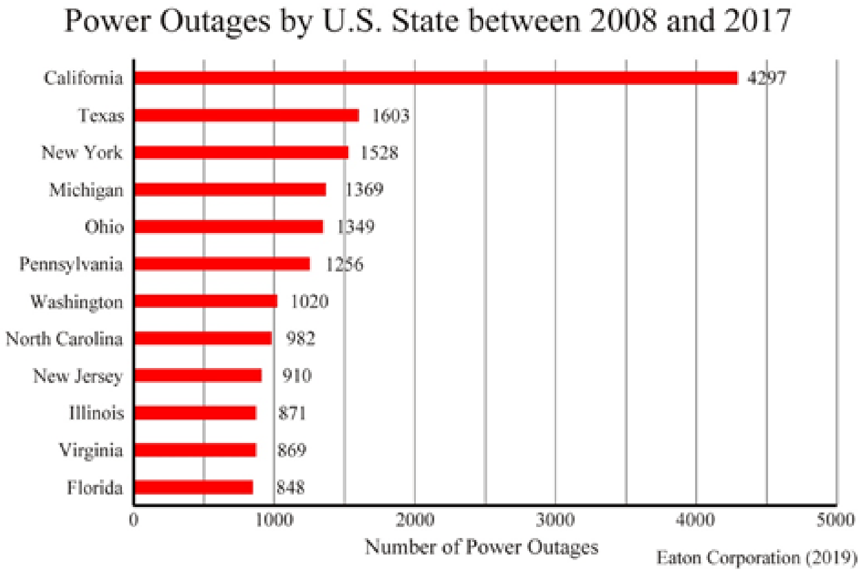

Image Semper Solaris


Image from Earth911

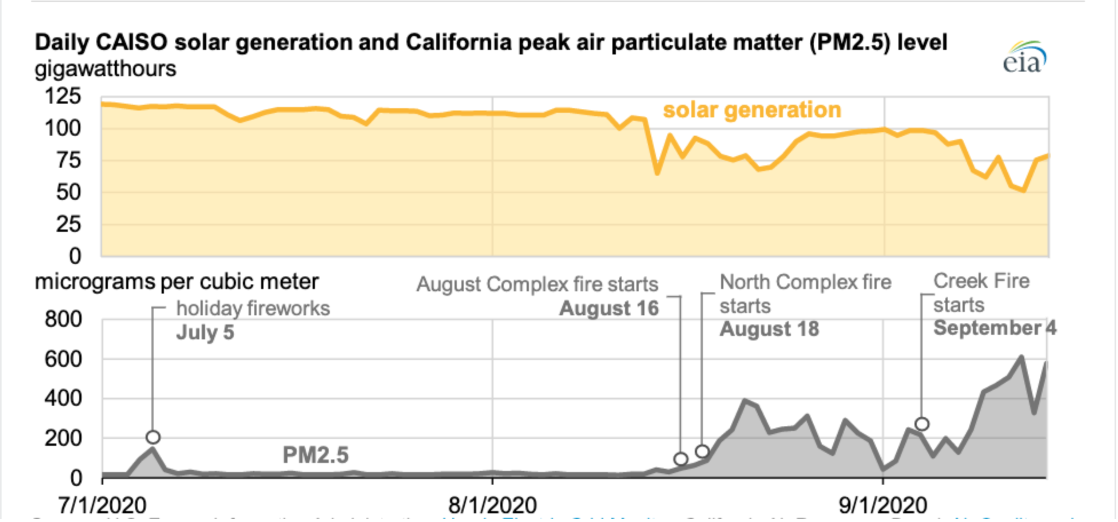
Risk of shortfall in the power capacity whenever the weather and seasons change







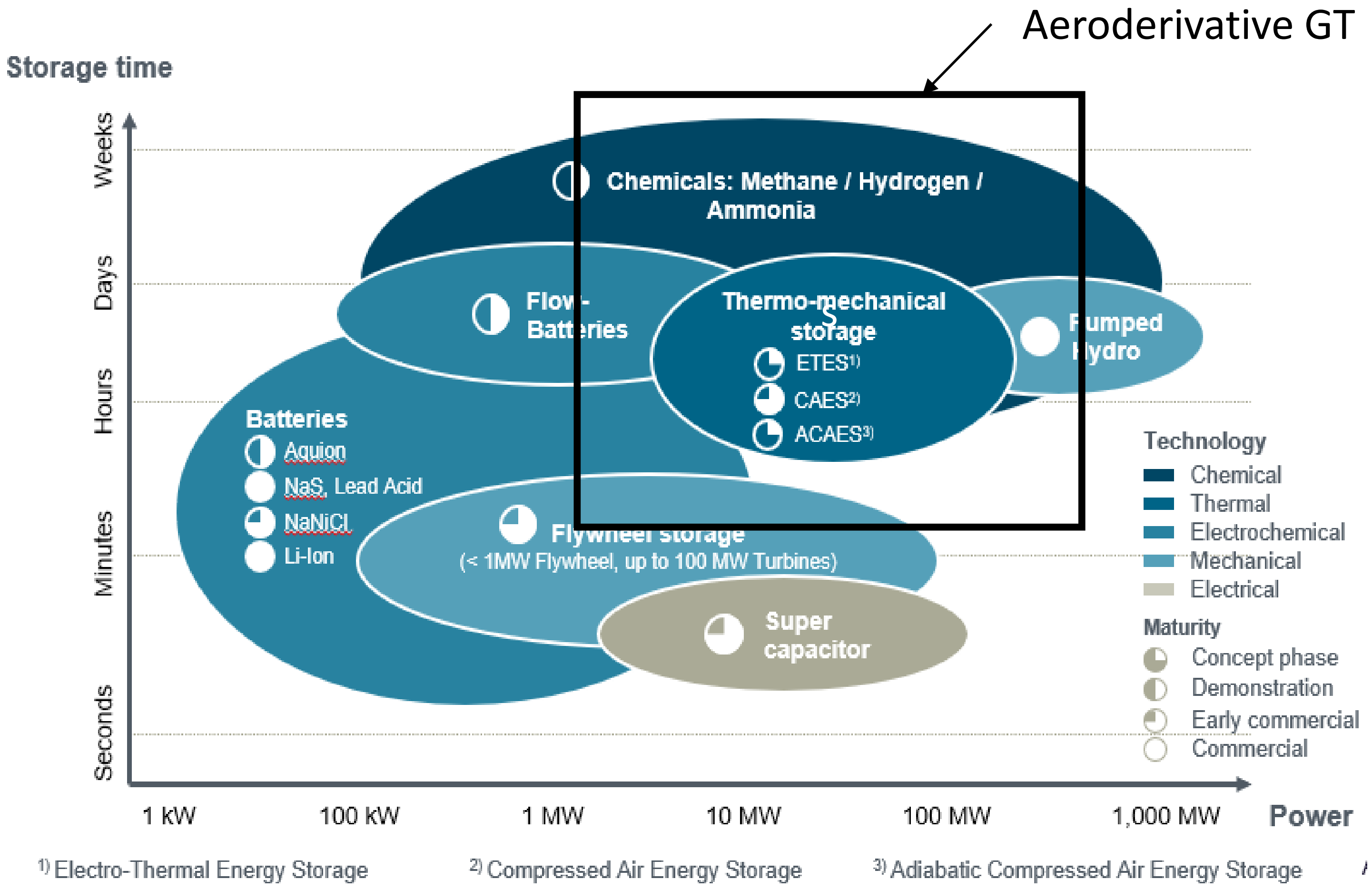
California wildfire reduces solar capacity by 13%



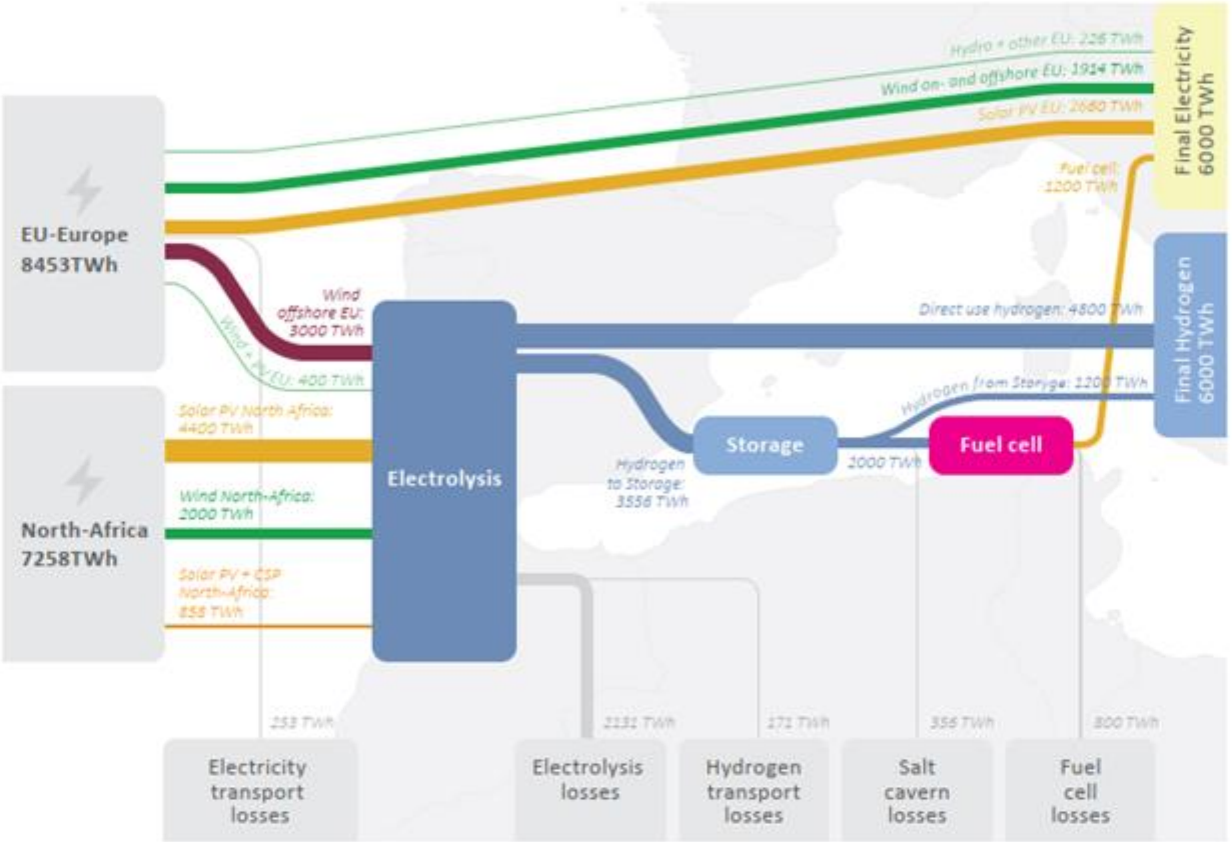
Source: U.S. Energy Information Administration, Hourly Electric Grid Monitor; California Air Resources Board, Air Quality and Meteorology System Note: CAISO=California Independent System Operator

Available power by the storage of energy

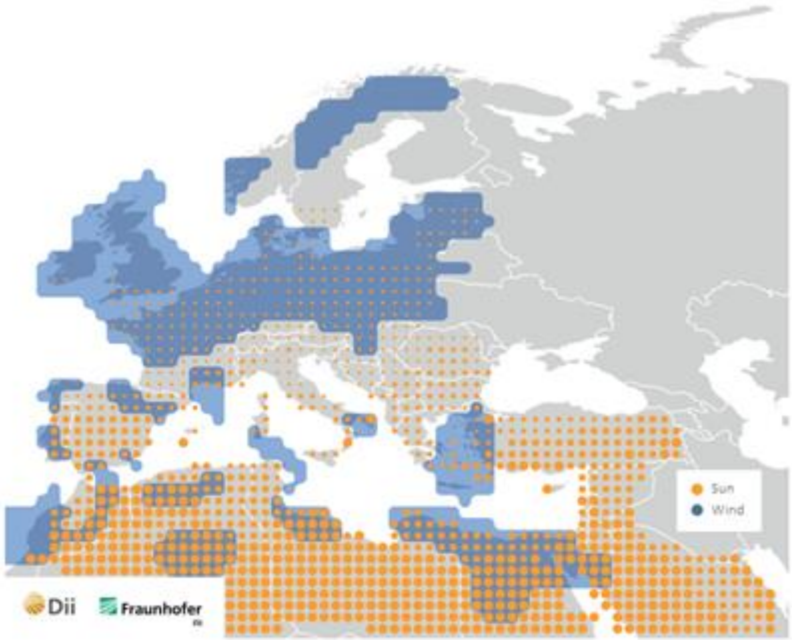
- "Engines" fueled from stored supplies of chemical energy provide;
- Short & medium term solutions
- For supplying continuous power whenever there are shortfalls in renewable generating capacity



“Europe’s back bone” plan to supply its Energy demand by 2050
Excess power from renewables is “<u>harvested</u>” for energy storage

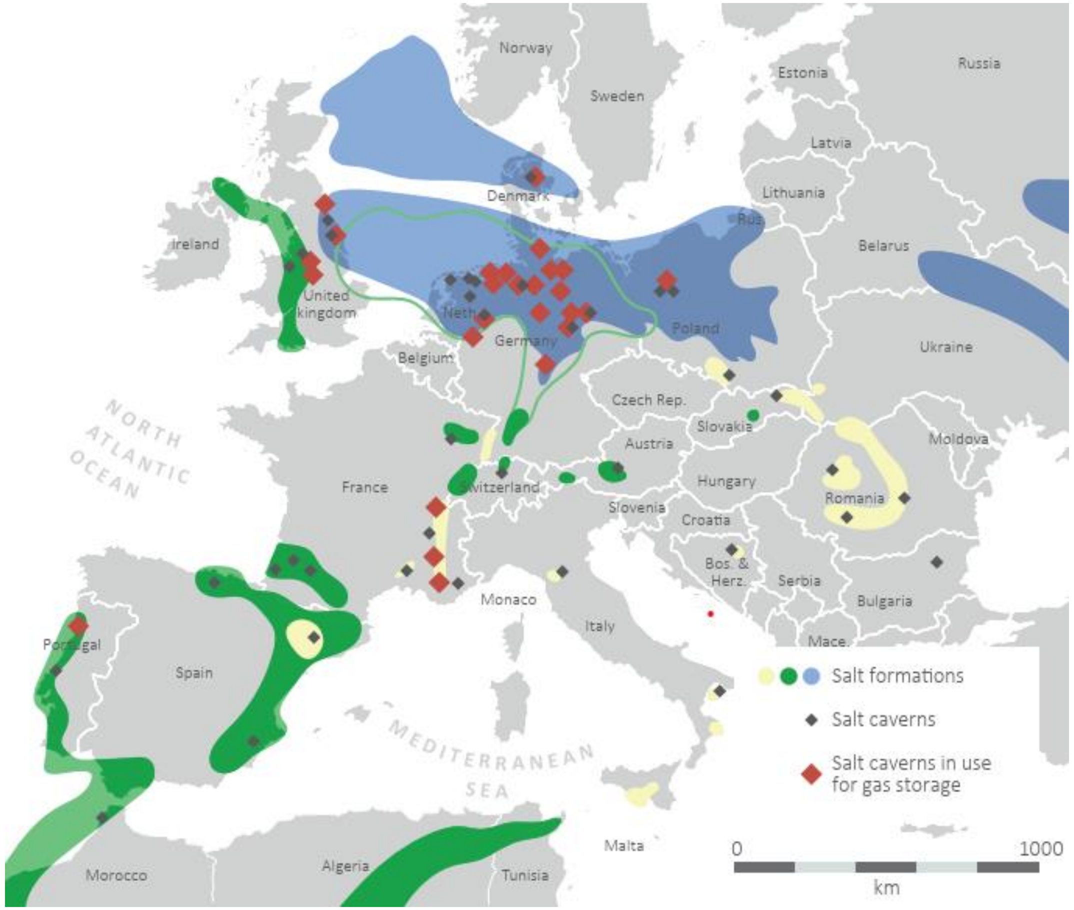


Dii A North Africa – Europe Hydrogen Manifesto Dii Desert Energy



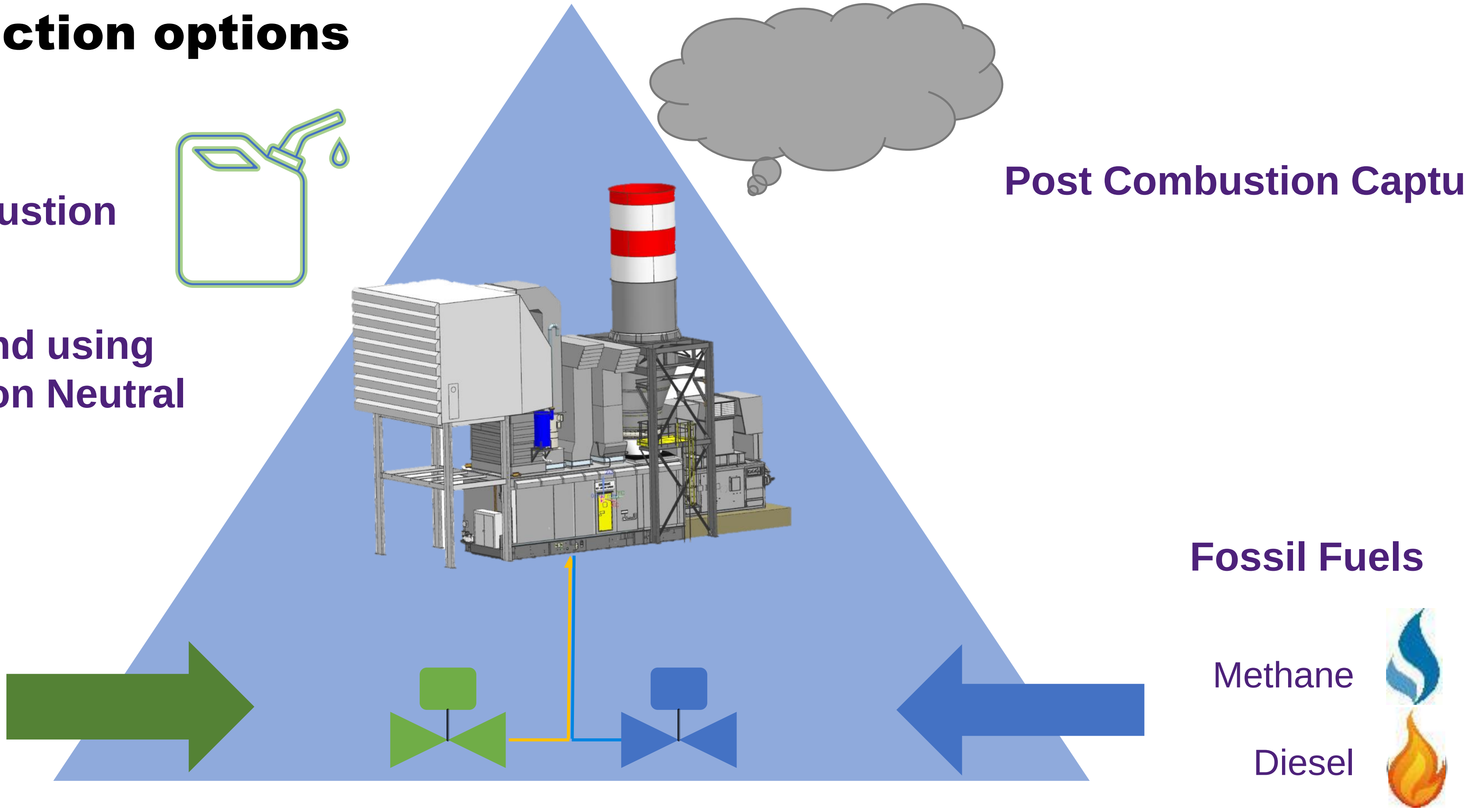
Large scale quantities of hydrogen transported through existing infrastructure of pipelines and storage caverns

Green Hydrogen for a European Green Deal A 2x40 GW Initiative, Hydrogen Europe, March 2020



Hydrogen - the bridge between – Africa –and -Europe Dr. Ad van Wijk Ir F Wouters

CO_2 Reduction options



CO_2 capture with Exhaust Gas Recirculation

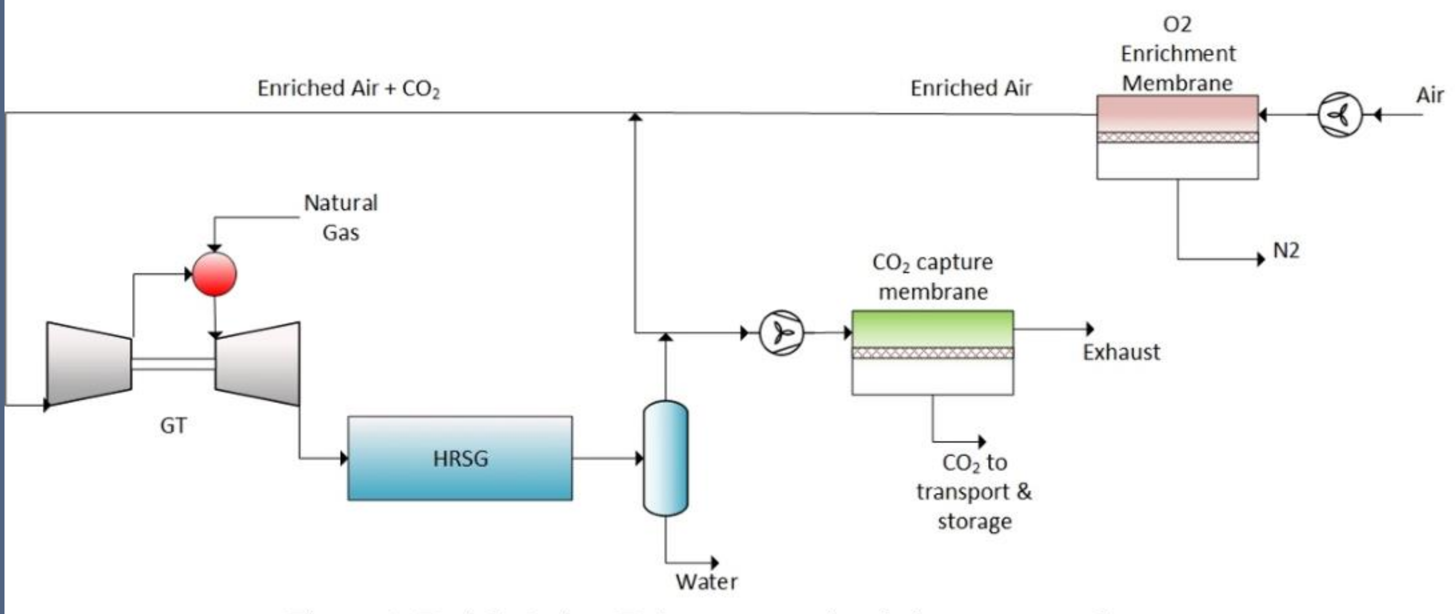


Figure 2: Enriched air + Exhaust gas recirculation process scheme

Image: R. Anantharaman, Simon Roussanaly, M. Ditaranto

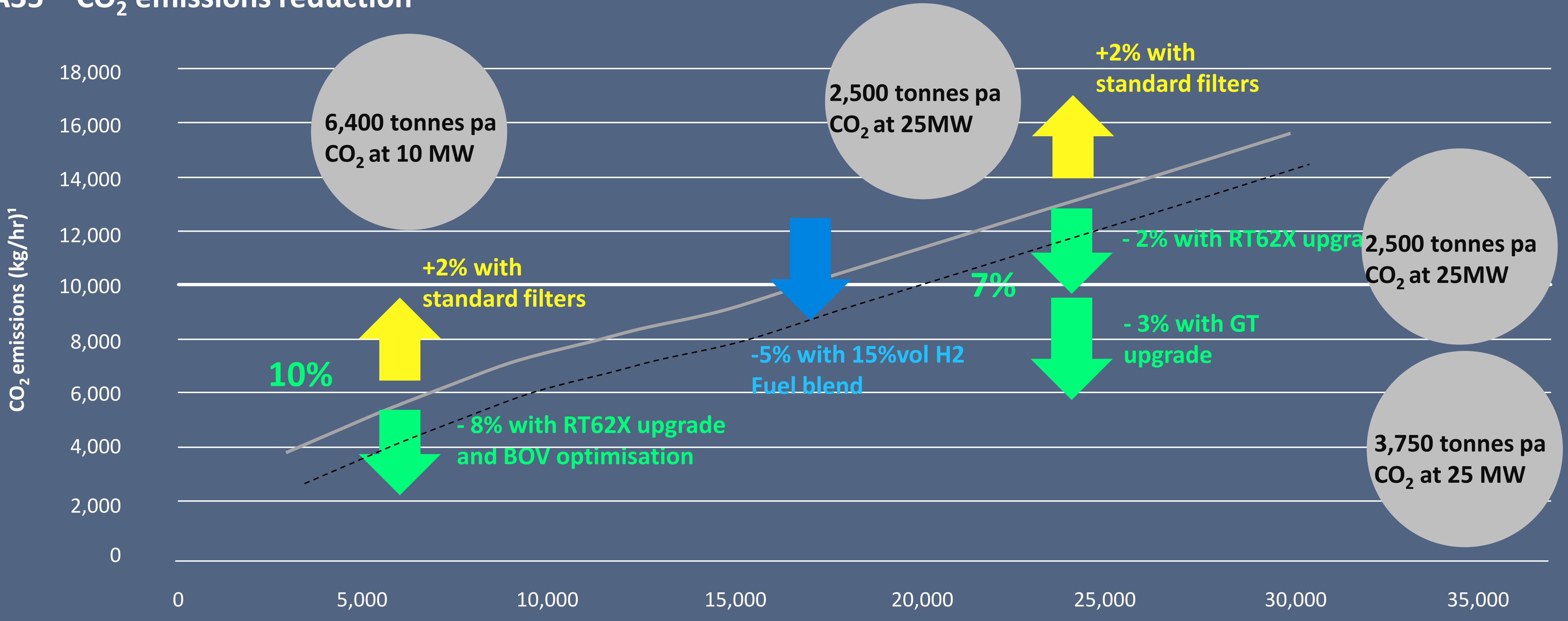
Amine based solutions require at least :
CO2 concentration of 9-14%

Typical gas turbine exhaust CO2 concentration 2.5-4%

Amine is organic derivative of Ammonia

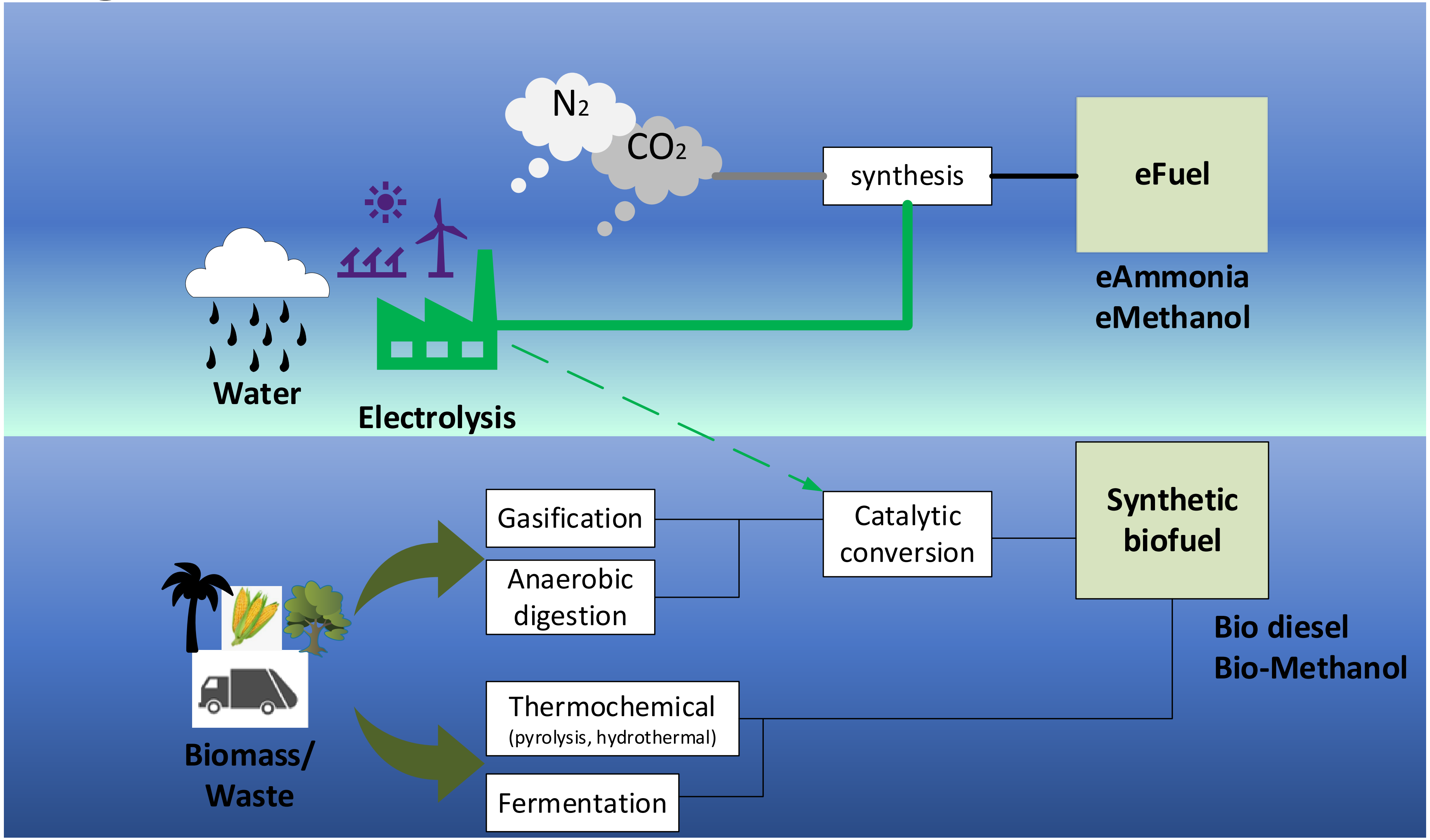
Product Efficiency Modifications

SGT A35 – CO_2 emissions reduction



[1]Methane natural gas

Synthetic fuels – Electro and Biomass manufactured fuels
.....knowing the source of fuel and how it is made sustainably



Alternative fuels

Biofuels

- Bio-methane
- Bio-propane
- Bio-Ethanol
- Bio-Diesel
- FAME[1]
- HVO[2]
- Fischer-Tropsch Bio-Diesel

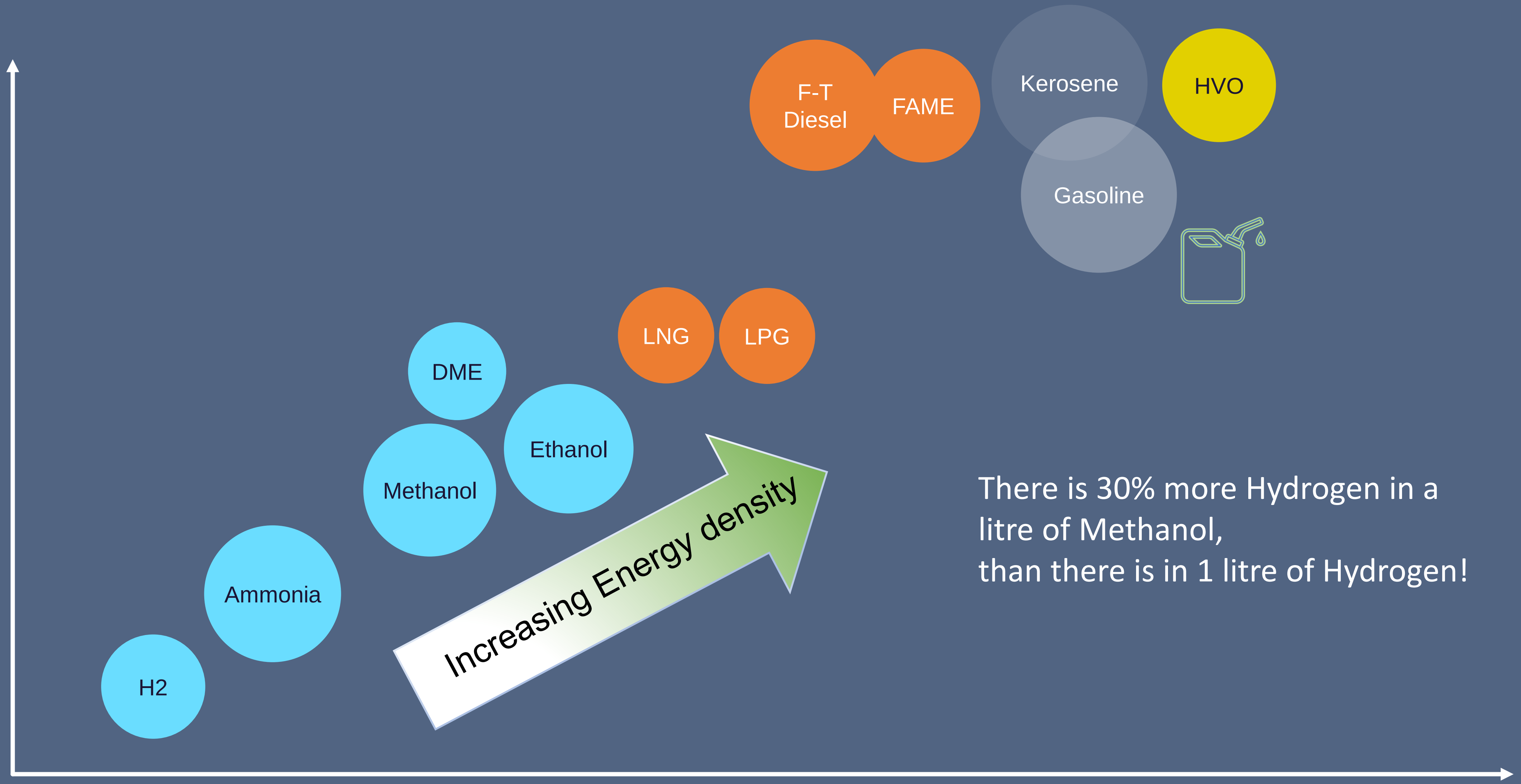
Electro fuels

- Hydrogen
- E-methane
- E-methanol
- E-Ammonia
- DME[3]

- Flexible operation using synthetic low and carbon neutral fuels
- Variety of fuels enable optimization based on availability and price fluctuations
- Fuel switch over whilst operating
- Blended operation on fuel mixtures (liquid and/or gaseous)
- Cleaner less particulate matter PM

[1]Fatty Acid Methyl Ester [2]Hydrogenated Vegetable Oil [3]Dimethyl ether

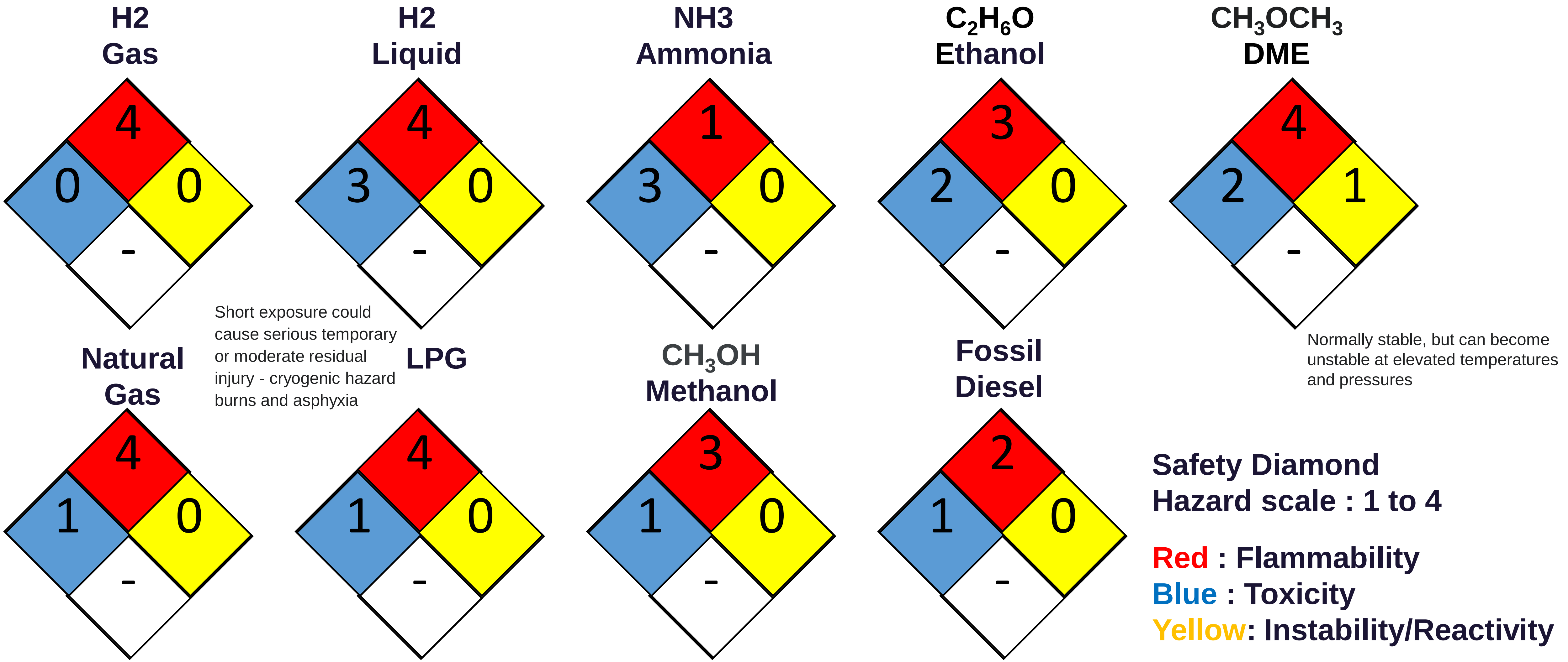
Energy Density



There is 30% more Hydrogen in a litre of Methanol,
than there is in 1 litre of Hydrogen!

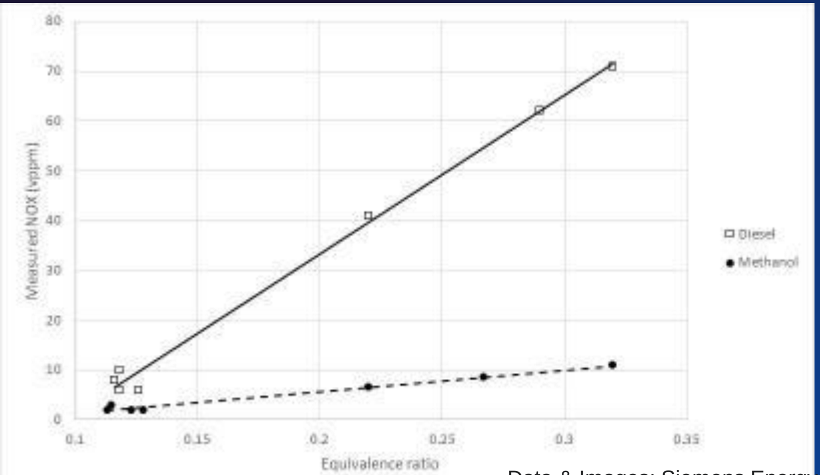
Health and Safety

……important choices to protect people and the environment



National Fire Protection Association (NFPA) 704 Safety square or fire diamond

e-Methanol
Alternative to diesel with lower NOx



Rig tests of Industrial Olympus produced 80% less NOx

270 million litres of Methanol produced from 360,000 tonnes of municipal waste from 700,000 homes saving 300,000 tonnes of CO2

- Methanol benefits **established infrastructure**
- 9% less CO2 using grey methanol versus diesel
- 10% power boost
- 80% Lower NOx emissions – Low combustion temperature
- Biomass or Electro - renewable **H_2** with **CO_2** from waste
- Practical alternative for long-distance transportation
- Environmentally friendly – **Biodegradable**
- No SO2 emissions – no sulphur
- No visible exhaust plume
- Alternative fuel to diesel for managing the Energy Transition

SGT-A20 Methanol Demonstration Test

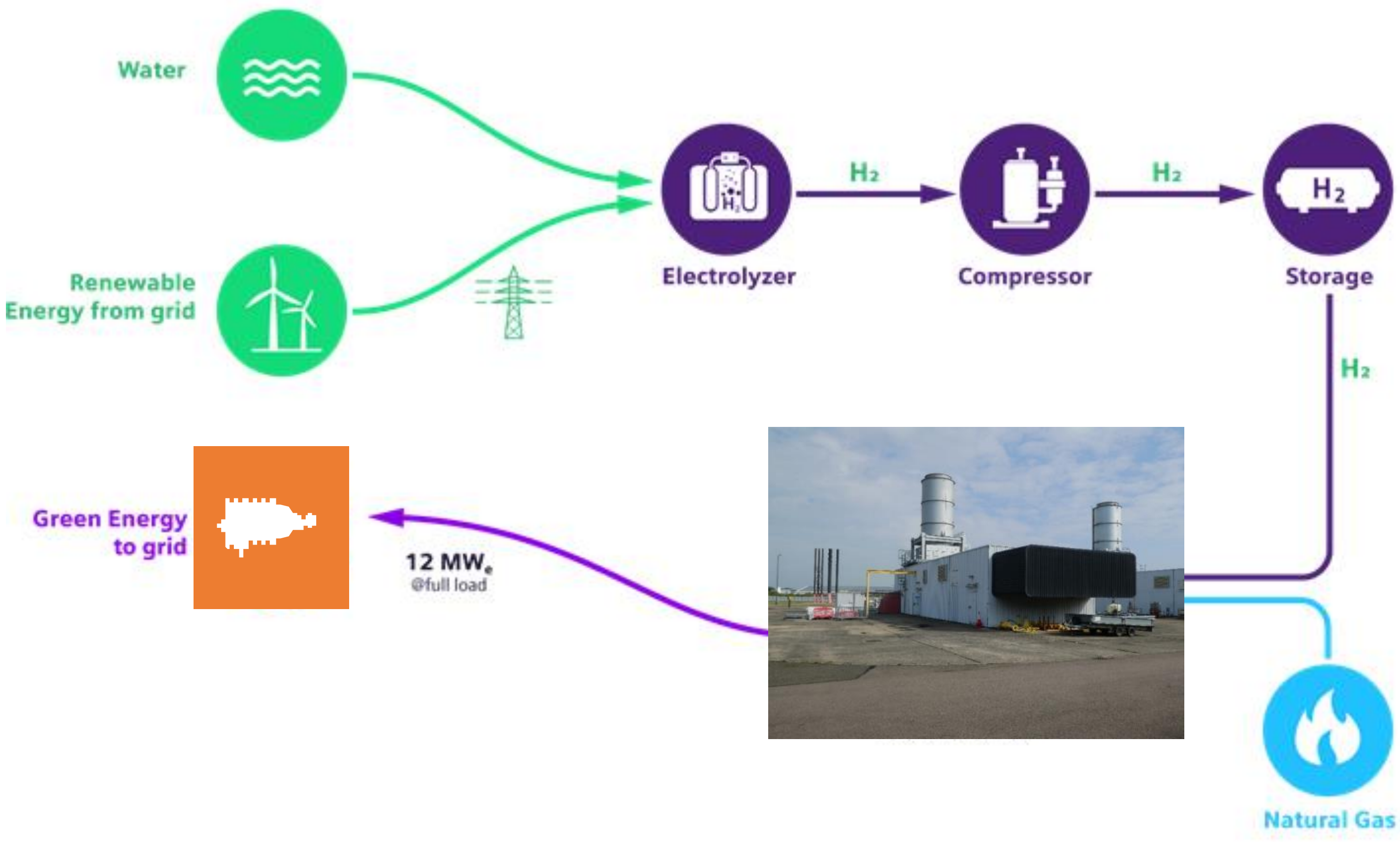
- Full performance and emissions testing of an SGT-A20 operating on methanol fuel.
- The demonstration test will take place at the RWG production facility in Aberdeen, UK.
- Installing higher capacity swirler burners into the gas turbine.
- Integrated methanol fuel system.

Hydrogen production & storage adjacent to plant

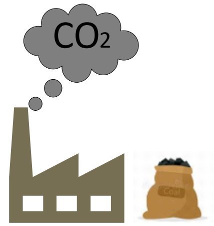
Carbon-free power produced from stored excess renewable energy

CO_2 saving 65,000t/yr

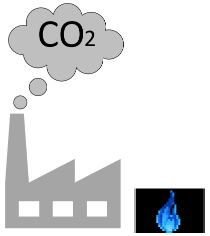
Power to X – Gas turbine fueled with Renewable Energy



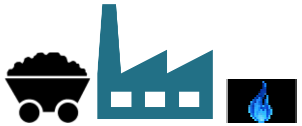
Hydrogen Spectrum
.....knowing the source of fuel and if it is made sustainably



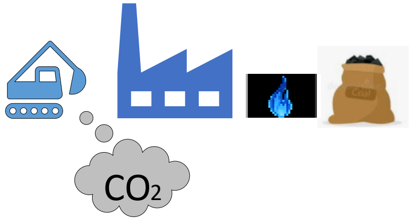
Black/Brown
H2 extracted from coal using gasification



Grey
H2 extracted from natural gas using steam reformation

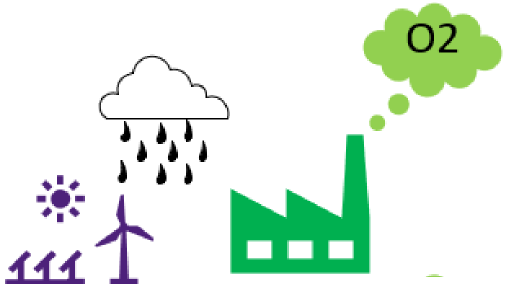


Cyan/Turquoise
H2 produced by thermal splitting of methane (Pyrolysis)



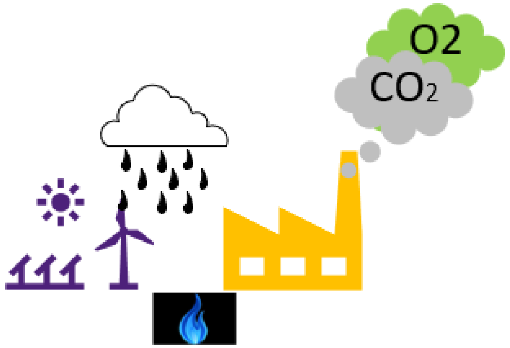
Blue
H2 produced from fossil fuels & CO2 is captured and stored

Green
H2 produced by electrolysis of water using renewable energy

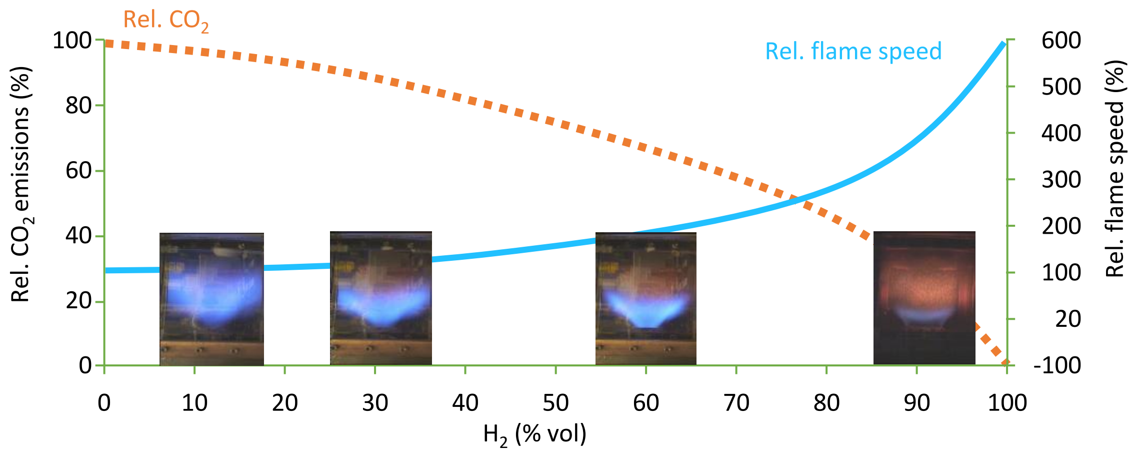


Pink/Purple
H2 produced by electrolysis using nuclear energy

Yellow
H2 produced by electrolysis using power from grid



Hydrogen Challenges for Gas Turbines



Values shown are relative to natural gas (indicative only)

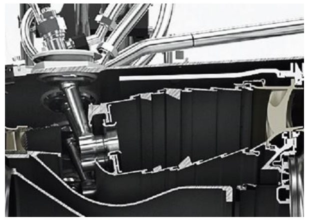
Combustion Systems

DLE – Dry Low Emissions

- Premixing of fuel and air to control flame temperature and therefore emissions

WLE – Wet Low Emissions / Aero Combustors

- Diffusion flame combustion systems – no premixing
- Water used for controls of lame temperatures and emissions



Challenges

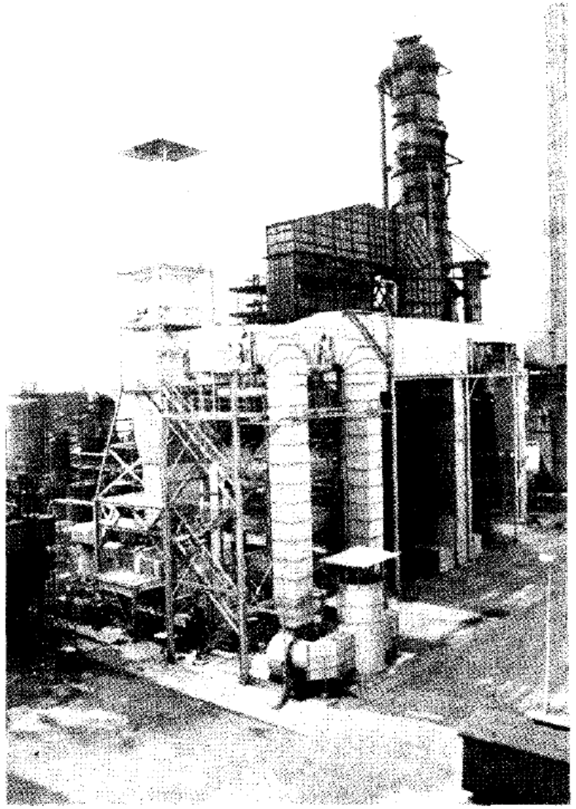
Combustion

- **Higher reactivity** pushes flame towards burner, increases risk of flashback for DLE
- **Higher flame temperature** can lead to local hotspots if imperfectly mixed and thus increased NOx emissions

Fuel System and Package

- **Higher diffusivity** requires assessment of leakage and material, as well as gas detection
- **Lower volumetric energy content** requires larger flows to be handled by fuel system
- **Low flame radiation / luminosity** requires hydrogen-specific flame detectors

Hydrogen fuelled SGT-A20 Rotterdam



BRIEF DESCRIPTION OF SUCH A TYPE OF CO-GENERATION IN OPERATION

Process

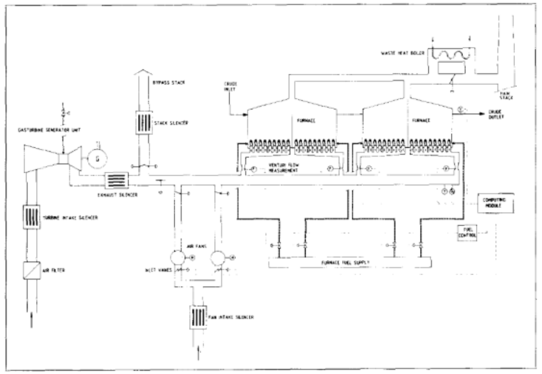
The co-generation system that will be described hereafter consists of a gas turbine in combination with two crude furnaces. The furnaces have a total throughput of 220.000 barrels per day.
It is installed at the Chevron/Texaco Refinery at Pernis Rotterdam.
Figure 10 shows the process flow scheme of this installation.
Figure 11 gives a picture of the total installation.
The gas turbine is a Rolls-Royce Avon type 1535 with a base load output of 14.4 MW at ISO conditions.

The gas turbine operates with two fuel sources, one is natural gas from the Gasunie and the other is hydrogen gas from the reformer. The fuel system is designed to operate the gas turbine on either fuel type or a mixture of both.

The gas turbine supplies approx. 78 kg/sec. exhaust gases to the crude furnace burners at a temperature of 470°C. The oxygen content of the gases is 15.5% vol.

The furnaces were originally of the natural draft type.
With the modification to a co-generation system they were changed into forced draft type, however, in such a way that there still exists underpressure in the firebox.

Under normal conditions the gas turbine provides sufficient oxygen to the furnace.
However, parallel operation with a fan is possib!e.
In that case the fan capacity is controlled by inlet guide vanes.
The guide vanes are controlled by the fuel/air control of the furnaces.



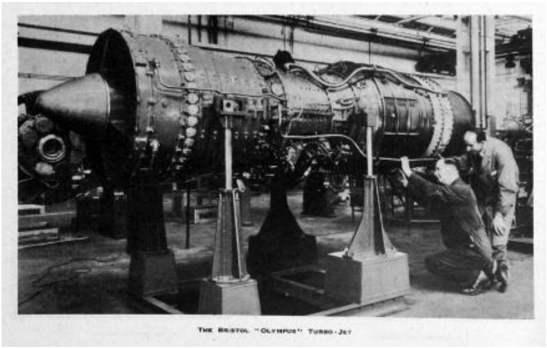
Co-generation system at the Chevron / Texaco refinery, Pernis Rotterdam

Project Gas	H2 rich refinery gas Normal min. H2	Normal max. H2	Highest H2 on record	Natural Gas min. LHV	avg. LHV	max. LHV
	(% mol.)	(% mol.)	(% mol.)	(% mol.)	(% mol.)	(% mol.)
Methane	11.4	7.7	5.3	85.2	87.6	89.1
Ethane	14.7	7.2	4.4	5.4	5.6	5.4
Propane	6.8	4.1	2.3	1.1	1.1	1.5
I Butane	2.9	1.8	0.9	0.2	0.2	0.3
N Butane				0.25	0.2	0.3
I Pentane	0.5	0.6	0.3	0.1	0.1	0.1
N Pentane						
Hexane	0.6	0.6	0.9	0.1	0.1	0.1
N Heptane						
N Octane						
N Nonane						
N Decane						
undecane						
Hydrogen	63.1	78	85.9			
Carbon monoxide						
Nitrogen				7.35	4.3	1.85
Carbon Dioxide				0.2	0.8	1.45

“Application of Gas Turbine Operators for Preheating Combustion Air with Conventional boilers or Furnaces”,
84 GT 161 – ASME American Society of Mechanical Engineers
J Davidse, J Roukema – Comprimo BV, Amsterdam, The Netherlands 1983

Siemens Energy “Aeroderivative” Hydrogen Fleet Experience

Image: Siemens Energy



Milford Haven
United Kingdom
47-60 vol% H2
1 x SGT-A20

Hours total: 104K

Pernis Rotterdam
Netherlands
63-85 vol% H2
1 x SGT-A20

Hours: 100K

Propylene Plant
United States
Up to **15 vol% H2**
5 units (+1 spare) SGT-A20

Hours: First unit 30K overhaul Oct. 2014

Coal Gasification Plant
United Kingdom
26-31.5 vol% H2
1 x Industrial Olympus SK30

Hours: 1166

+230K hours of recorded operation on Hydrogen fuels (up to 85 vol%) since 1968

Up to 32 vol% hydrogen: +150K hours   47-85 vol% hydrogen: +80K hours

Siemens Energy Aeroderivative Gas Turbines Hydrogen Capability

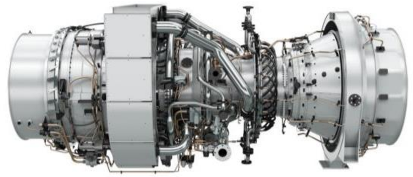
Gas turbine	Power Output[1]
SGT-A65	60 to 71/58 to 62 MW
SGT-A45	41 to 44 MW
SGT-A35	27 to 37/28 to 38 MW
SGT-A20	12 to 17 MW
SGT-A05	4 to 6 MW

Hydrogen Capability (vol%)

DLE | Aero | Diffusion burner with unabated NOx emissions

[1]ISO, Base Load, Natural Gas

Values shown are indicative for new unit applications and depend on local conditions and requirements. Some operating restrictions and special hardware and package modifications may apply.



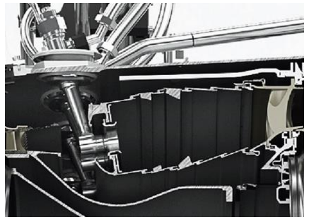
SGT-A65 WLE

SGT-A35 WLE

SGT-A20

SGT-A05

Aero Diffusion Combustion Systems



- Capable of Co-firing with natural gas up to 100% H2
- Same power rating on 100% H2 as high-methane natural gas
- NO_x < 25 vppm with water injection
- Stable flame
- Flashback resistant

Dry Low Emissions Combustion Systems

For 15 vol% hydrogen, no change for new units to:

Emissions capability

Component life and overhaul interval

Power rating

Data & Images: Siemens Energy

Primary package systems requiring modification with increasing Hydrogen blends

<30 vol% H_2

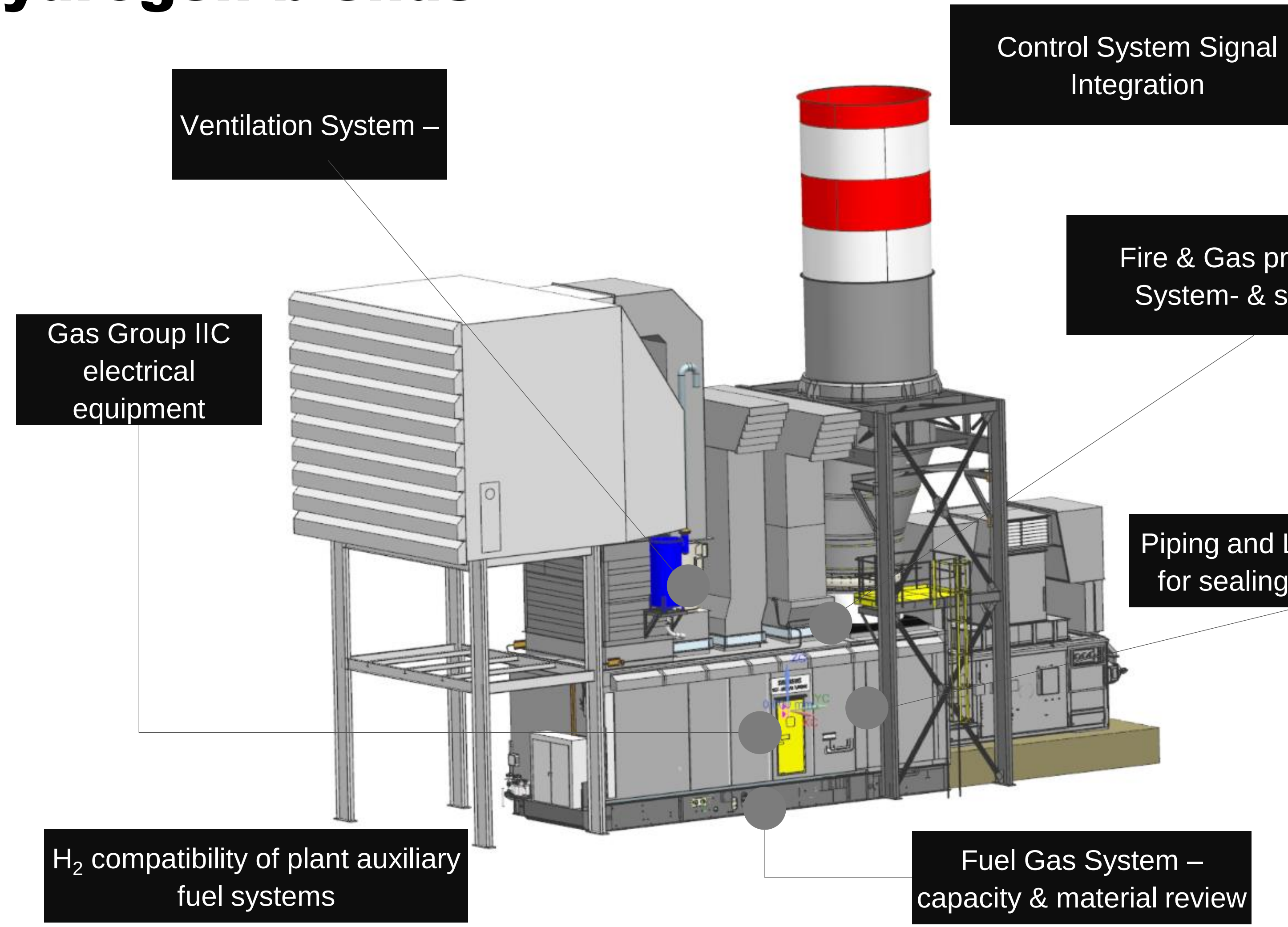
Core: No Changes

[1]Package: potential modifications, confirm through engineering assessment

≥30 to 100 vol % H_2

Core: No Changes

Package: [2] Re-certification with respective authorities, sub-system capacity increase, safety protection



[1] Site survey recommended to assess older equipment, [2] IEC 60079-10-1 H2 hazardous area classification

[3]BS EN ISO 80079-20-1:2019 *Explosive atmospheres - Material characteristics for gas and vapour classification*

Micro Mixing Technology for combustion of H2 with low NOx

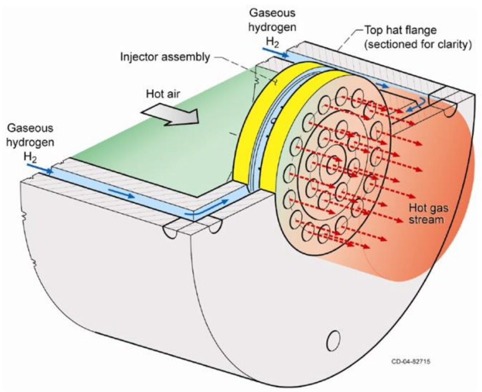
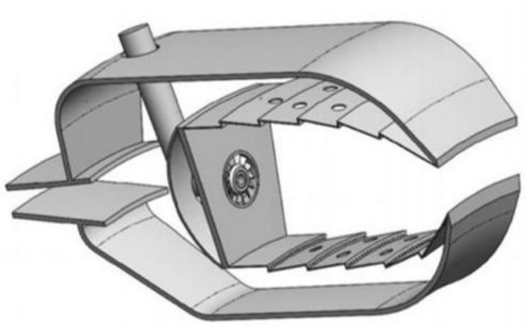
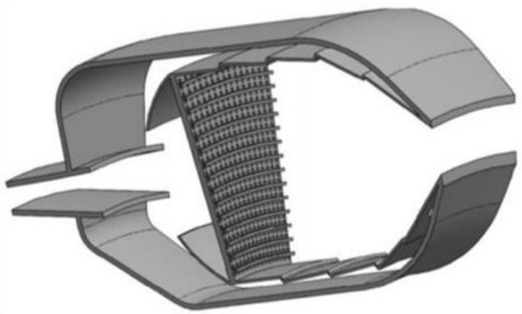


Figure 6: NASA low emissions LDI hydrogen combustor assembly.



Aero combustor



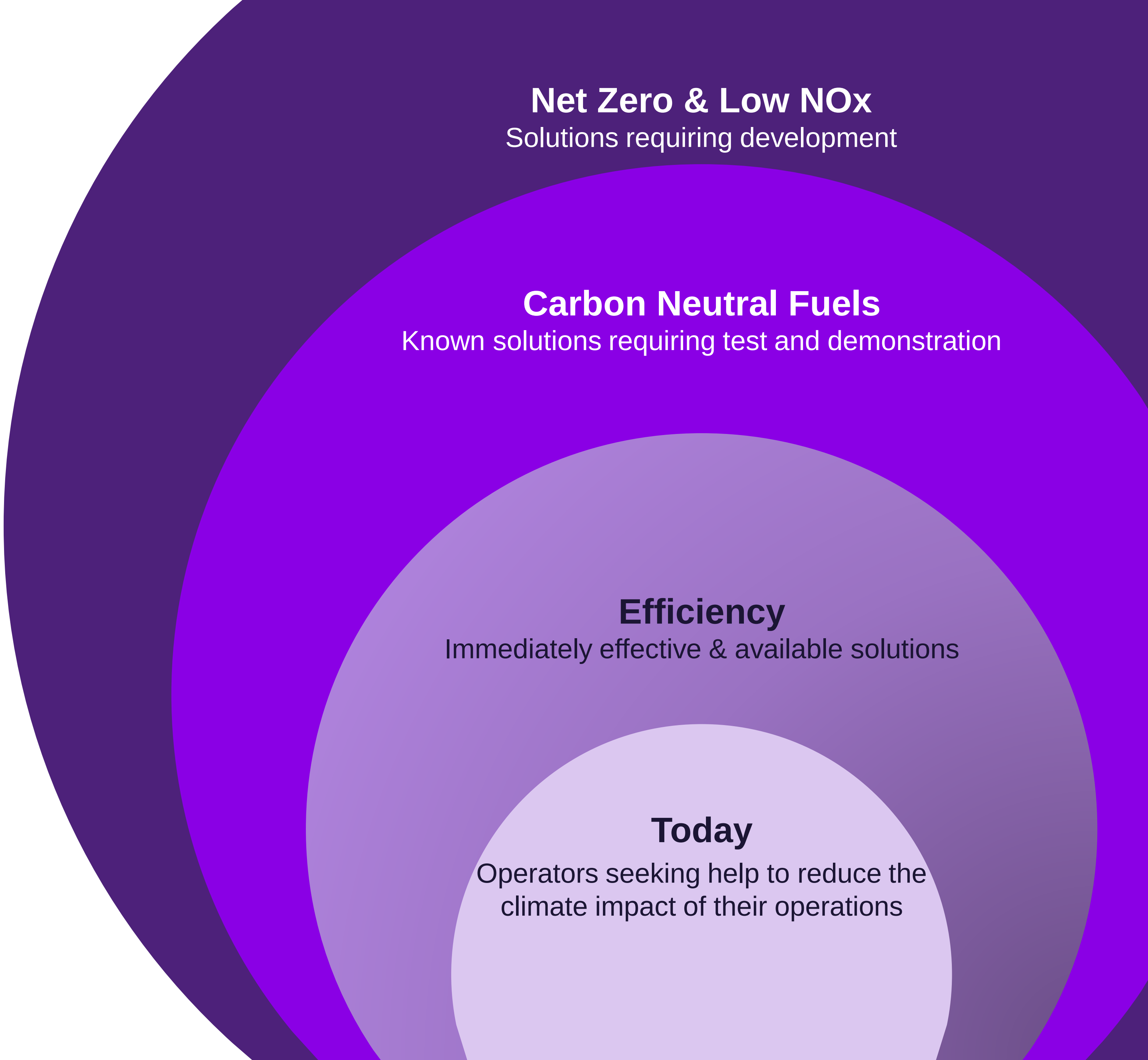
Compact Micro-mix combustor

Multi-nozzle combustor technology provides:

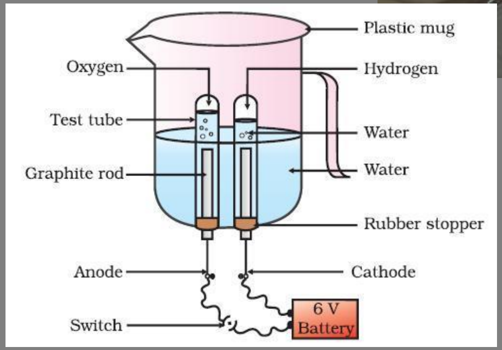
- a greater resistance to flashback resistance and achieve control for low NOx combustion
- enabling mixing to be performed in a shorter time and in a narrow space, with a greater number of nozzles
- greater number of smaller scale mixtures of air and hydrogen removes the need for swirling flow,
- Each nozzle hole is made much smaller, into it is fed both air with hydrogen blown into it.
- injects air from the tip of the nozzle to raise the flow velocity of the vortex core, this compensates for the low flow velocity region of the vortex core and prevents the occurrence of flashback.

Aeroderivative Gas Turbine Decarbonization Solutions

- Faster starting, efficient and reliable
- Proven fuel flexibility experience
- Capable of Co-firing with natural gas up to 100% H_2 (DLE 15%vol H_2)
- Low risk for managing the Energy Transition
- Efficiency solutions and modifications
- Low NOx Technology roadmap 2030



Questions?


Plastic mug
Oxygen
Hydrogen
Test tube
Water
Graphite rod
Water
Rubber stopper
Anode
Cathode
Switch
6 V Battery

Questions?

Q1 - How much Hydrogen can be manufactured from water contained in Olympic Swimming pool ?

a) 1000 kg b) 100 tonne c) 200 tonne d) 1000 tonne?

Q2 –what can you do with the H2 manufactured ?

a)1 x SGT-A20 for 1 week b) 2 x SGT-A35 for 2 days c) 10 x SGT A65 for 5 hours

Q3 – How much energy is required to make the H2?

a)3000 homes annual b) city of 100,000 people 1 month c) daily consumption of NYC

Siemens Energy Aeroderivative Gas Turbines

- emergency and peak duty
- start up and accept full load rapidly preventing shutdown of grid
- Remote oil & gas production facilities
- Transportation of oil & gas across continents N America, Asia, Europe through pipelines to consumers

(Image: BP)

(Image: BP

(Image: TC Energy)

SGT-A65

SGT-A35

SGT-A20

SGT-A05

World's largest renewable energy storage project ACES (Advanced Clean Energy Storage) & Intermountain Power Agency, Utah

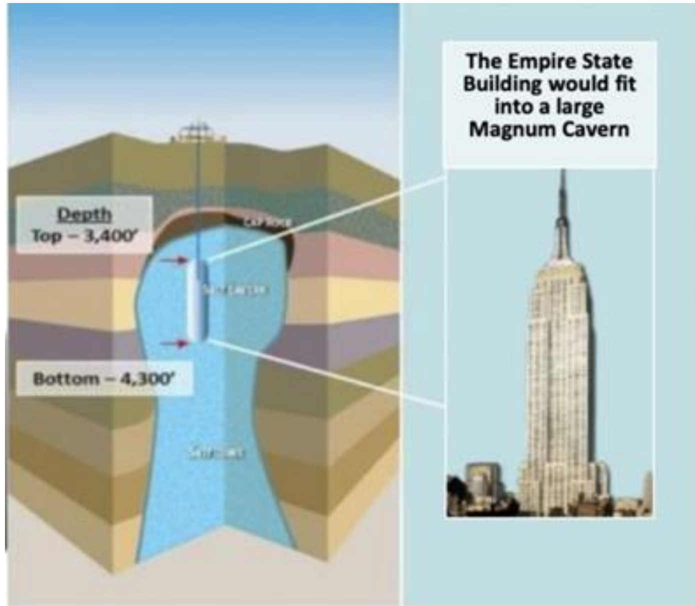
Los Angeles Times

$1.9 bn project to produce clean H_2 from excess renewable energy and stored in underground salt caverns.

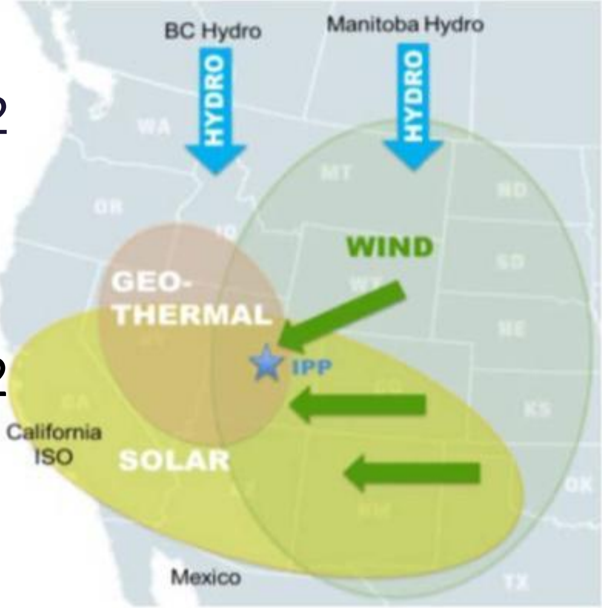
Entry into service 2025 where the turbines will initially operate 30 vol%H2

Ten caverns contain 37500 tonnes of Hydrogen enough for two weeks continuous operation with 100 vol%H2

Adjacent to 1800 MW Intermountain Power Agency power station providing one-fifth of Los Angeles' electricity



Images: Los Angeles Department of Water and Power



Images: Los Angeles Department of Water and Power

Large scale green Hydrogen is the long term solution for energy storage

- 75 mill ton/year of H_2 is produced from methane
- 10 ton of CO_2 emitted for every 1 ton of H2 manufactured
- CO2 is required to be captured and stored to turn it into BLUE H_2
- To supply today's H2 capacity using electrolysis requires equivalent of Europe's electrical power generated in 2018
- This would require either ~1,500 GW Wind or ~2,500 GW Solar PV capacity
- H2 production projected to increase 10 fold to 650-750 mill ton per year by 2050.

Grey H_2 is produced using fossil fuels such as natural gas
Emission ~ 10t of CO_2 / t of H2
Status: **PROVEN, LOW COST**

Blue H_2 is generated using natural gas process with carbon capture & storage or usage
Status: PILOT STAGE

Green H_2 is generated using renewable energy sources in electrolysis systems
Status: **PILOT STAGE**

Cyan H_2 is generated using pyrolysis (molecule cracking with heat) process
Status: projects planned

Source: CEH 2018, SMR - Steam Methane Reforming