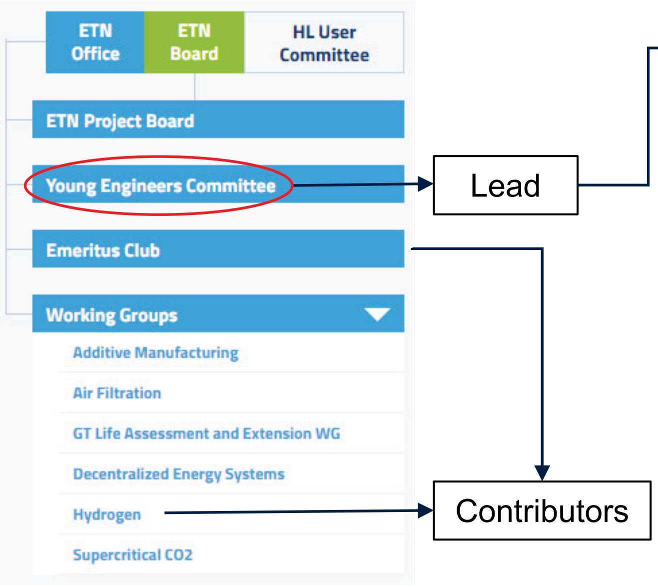
11th International Gas Turbine Conference
Dispatchable technology & innovations for a carbon-neutral society

ETN Global

Prerequisites for the use of low-carbon alternative fuels in gas turbine power generation

Lorenzo Pilotti, Politecnico di Milano

Framework of the study



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Young Engineers Committee (YEC)

- 35 members and growing
- Formed in 2020
- Chair switches every 3 months

SCAN ME

Outline

- Past work by the YEC
- Introduction
- Availability of alternative fuels
- GHG emissions reduction/European Taxonomy
- Alternative fuel composition and impurities
- Next steps
- Conclusions

Past works by YEC

ETN Global

Hydrogen Deployment in Centralised Power Generation

A techno-economic case study

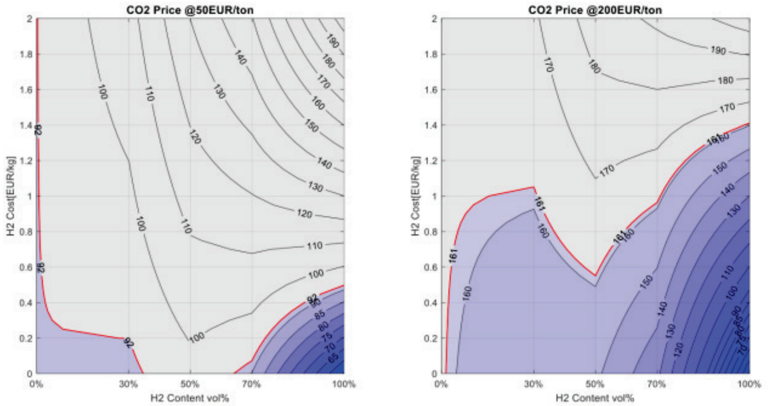
SCAN ME

Gas turbine type	GT Output (MW_e)	Configuration	Operating Regime	Annual Operating Hours	Designation
Small	20	OCGT	Peak	800	S-OCGT
Small	20	CHP	Base	6000	S-CHP
Medium	60	OCGT	Peak	800	M-OCGT
Large	450	OCGT	Peak	800	L-OCGT
Large	450*	CCGT	Base	6000	L-CCGT

* Combined cycle output = 650 MW_e

Hydrogen GT configurations considered

M-OCGT **LCOE maps** as function of H2 price and H2% content in fuel and different CO2 price (50€/ton on the left and 200€/ton on the right).



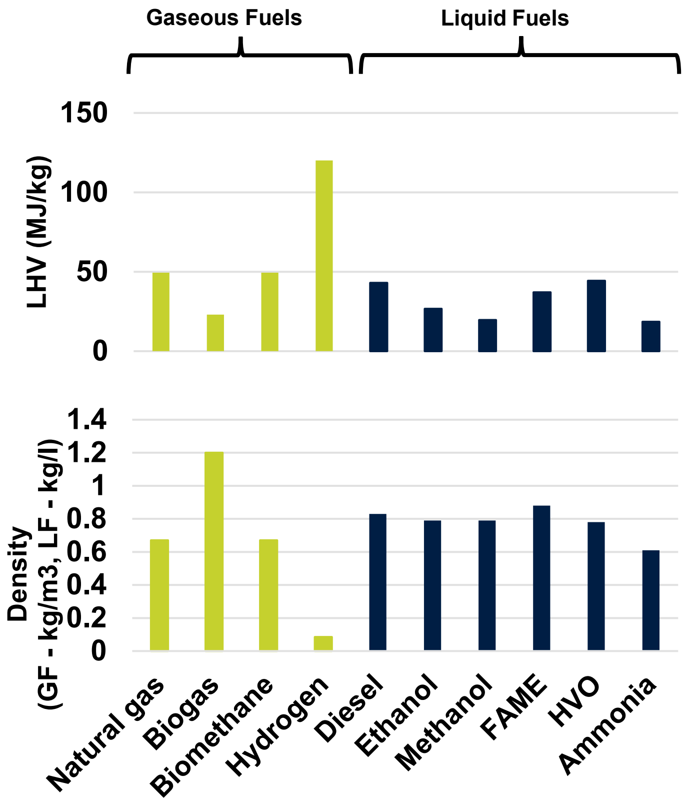
Introduction

Biomass or waste-derived fuel (biofuels):
- **Biomethane**
- **Biogas**
- **Biodiesel**

Alcohol-derived fuel:
- **Methanol**
- **Ethanol**

Hydrogen-derived fuel:
- **Ammonia**

Objective: **Identification of necessary prerequisites for use and establishing a common framework to compare these fuels to identify the most promising alternative fuel for GTs**



Commercial operation & testing of AFs

Fuel	Country	Operator (T = Test / C = Commercial)	GT OEM	GT	GT Output (MWe)	Year
Methanol	UK	RWG/Siemens (T)	Siemens	SGT-A20	15	2023
	Israel	Israel Electric Corporation (C)	P&W	FT4C	50	2014
	USA	Southern Calinfornia Edison (T)	P&W	FT4C	26	1979
	USA	Florida Power Corporation (T)	P&W	FT4C	24	1974
Ethanol	USA	LPP Combustion (T)	Capstone	C30	0.03	2014
	Brazil	Petrobras (C)	GE	LM6000PC	87	2010
	India	Reliance Energy (T)	GE	6B	48	2008
Biogas	Taiwan	Taipei Public Works Department (C)	Capstone	C30	0.03	2016
	Norway	Risavika Gas Centre (T)	Turbec	T100	0.1	2013
Biodiesel (FAME)	Switzerland	Groupe E (T)	GE	6B	36	2007
Biodiesel (HVO)	UK	Uniper (T)	Rolls-Royce	Olympus	17.5	2022
	Germany	Uniper (T)	KWU/Siemens	V93.1	63	2022
	Sweden	Göteborg Energi (T)	Siemens	SGT-800	45	2021
	Sweden	Uniper (T)	KWU/Siemens	V93.0	63	2021
Ammonia	Japan	AIST (T)	Toyota	TPC-50	0.05	2015
	USA	International Harvester Company (T)	Solar	T-350	250 hp	1966

Demand and availability of AFs

EU NG consumption for powergen in 2022: 1109 TWh

↓

20% retrofit of the current NG fleet with AFs

↓

Potential demand of 222 TWh (0.8 EJ) of AFs in EU

Power Generation

NG Consumption in EU27	1109 [1] TWh (2022) 253 [1] TWh (2050)
Alternative Fuel Potential in **EU27** - Retrofit – 20%	0.8 EJ / 222 TWh
Worldwide NG Consumption	6521 [1] TWh (2022)
Alternative Fuel Potential **Worldwide** - Retrofit – 20%	4.7 EJ / 1304 TWh

↓ 1.16 % of worldwide energy demand

1. ENTSOG and ENTSO-E, Ten-Year Network Development Plan (TYNDP) scenario report (2022): https://2022.entsos-tyndp-scenarios.eu

2. IEA, "World Energy Outlook 2022" (2022): https://www.iea.org/reports/world-energy-outlook-2022

Availability of bio-derived fuels

Sustainable Biomass potential by 2030 [1]

97-147 EJ

Sustainable Biomass potential after conversion losses [2]

85 EJ

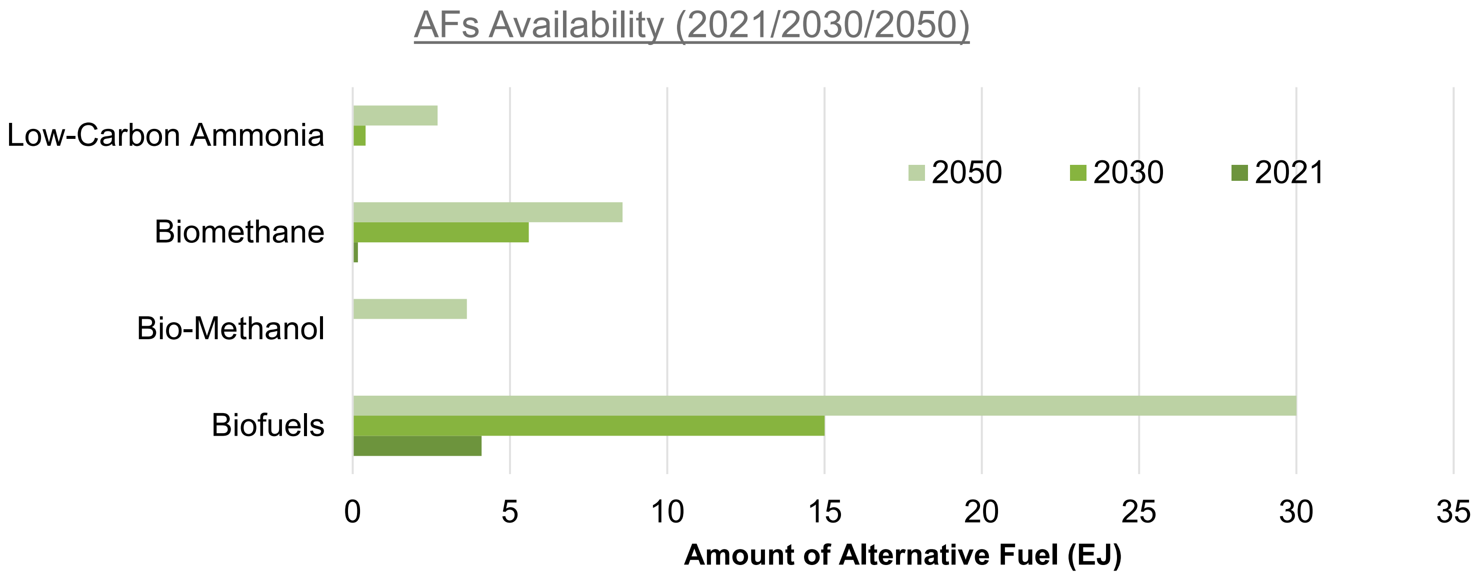
Sustainable Biomass Potential after conversion losses for biofuels [3]

40-45 EJ

10% would be enough to retrofit 20% of current GT for power generation

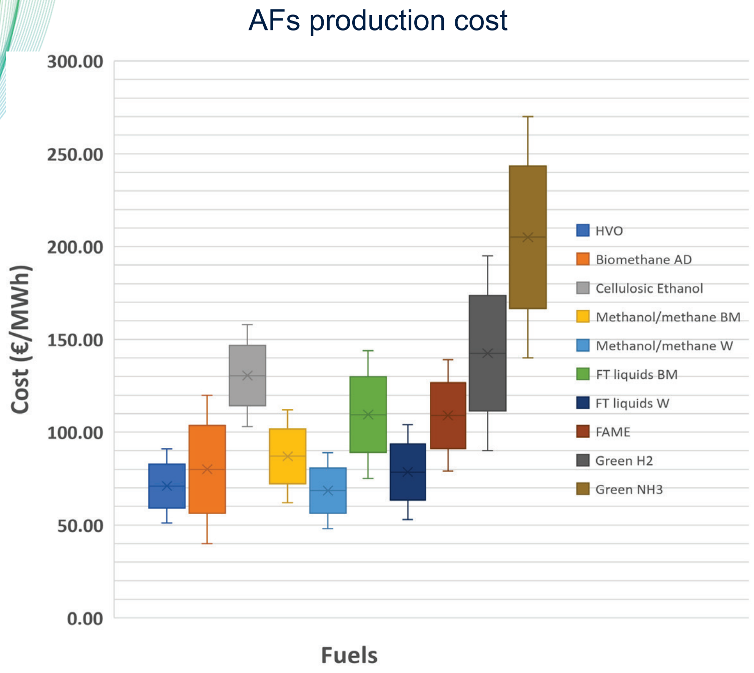
1. IRENA (2022) “World Energy Transitions Outlook 2022”: https://www.irena.org/Digital-Report/World-Energy-Transitions-Outlook-2022
2. Assuming biomass potential constraint to 100 EJ
3. Half would be directly employed by solid bioenergy for heat and power generation

Current and future availability of AFs



Biofuels (2021): Ethanol: 59%; FAME: 35%; HVO/HEFA: 6%. Sources: REN21, IRENA
Biomethane (2021) amount. Source: Statista
Biomethane (2030/2040) amount considering IEA SDS Scenario. Source: IEA
Ammonia (2030/2050) amount considering electrolysis, gas with CSS and coal with CSS. Source: IEA

Cost and main challenges



Fuel	Current Challenges
HVO	- Waste feedstock availability - Competition from transport applications
Biomethane – anaerobic digestion	- Low production volumes
Cellulosic ethanol	- Low feedstock availability - Poor retrofitability - Competition from transport fuel blending
Methanol and methane – biomass	- Low production volumes - Poor retrofitability
Methanol and methane – wastes	- Low production volumes - Poor retrofitability
FT liquids – biomass	- Lack of commercial production
FT liquids – wastes	- Lack of commercial production
FAME	- Long-term storage stability - Competition from transport fuel blending
Green hydrogen	- Efficient storage/transmission infrastructures - Low NO_x combustion system development.
Green ammonia	- Green hydrogen availability - Efficient ammonia synthesis - Geographic separation of production and use - Low NO_x combustion system development

GHG reduction

In Europe, **RED II*** set out the minimum requirements for GHG reduction for biofuels used in electricity, heating, and cooling:

- 70% (until end of 2025)
- 80% (from 2026)

$$GHG\ Savings = \frac{(EC_{F(h\&c,el)} - EC_{B(h\&c,el)})}{EC_{F(h\&c,el)}}$$

$EC_{B(h\&c,el)}$: carbon intensity of the electricity production from biofuel in use computed on a lifecycle basis (including the extraction and cultivation of raw materials, processing, transport and distribution and end use)

$EC_{F(h\&c,el)}$: carbon intensity of the electricity production from a fossil fuel comparator (defined equal to $183 \frac{gCO_{2,eq}}{MJ}$, which is the equivalent carbon intensity of grid electricity)

*European Commission "Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (recast)", Official Journal of the European Union L328/83, 21 December 2018, p. 82: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02018L2001-20220607

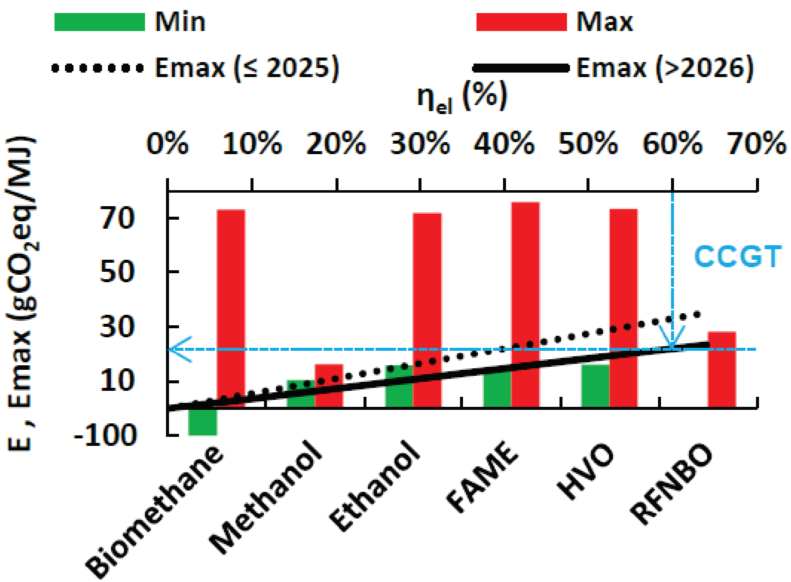
GHG reduction

Maximum lifecycle biofuel GHG emissions to achieve RED II GHG savings targets:

$$E_{max} = \eta_{el}(54.9\, gCO_2eq/MJ) \longrightarrow$$ 70% reduction

$$E_{max} = \eta_{el}(36.6\, gCO_2eq/MJ) \longrightarrow$$ 80% reduction

→ By comparing the maximum and minimum default values with the maximum GHG value to achieve the required GHG savings from electricity generation, **<u>GHG limits</u>** <u>for each biofuel can be identified</u>



*default maximum and minimum GHG emissions for biofuels derived from RED II (minimum values not necessarily the lowest)

Compliance with EU Taxonomy

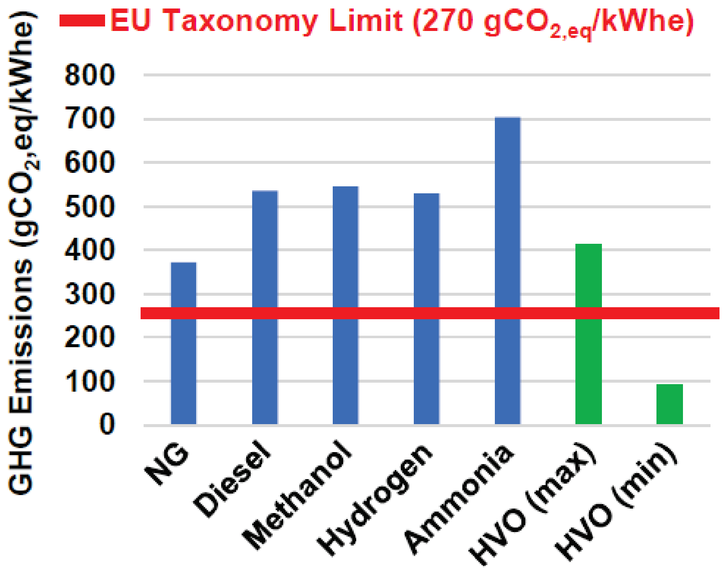
EU taxonomy: Complementary Climate Delegated Act* to accelerate decarbonization

EU gas turbine plants need to meet the following emissions thresholds:

- Lifecycle GHG emissions below 100 $gCO_{2,eq}$/kWh

or

- Direct GHG emissions below 270 $gCO_{2,eq}$/kWh (until 2030), full switch to renewable or low-carbon gases by 2035



H-class CCGT with 64% efficiency would exceed the 2030 EU taxonomy limit in all cases except the HVO produced from a feedstock yielding its lowest default carbon intensity value in RED II

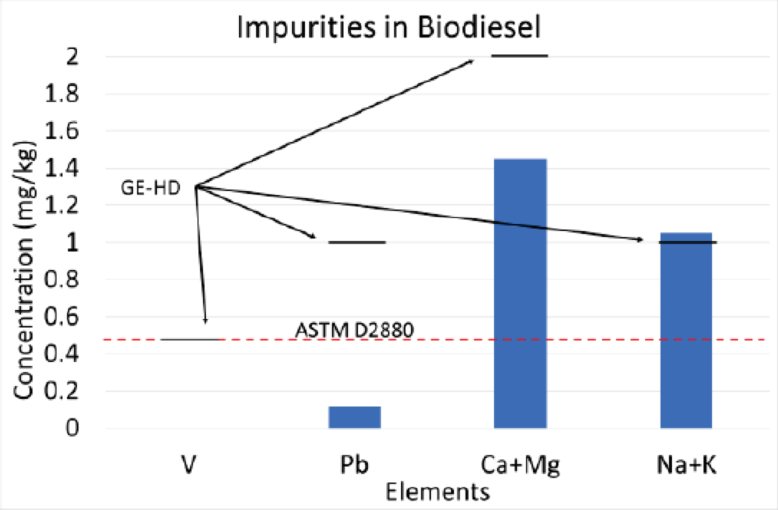
*European Commission, "REPower EU Plan" (2022): https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2022%3A230%3AFIN&qid=1653033742483

AFs composition and impurities

Many of the proposed AFs to NG and diesel are not primarily produced for use as fuel in GTs.

Standards

- ASTM D2880: GT Fuels
- ASTM D4806-21: Ethanol
- ASTM D6751-20a: Biodiesel
- GE-HD OEM Guidelines



Measured impurities in biodiesel. Comparison with GE-HD and ASTM D2800 guidelines and standards

Parameters	Units	Methods	SNI 7182	EN14214	GE-HD
Phosporus	wt%	ASTM D4951	4	4	-
Ca+Mg	mg/kg	ASTM D7111	-	5	2
V	mg/kg	ASTM D7111	-		0.5
Pb	mg/kg	ASTM D7111	-		1
Na+K	mg/kg	ASTM D7111	-	5	1

Impurity levels of FAME Biodiesel, adapted from Amri et al. (2021)*

*Amri, K., Kismanto, A., Solikhah, M.D., Pratiwi, F.T., Arisanti, A.G. (2021) 'Study of biodiesel specifications for heavy-duty gas turbine application', Journal of Physics: Conferences Series, 1858, pp. 012040, doi: 10.1088/1742-6596/1858/1/012040.

Ammonia composition

Ammonia is commercially available in various grades in the market (Atchison, 2020):

- Premium or Metallurgical (Met-grade) ammonia at 99.995% purity
- Refrigeration (R-grade) ammonia at 99.98% purity
- Commercial or Agricultural (C-grade) ammonia at 99.5% purity

Ammonia as Fuel

Unknown exact composition

There is a need for a Standard that can inform about the interaction of exhaust gases from the combustion or the use of ammonia with alloys.

ABS plastic	D	CPVC	A	Polycarbonate	D
Acetal (Delrin ®)	D	EPDM	A	PEEK	A
Aluminium	A	Epoxy	A	Polypropylene	A
Brass	D	Fluorocarbon (FKM)	D	Polyurethane	D
Bronze	D	Hastelloy-C ®	B	PPS (Ryton ®)	A
Buna N (Nitrile)	B	Hypalon ®	D	PTFE	A
Carbon graphite	A	Hytrel ®	D	PVC	A
Carbon Steel	B	Kalrez	A	PVDF (Kynar ®)	A
Carpenter 20	A	Kel-F ®	A	Silicone	C
Cast iron	A	LDPE	B	Stainless Steel 304	A
Ceramic Al2O3	N/A	Natural Rubber	D	Stainless Steel 316	A
Ceramic magnet	N/A	Neoprene	A	Titanium	C
ChemRaz (FFKM)	B	NORYL ®	B	Tygon ®	A
Copper	D	Nylon	A	Viton ®	D

Compatibility of different materials with ammonia. A = Excellent, B = Good (but some effort), C = moderate effect (continuous use not recommended), D = severe.

Next steps: AFs classification methodology

Overview

- Availability/Cost of AFs
- GHG Emissions
- Regulations/Incentives
- Operation & Maintenance

AFs Selection

Definition of decision criteria

Technological

Social-Political

Economic

Environmental

Application **Requirements**

Classification/ranking of AFs for a specific GT application

Conclusions

- GT in the Oil&Gas sector are difficult to electrify; AFs will play a major role in achieving the decarbonisation targets
- GT in the utility and industrial sectors have other possibilities to be decarbonized, expecting Hydrogen and CCS to play a major role. However, running hours will decrease sharply for power generation as the share of renewable generation in the power grid increases
- GHG emission target reduction for GT will be reduced drastically; OEM and users must work together to achieve flexible and reliable combustion systems that are ready to burn different mixtures of hydrogen/NG and other AFs
- AF composition standards are lagging behind technology development. Experimental tests and a proactive approach to building testing methodologies and measurement processes are urgently needed. Only extensive experience will allow us to have high-quality standards and first-class technology for achieving energy goals

Acknowledgement

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Q&A