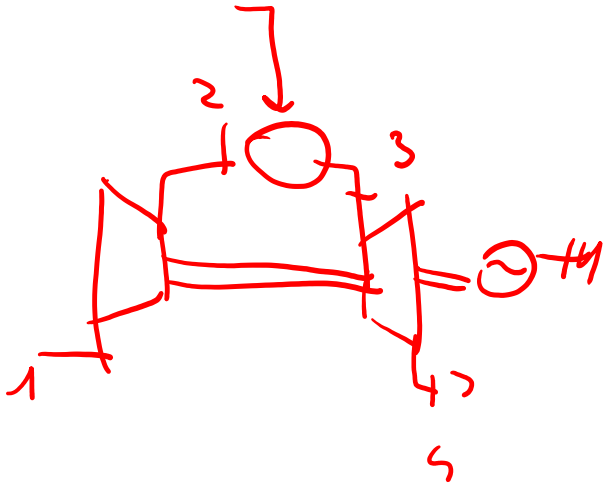
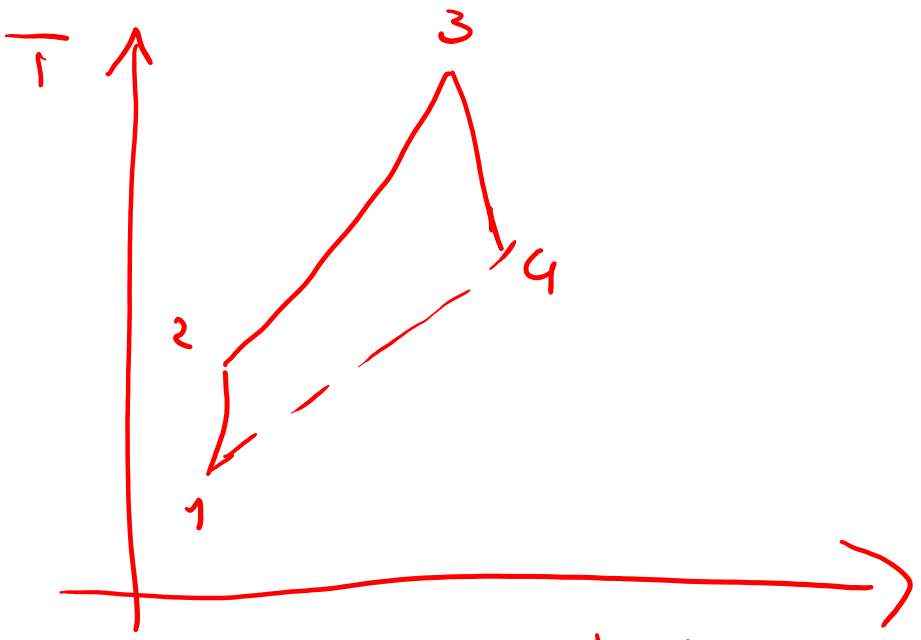
Use of hydrogen in Gas turbines

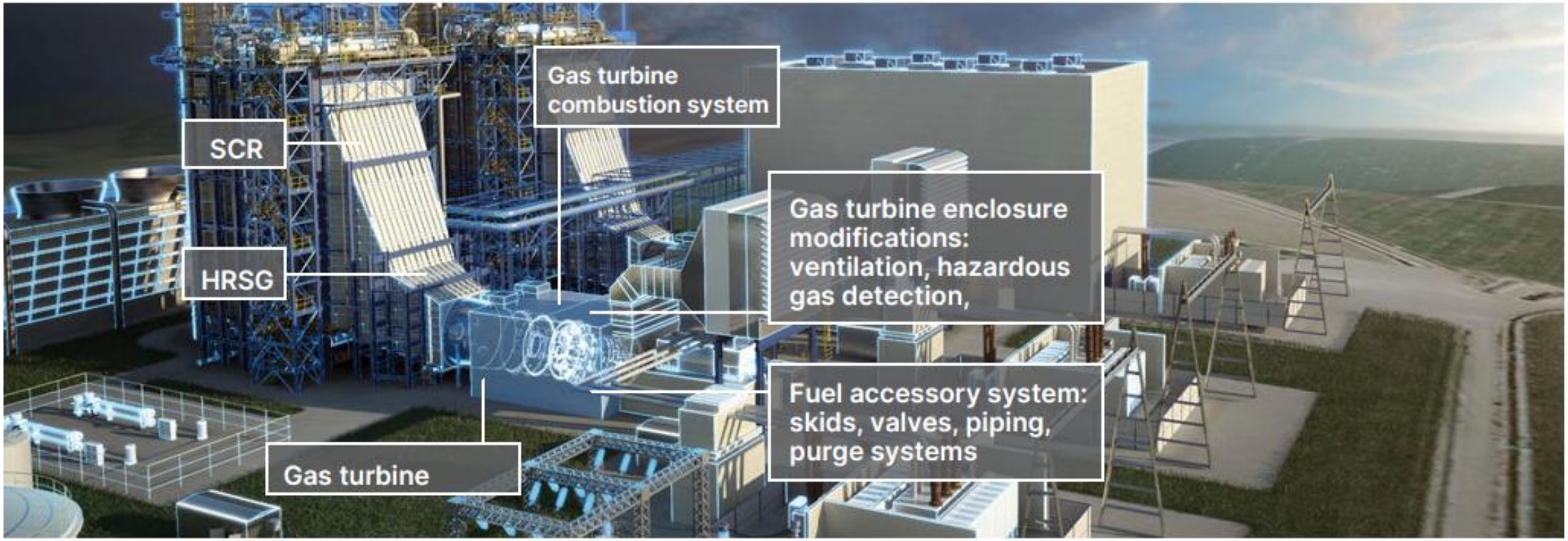




$H_2 + \frac{1}{2} O_2 \rightarrow H_2O$

$CH_4 + 2O_2 \rightarrow CO_2 + H_2O$

	mass basis	air
H_2	1 : 8	$1 : 24.5 \frac{kg_{air}}{kg_{H_2}}$
CH_4	1 : 4	$1 : 17.2 \frac{kg_{air}}{kg_{H_2}}$


Gas turbine combustion system
SCR
HRSG
Gas turbine enclosure modifications: ventilation, hazardous gas detection,
Fuel accessory system: skids, valves, piping, purge systems
Gas turbine

$\frac{LHV}{\sqrt{\rho^*}}$

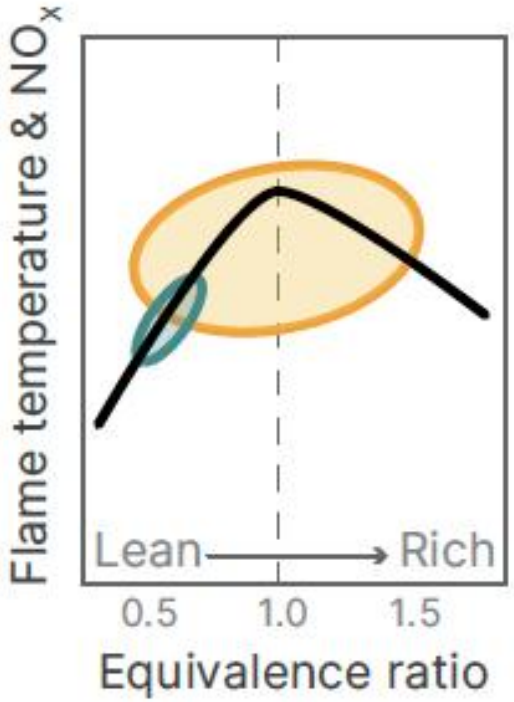
CH_4 H_2

PROPERTY	UNITS	METHANE	GAS POWER
Formula		CH_4	H_2
LHV (per volume)	MJ/Nm^3	35.8	10.8
	BTU/scf	911.6	274.7
LHV (per mass)	MJ/kg	50	120
	BTU/lb	21,515	51,593

WOBBE

$53.28 \frac{MJ}{m^3}$ $48 \frac{MJ}{m^3}$

CHARACTERISTIC	UNITS	METHANE	HYDROGEN
Formula		CH_4	H_2
Molecular weight	grams/mol	16	2
Molecular size	Picometers, 10^{-12}meters	380	289
Lower/Upper flammability limits	%	4.4/17	4/75
Flame speed	cm/sec	~30–40	~200–300
Adiabatic flame temperature	° F (° C)	~3565 (~1963)	~4000 (~2204)
Lower Heating value	MJ/Nm^3(BTU/scf)	35.8 (911.6)	10.8 (274.7)
Lower Heating value	MJ/kg (BTU/lb)	50 (21,515)	120 (51,593)



DIFFUSION FLAME

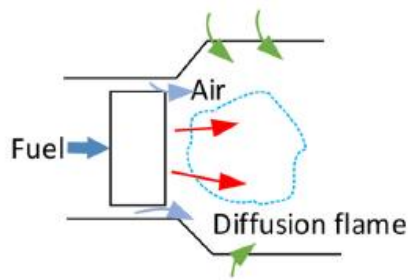
Flame characteristics

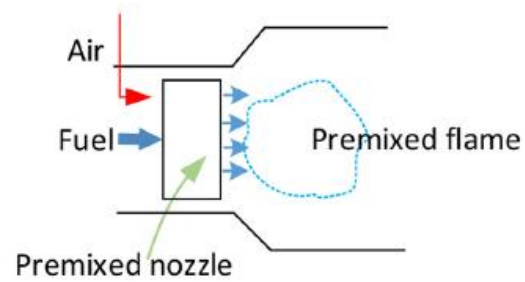
- Highly stable
- High peak flame temperature
- NO_x: ~200 to ~600 ppm

LEAN PREMIXED FLAME

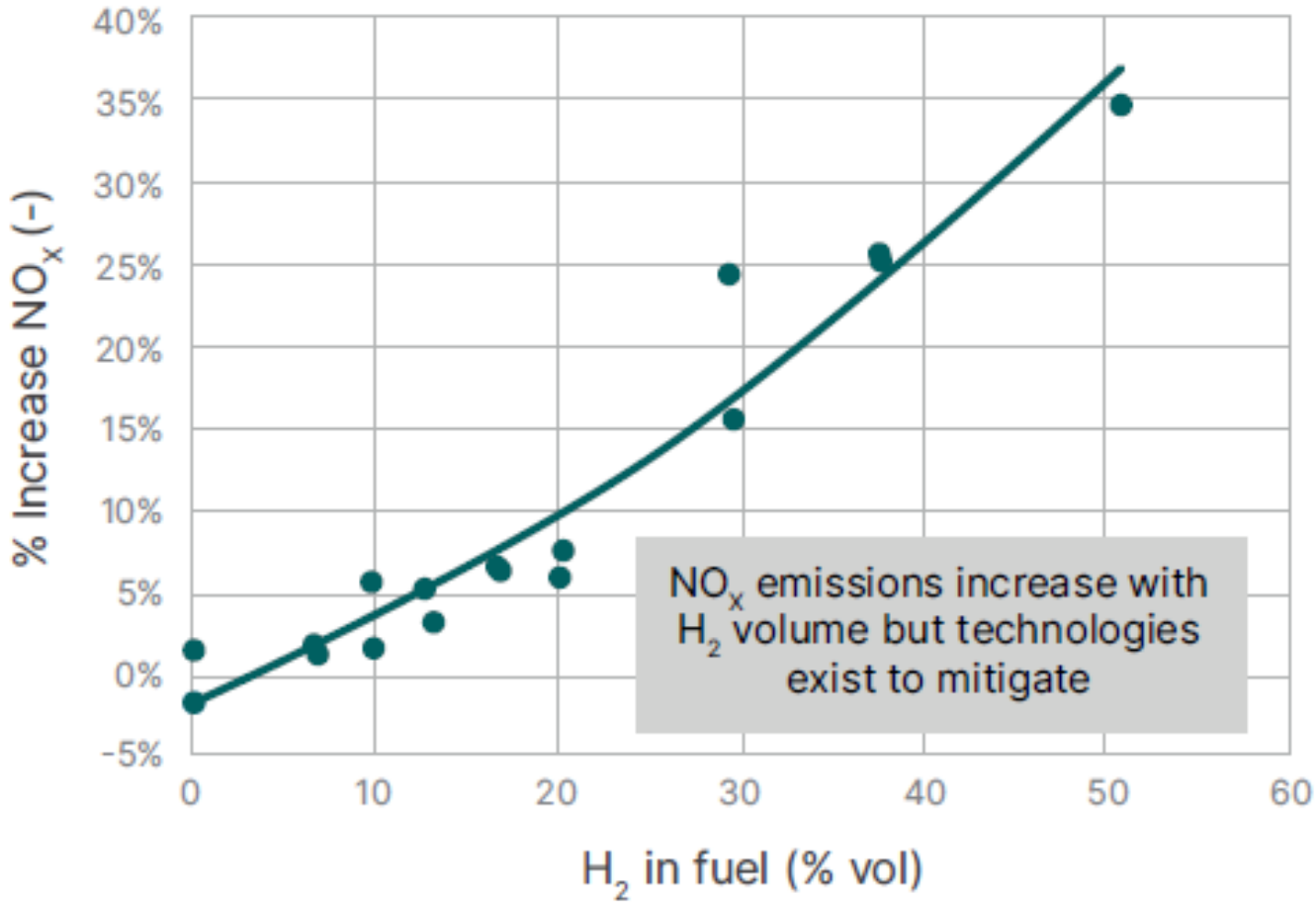
Flame characteristics

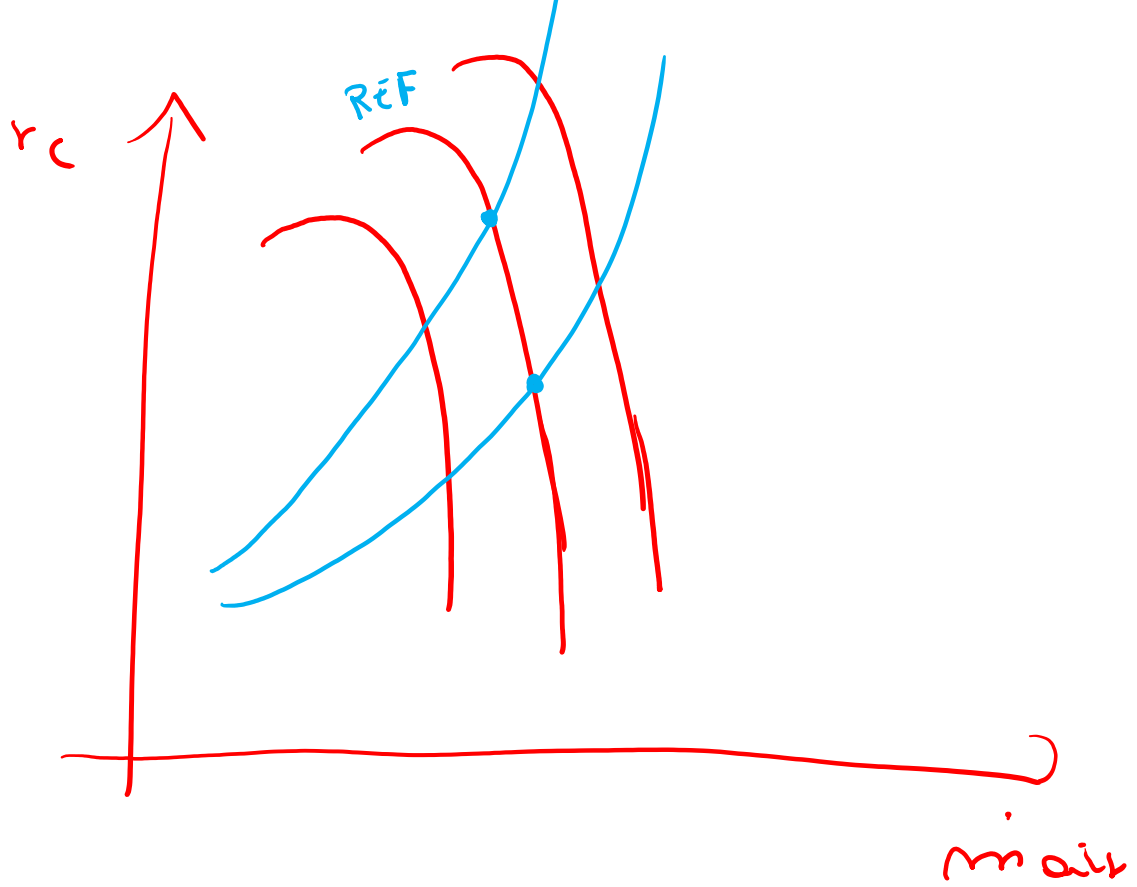
- Low NO_x without diluent
- Susceptible to flashback and combustion dynamics
- NO_x: single digit ppm





(a) Diffusion combustion (b) Premixed combustion


40%
35%
30%
25%
20%
15%
10%
5%
0%
-5%
% Increase NO_x (-)
0
10
20
30
40
50
60
H_2 in fuel (% vol)
NO_x emissions increase with H_2 volume but technologies exist to mitigate



- COMPRESSOR-GAS TURBINE MATCHING: at constant TIT and VGV opening the, coupling point moves closer to surge

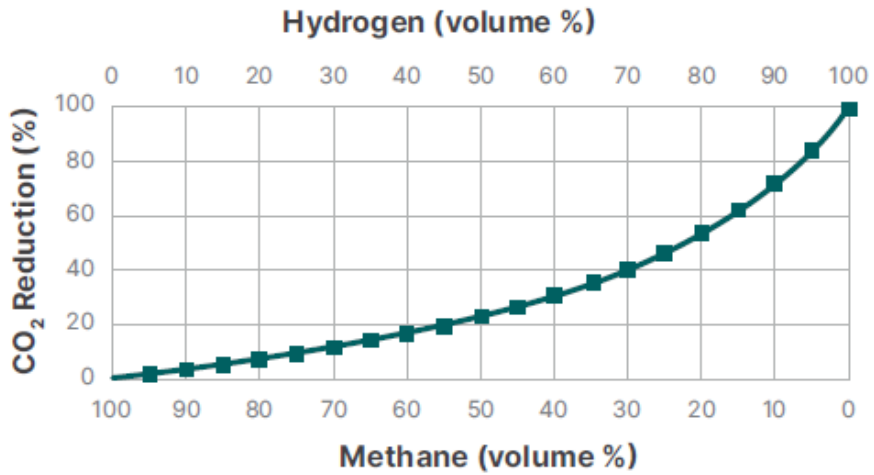


FIGURE 5: Relationship between CO2 emissions and hydrogen/methane fuel blends (volume %)

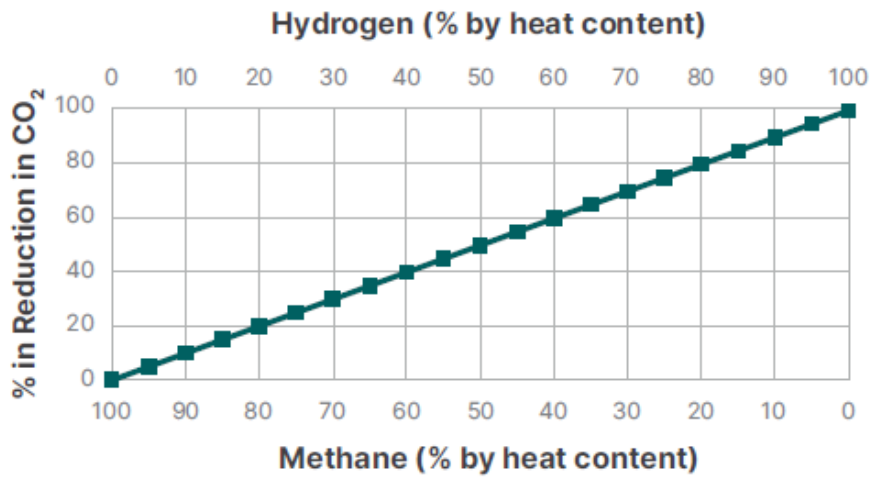
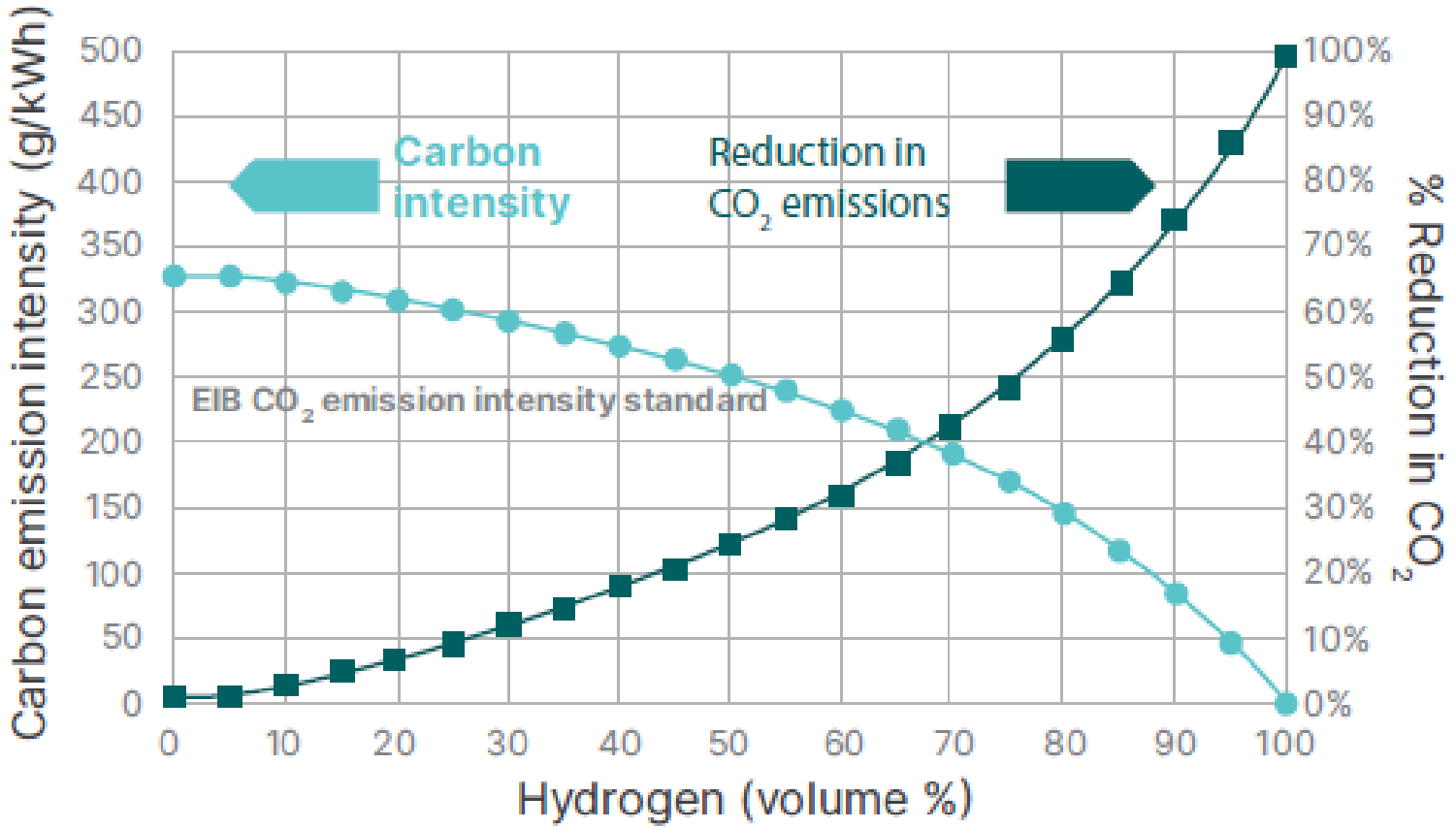
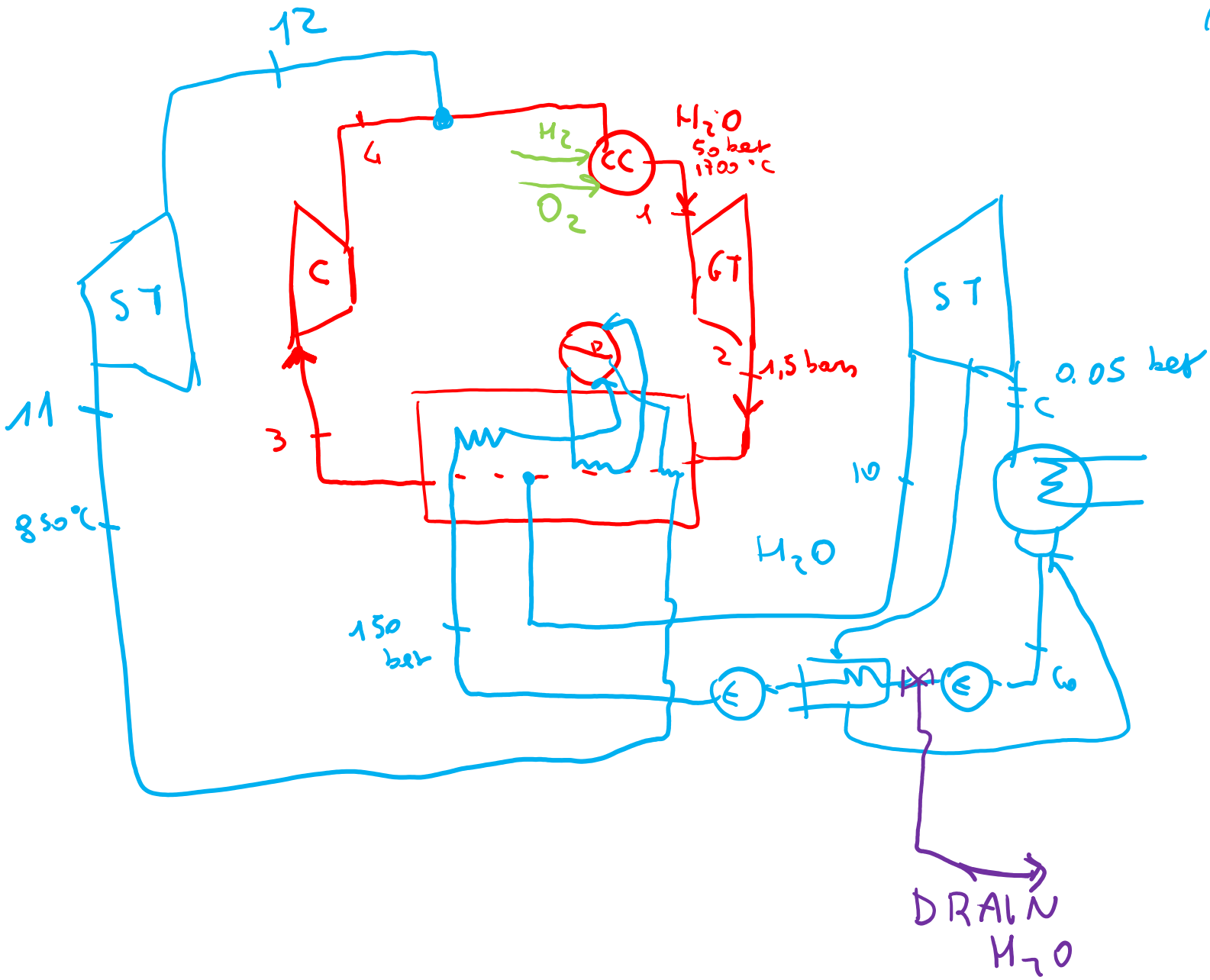
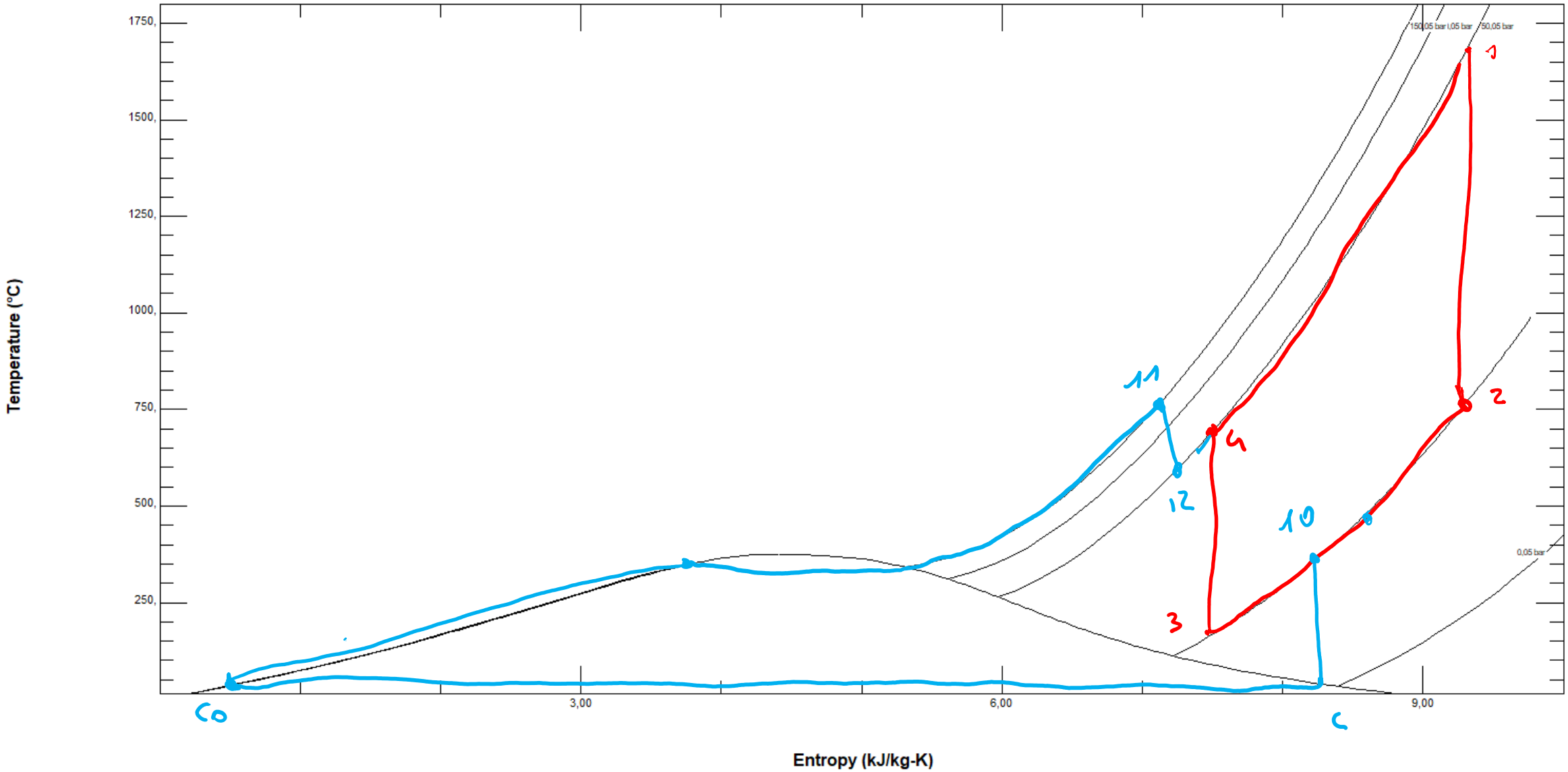


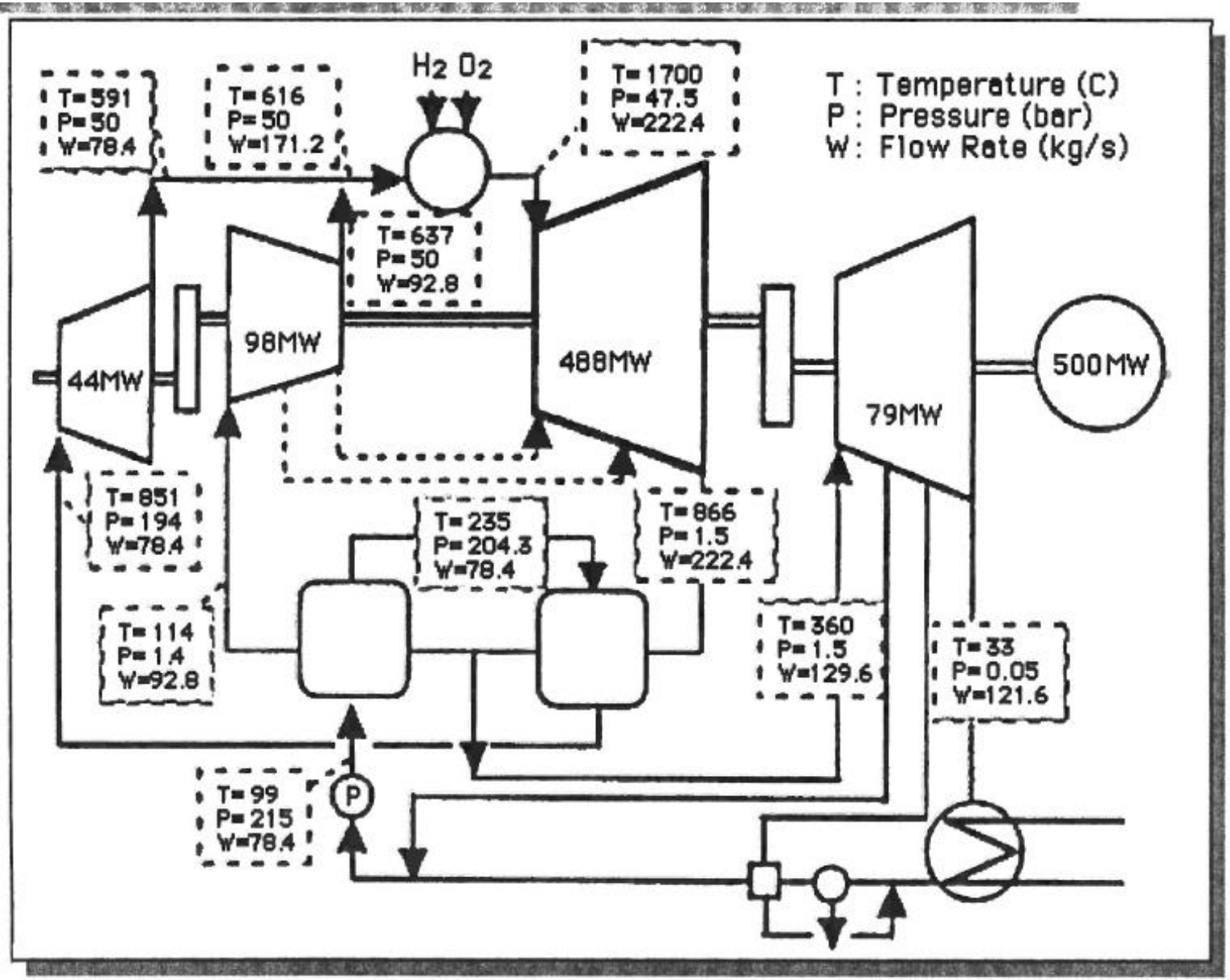
FIGURE 6: Relationship between CO2 emissions and hydrogen/methane fuel blends (% heat input)


Carbon emission intensity (g/kWh)
500
450
400
350
300
250
200
150
100
50
0
Carbon intensity
Reduction in CO_2 emissions
EIB CO_2 emission intensity standard
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
% Reduction in CO_2
0
10
20
30
40
50
60
70
80
90
100
Hydrogen (volume %)

η 73%


12
4
H_2
O_2
CC
H_2O
50 bar
1700 °C
1
C
GT
ST
ST
11
850°C
3
2
1,5 bars
0.05 bar
10
H_2O
150 bar
DRAIN
H_2O


Temperature (°C)
1750,
1500,
1250,
1000,
750,
500,
250,
3,00
6,00
9,00
Entropy (kJ/kg-K)
150,05 bar
1,05 bar
50,05 bar
0,05 bar
1
2
3
4
10
11
12
Co
C


T=591
P=50
W=78.4
T=616
P=50
W=171.2
H2 O2
T=1700
P=47.5
W=222.4
T : Temperature (C)
P : Pressure (bar)
W : Flow Rate (kg/s)
T=637
P=50
W=92.8
44MW
98MW
488MW
79MW
500MW
T=851
P=194
W=78.4
T=235
P=204.3
W=78.4
T=866
P=1.5
W=222.4
T=114
P=1.4
W=92.8
T=360
P=1.5
W=129.6
T=33
P=0.05
W=121.6
T=99
P=215
W=78.4
P

FUEL FLEXIBILITY

GE

$$\frac{HHV}{\sqrt{S^*}}$$

$$S^* = \frac{S_{FUEL}}{S_{AIR}}$$

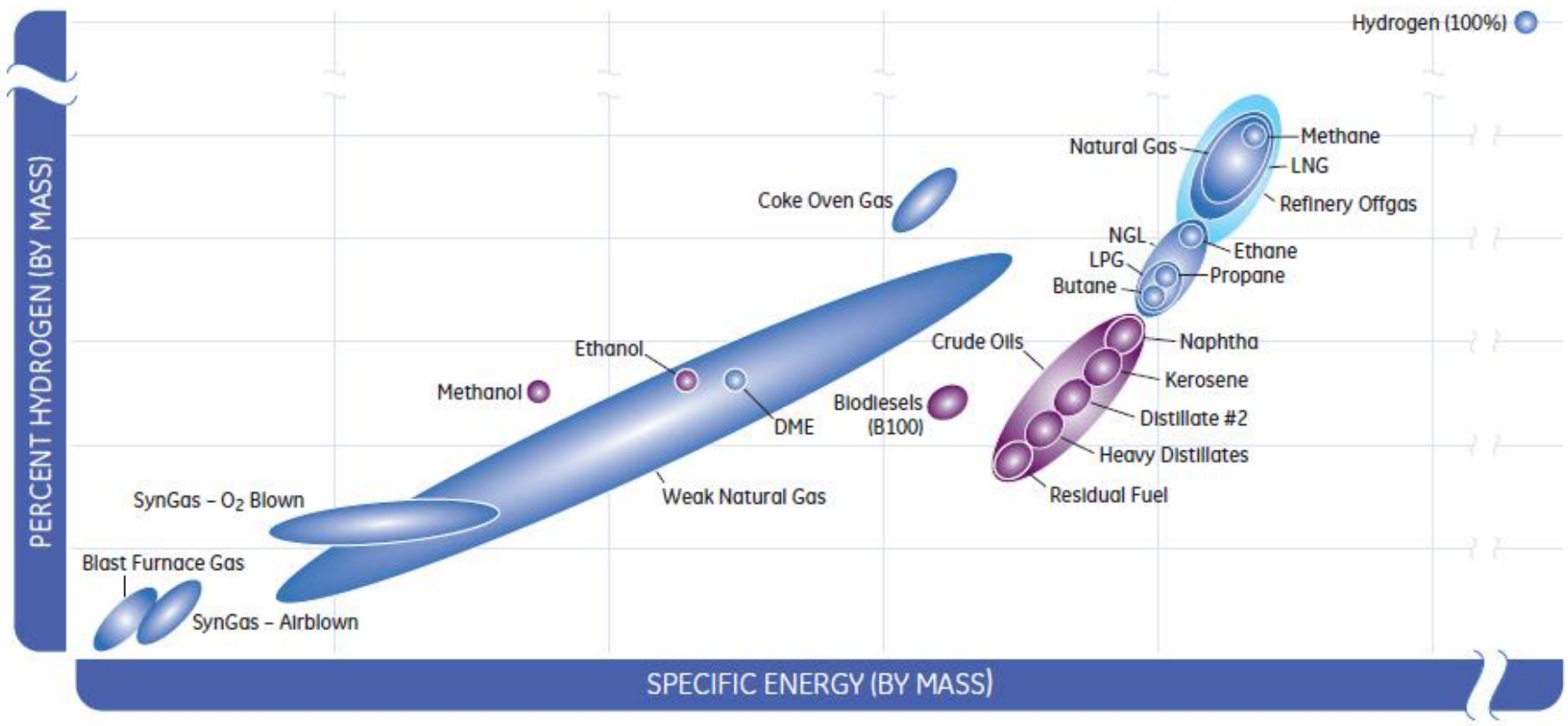
		LMS100 PA+	LMS100 PB+
Gas Turbine Rating	ISO Base Rating (MW)	114	108
	Gross Heat Rate (Btu/kWh, LHV)	7,885	7,776
	Gross Heat Rate (kJ/kWh, LHV)	8,319	8,204
	Gross Efficiency (%, LHV)	43.3%	43.9%
	Exhaust Temperature (°F)	792	790
	Exhaust Temperature (°C)	422	421
	Exhaust Energy (MM Btu/hr)	358	344
	Exhaust Energy (MM kJ/hr)	377	363
Gas Turbine Parameters	GT Turndown Minimum Load (%)	25%	50%
	GT Ramp Rate (MW/min)	50	50
	NO_X (ppm) (@15% O_2)	25	25
	CO (ppm) (@15% O_2)	113/139	113/125
	Wobbe Variation (%)	+/-20%	+/-25%
	Startup Time (Hot, Minutes)	10	10
SC Plant Performance	SC Net Output (MW)	111	105
	SC Net Heat Rate (Btu/kWh, LHV)	8,021	7,918
	SC Net Heat Rate (kJ/kWh, LHV)	8,463	8,354
	SC Net Efficiency (%, LHV)	42.5%	43.1%
1x1CC Plant Performance	CC Net Output (MW)	135	127
	CC Net Heat Rate (Btu/kWh, LHV)	6,626	6,517
	CC Net Heat Rate (kJ/kWh, LHV)	6,991	6,876
	CC Net Efficiency (%, LHV)	51.5%	52.4%
	Plant Turndown – Minimum Load (%)	21%	42%
	Ramp Rate (MW/min)	50	50
	Startup Time (Hot, Minutes)	30	30
2x1CC Plant Performance	CC Net Output (MW)	270	256
	CC Net Heat Rate (Btu/kWh, LHV)	6,608	6,498
	CC Net Heat Rate (kJ/kWh, LHV)	6,971	6,856
	CC Net Efficiency (%, LHV)	51.6%	52.5%
	Plant Turndown – Minimum Load (%)	21%	21%
	Ramp Rate (MW/min)	100	100

GE

		9F.05
SC Plant Performance	SC Net Output (MW)	299
	SC Net Heat Rate (Btu/kWh, LHV)	8,810
	SC Net Heat Rate (kJ/kWh, LHV)	9,295
	SC Net Efficiency (%, LHV)	38.7%
Gas Turbine Parameters	Exhaust Temperature (°F)	1,187
	Exhaust Temperature (°C)	642
	Exhaust Energy (MM Btu/hr)	1,593
	Exhaust Energy (MM kJ/hr)	1,681
	GT Turndown Minimum Load (%)	35%
	GT Ramp Rate (MW/min)	24
	NO_X (ppmvd) at baseload (@15% O_2)	25
	CO (ppm) at Min. Turndown w/o Abatement	24
	Wobbe Variation (%)	+/-10%
	Startup Time (Conventional/Peaking, Minutes)	23/20
1x CC Plant Performance	CC Net Output (MW)	462
	CC Net Heat Rate (Btu/kWh, LHV)	5,640
	CC Net Heat Rate (kJ/kWh, LHV)	5,951
	CC Net Efficiency (%, LHV)	60.5%
	Plant Turndown – Minimum Load (%)	46%
	Ramp Rate (MW/min)	24
	Startup Time (RR Hot, Minutes)	30
2x CC Plant Performance	CC Net Output (MW)	929
	CC Net Heat Rate (Btu/kWh, LHV)	5,610
	CC Net Heat Rate (kJ/kWh, LHV)	5,919
	CC Net Efficiency (%, LHV)	60.8%
	Plant Turndown – Minimum Load (%)	23%
	Ramp Rate (MW/min)	48
	Startup Time (RR Hot, Minutes)	39

Wobbe Index of some fuel gases

Fuel gas	*Upper index* MJ/Nm³	*Lower index* MJ/Nm³
Hydrogen	48.23	40.65
Methane	53.28	47.91
Ethane	68.19	62.47
Ethylene	63.82	60.01
Natural gas	53.71	48.52
Propane	81.07	74.54
Propylene	77.04	71.88
n-butane	92.32	85.08
Iso-butane	91.96	84.71
Butylene-1	88.46	82.54
LPG	86.84	79.94
Acetylene	61.32	59.16
Carbon monoxide	12.80	12.80


Hydrogen (100%)
PERCENT HYDROGEN (BY MASS)
Natural Gas
Methane
LNG
Refinery Offgas
Coke Oven Gas
NGL
Ethane
LPG
Propane
Butane
Crude Oils
Naphtha
Ethanol
Kerosene
Methanol
Biodiesels (B100)
Distillate #2
DME
Heavy Distillates
Weak Natural Gas
Residual Fuel
SynGas – O_2 Blown
Blast Furnace Gas
SynGas – Airblown
SPECIFIC ENERGY (BY MASS)

Siemens Hydrogen Gas Turbines for our sustainable future

The mission is to burn 100% hydrogen

Gas turbine model	Power Output[1]	H_2 capabilities in vol. %
SGT5-9000HL	593 MW	30
SGT5-8000H	450 MW	30
SGT5-4000F	329 MW	30
SGT5-2000E	187 MW	30
SGT6-9000HL	405 MW	30
SGT6-8000H	310 MW	30
SGT6-5000F	215 to 260 MW	30
SGT6-2000E	117 MW	30
SGT-A65	60 to 71/58 to 62 MW	15 – 100
SGT-800	48 to 62 MW	50
SGT-A45	41 to 44 MW	100
SGT-750	40/34 to 41 MW	40
SGT-700	33/34 MW	55
SGT-A35	27 to 37/28 to 38 MW	15 – 100
SGT-600	24/25 MW	60
SGT-400	10 to 14/11 to 15 MW	10 – 65
SGT-300	8/8 to 9 MW	30
SGT-100	5/6 MW	30 – 65
SGT-A05	4 to 6 MW	2 – 15

DLE burner WLE burner Diffusion burner with unabated NOx emissions

Heavy-duty gas turbines Industrial gas turbines Aeroderivative gas turbines

DLE : Dry Low Emissions
WLE : Wet Low Emissions

1 ISO, Base Load, Natural Gas; Version 3.4, July 2020

2020-12-01

HYFLEXPOWER

Flexible Power Generation ETN Webinar Series

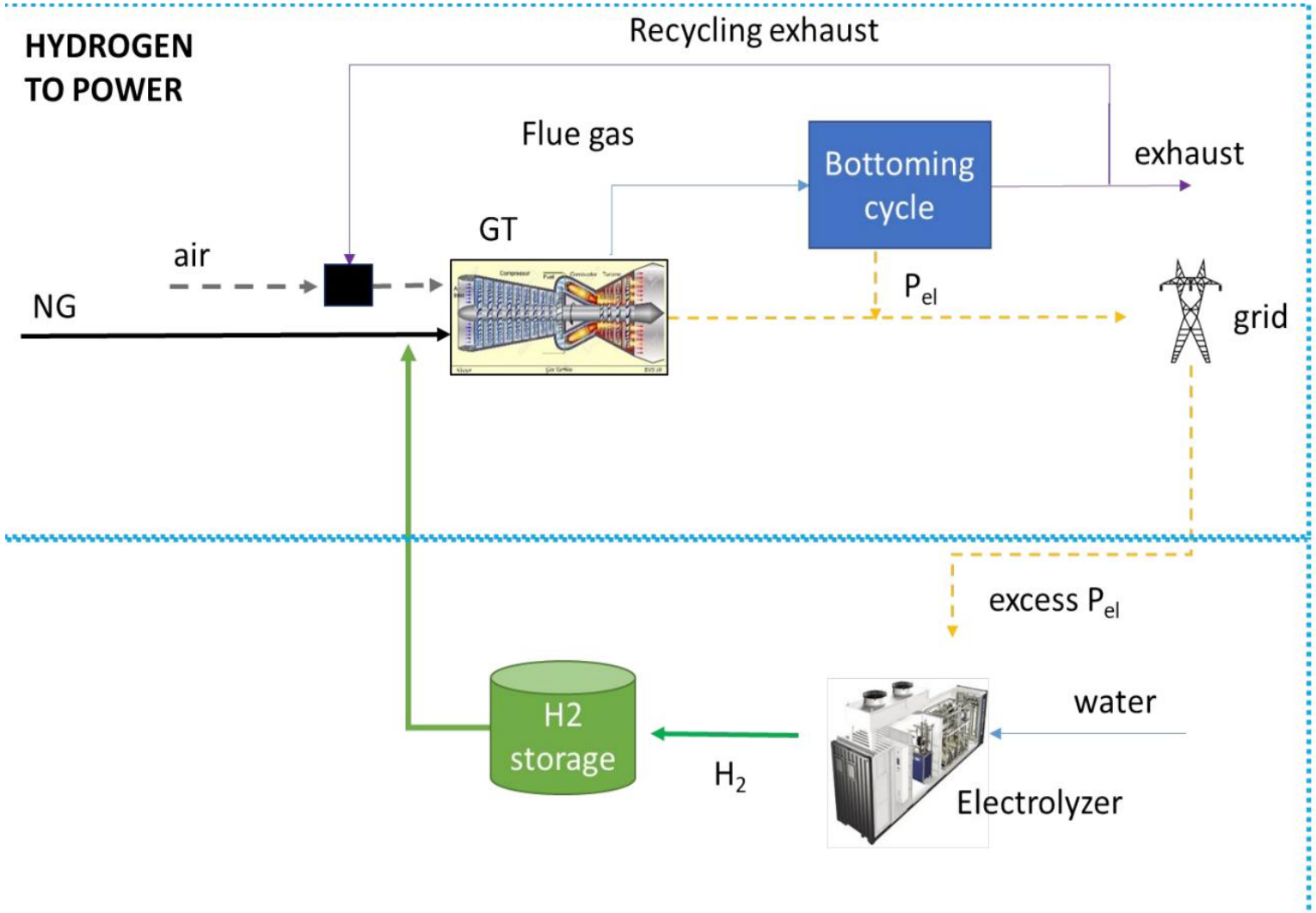
3rd Episode – 1/12/2020

SIEMENS energy

HYFLEXPOWER

Power-H_2-Power Pilot CO_2-Free Green Energy with H_2 GT

Dr. Ertan Yilmaz
Project Coordinator & H2 Portfolio Manager
Siemens Energy


HYDROGEN
TO POWER
Recycling exhaust
Flue gas
Bottoming cycle
exhaust
GT
air
NG
P_{el}
grid
excess P_{el}
H2 storage
water
H_2
Electrolyzer