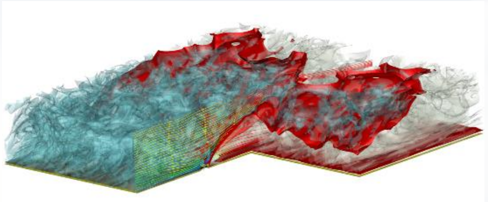
IS THERE ROOM FOR GAS TURBINES IN A DECARBONISED WORLD?



Dr. Nils A. Røkke, EVP Sustainability SINTEF, Chair European Energy Research Alliance (EERA)

9th Int. Gas. Turbine conference, 10-11 October 2018 Brussels Belgium

One of Europe's largest independent research organisations

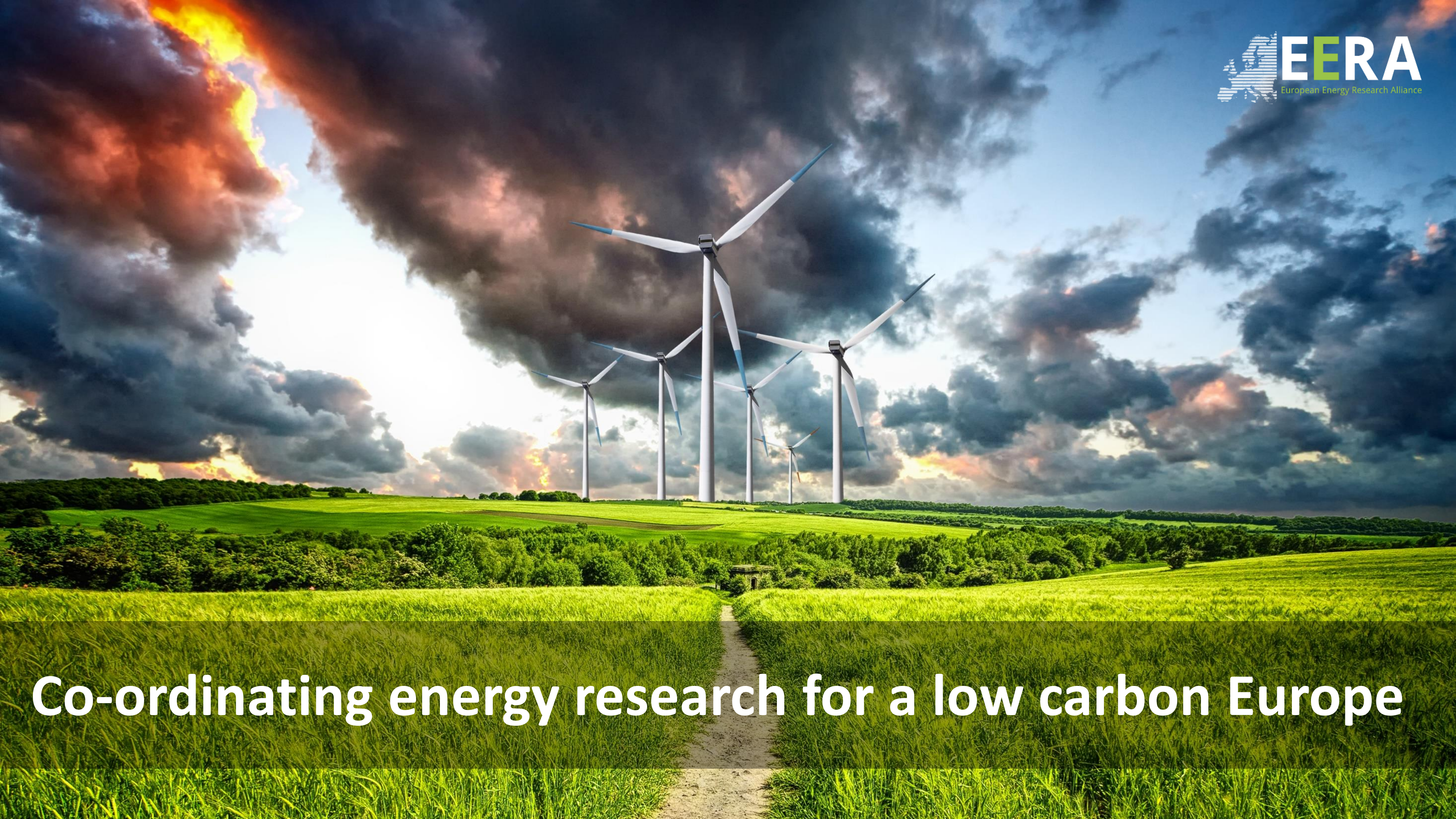
2000
Employees

75
Nationalities

4000
Customers

NOK 3.1 billion
Revenues

NOK 450 MILL
International sales


EERA
European Energy Research Alliance
Co-ordinating energy research for a low carbon Europe


ipcc
Global Warming of 1.5°C
An IPCC special report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.

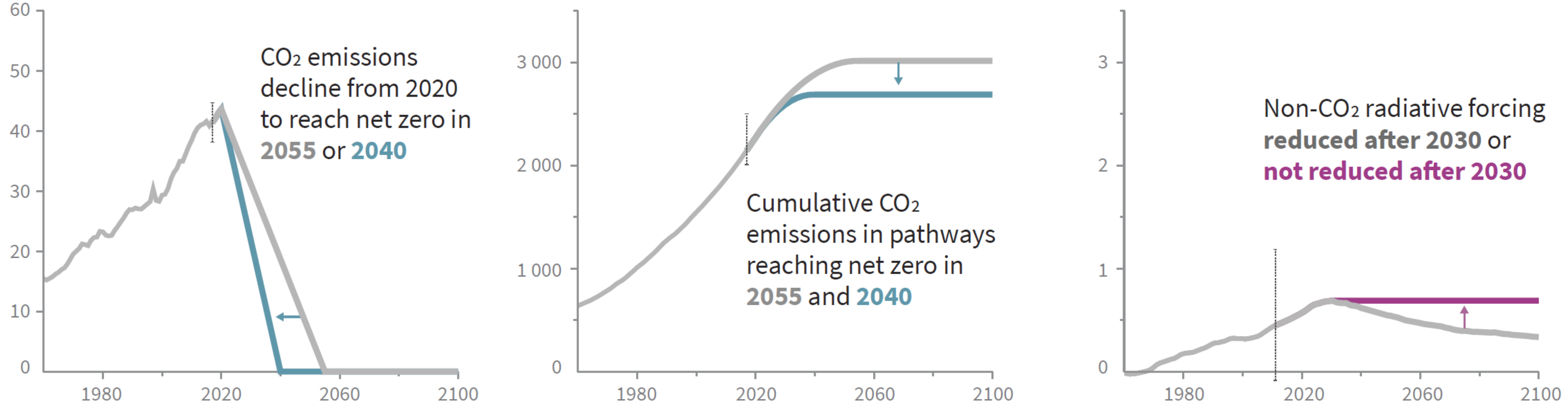
SINTEF

SR15- Special report on 1.5 deg warming - IPCC

b) Stylized net global CO_2 emission pathways
Billion tonnes CO_2 per year ($GtCO_2$/yr)

c) Cumulative net CO_2 emissions
Billion tonnes CO_2 ($GtCO_2$)

d) Non-CO_2 radiative forcing pathways
Watts per square metre (W/m^2)

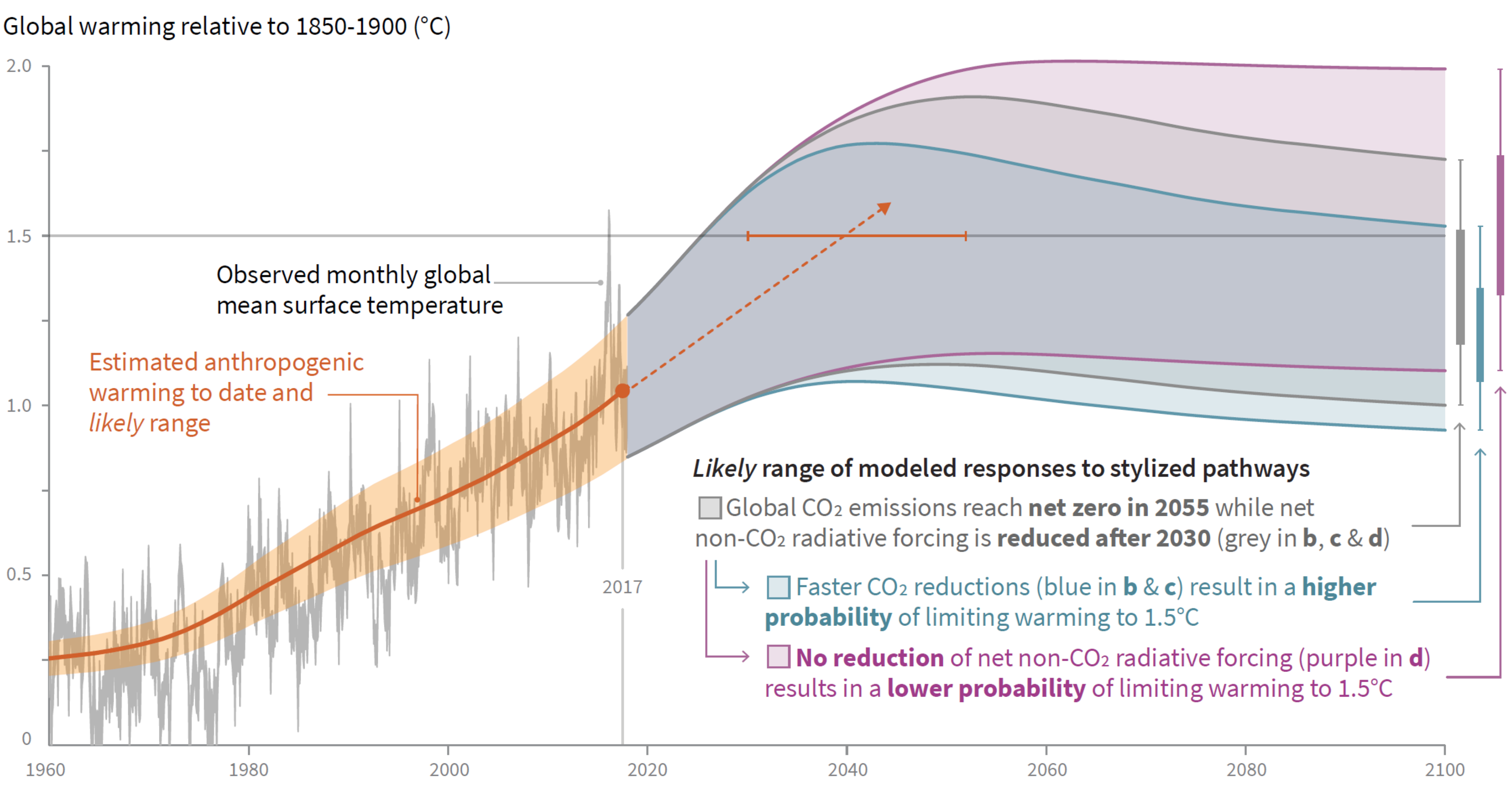


Faster immediate CO_2 emission reductions limit cumulative CO_2 emissions shown in panel **(c)**.

Maximum temperature rise is determined by cumulative net CO_2 emissions and net non-CO_2 radiative forcing due to methane, nitrous oxide, aerosols and other anthropogenic forcing agents.

Source: IPCC Special Report on Global Warming of 1.5°C

a) Observed global temperature change and modeled responses to stylized anthropogenic emission and forcing pathways

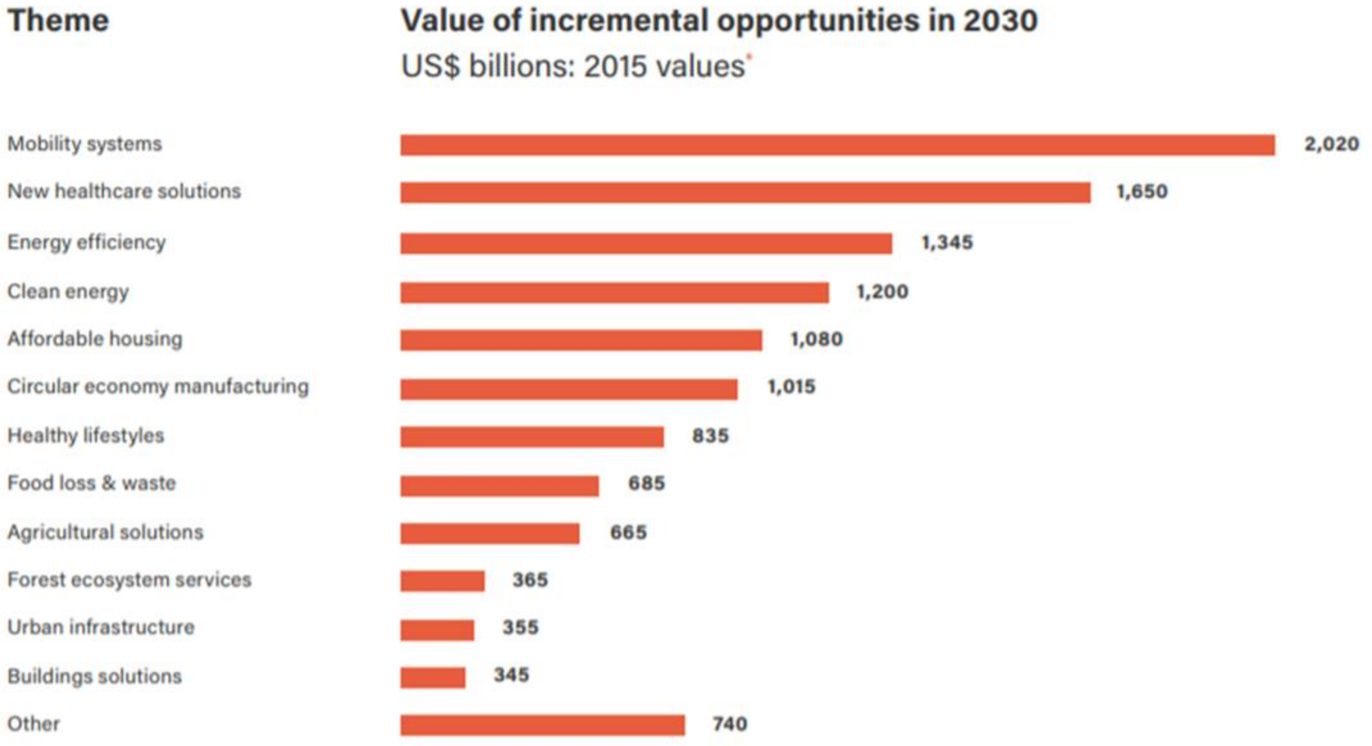


Disruption

Photo: Gorm Kallestad / NTB scanpix

EXHIBIT 5:

12 largest business themes in a world economy heading for the Global Goals



* Based on estimated savings or project market sizings in each area. Rounded to nearest US$ billion.

Source: Literature search; AlphaBeta analysis

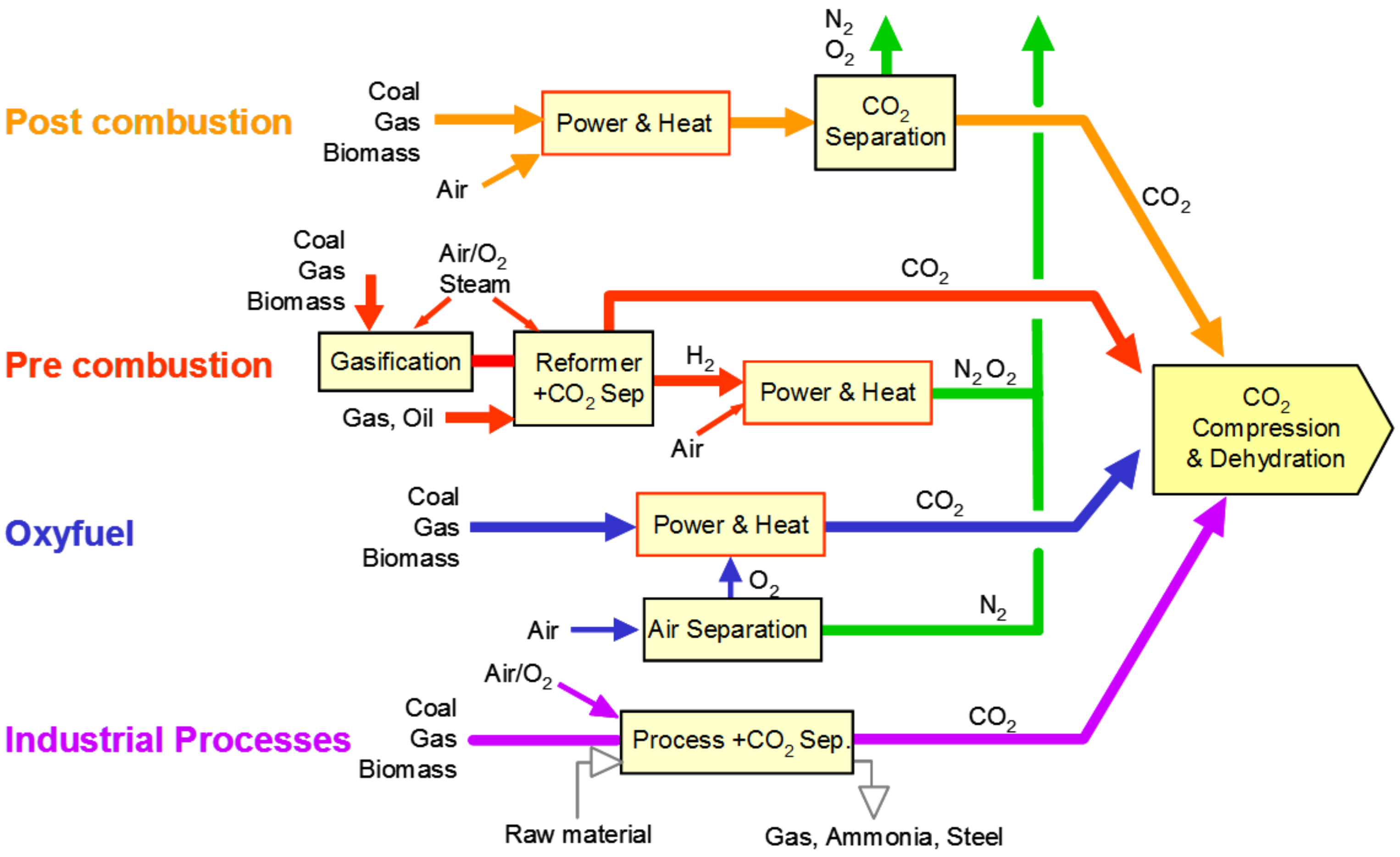
So…

- We need the energy, power and the flexibility which GT cycles can provide in a decarbonised world

- But- we don't need the emissions

Power cycles for zero emissions

- Continue burning hydrocarbons- post-cleanup
- Burn hydrogen – no GHG emissions
- Produce only CO_2 – oxy fuel cycles

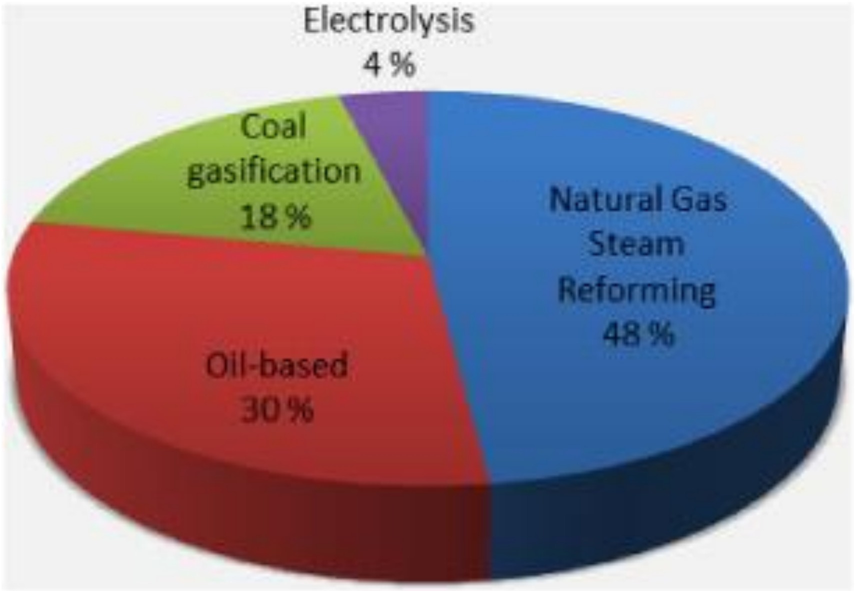


SINTEF

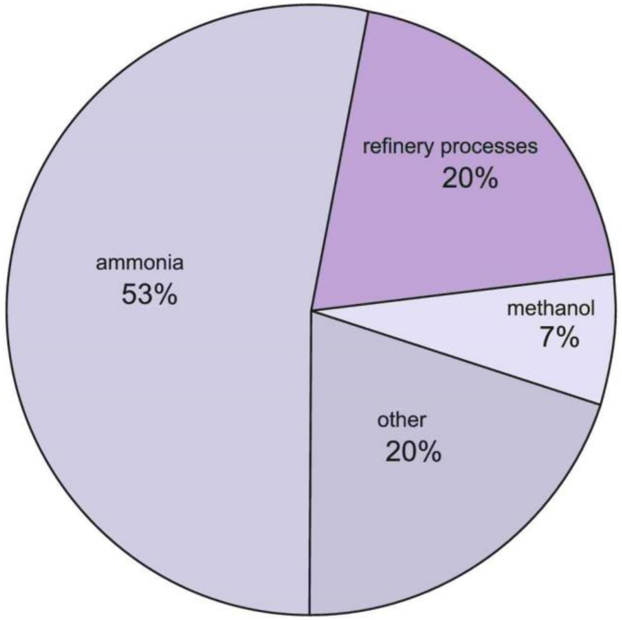
WHAT ABOUT HYDROGEN?

SINTEF

Hydrogen by source and use- mythbusting



Source: International Journal of Hydrogen Energy, Voldsund et al.



Source: The essential chemical industry - online

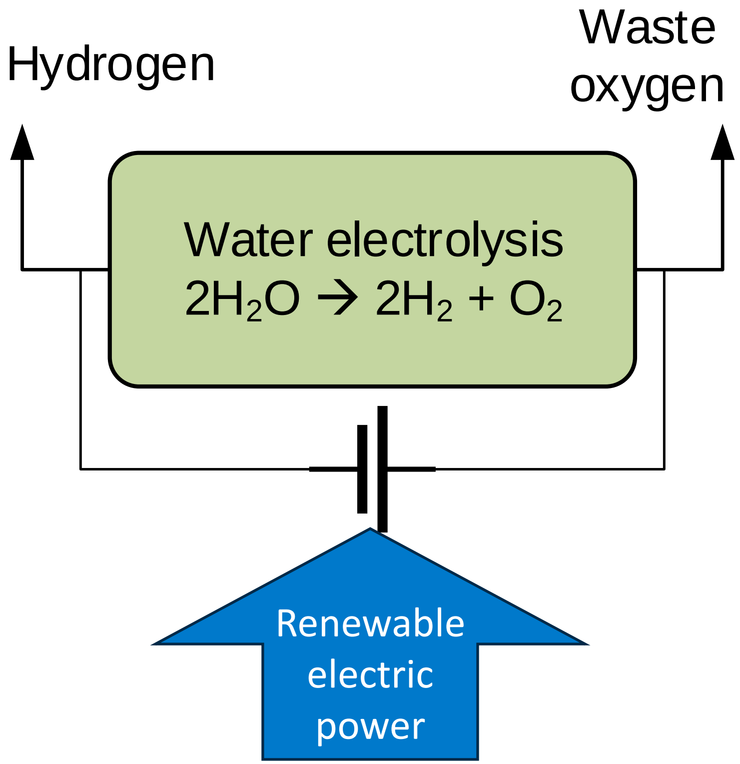
Global annual production: ~65M metric tons

SINTEF

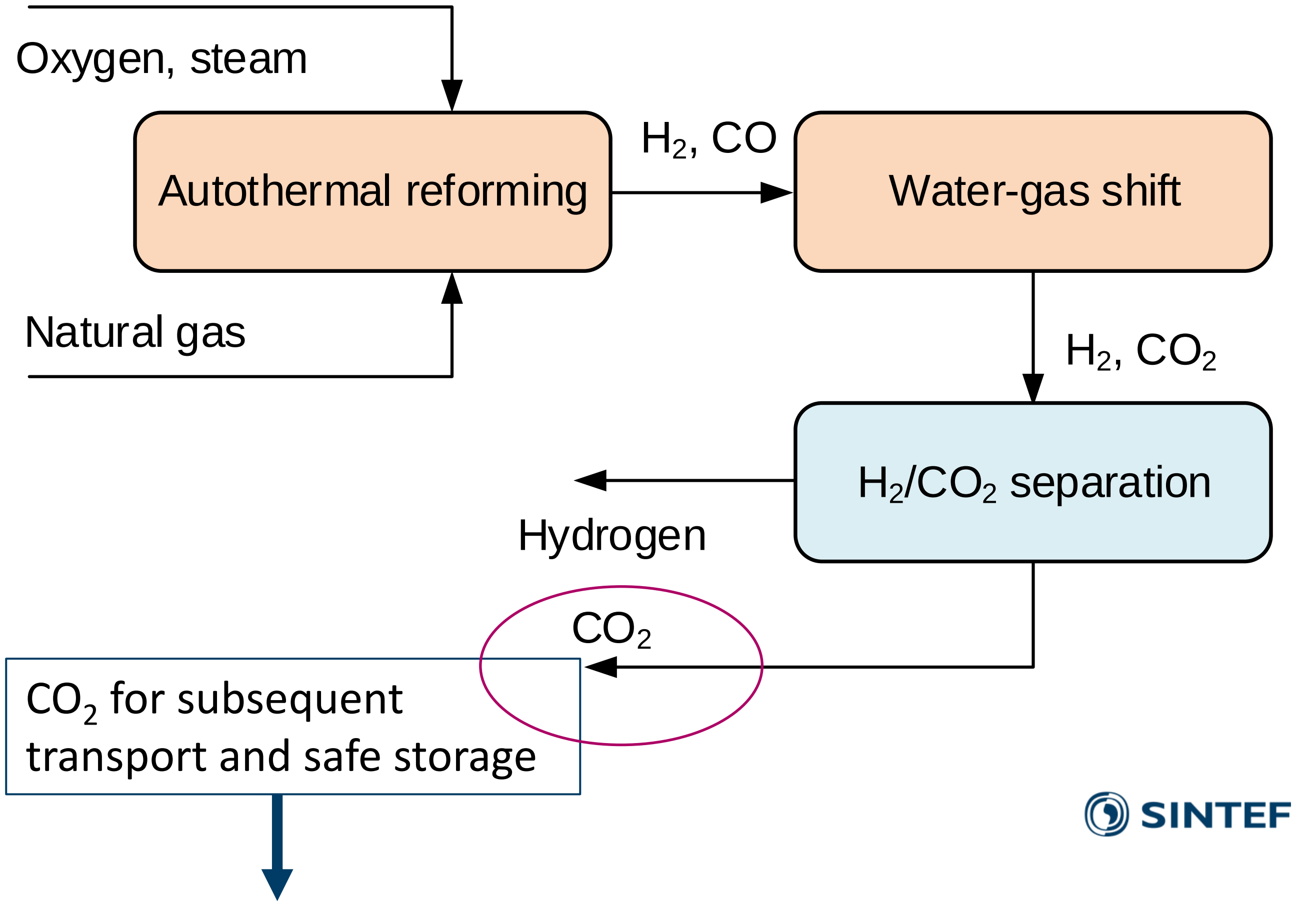
HYDROGEN AND CCS?

Hydrogen production schemes & CCS

From electrolysis



Decarbonised fossil route

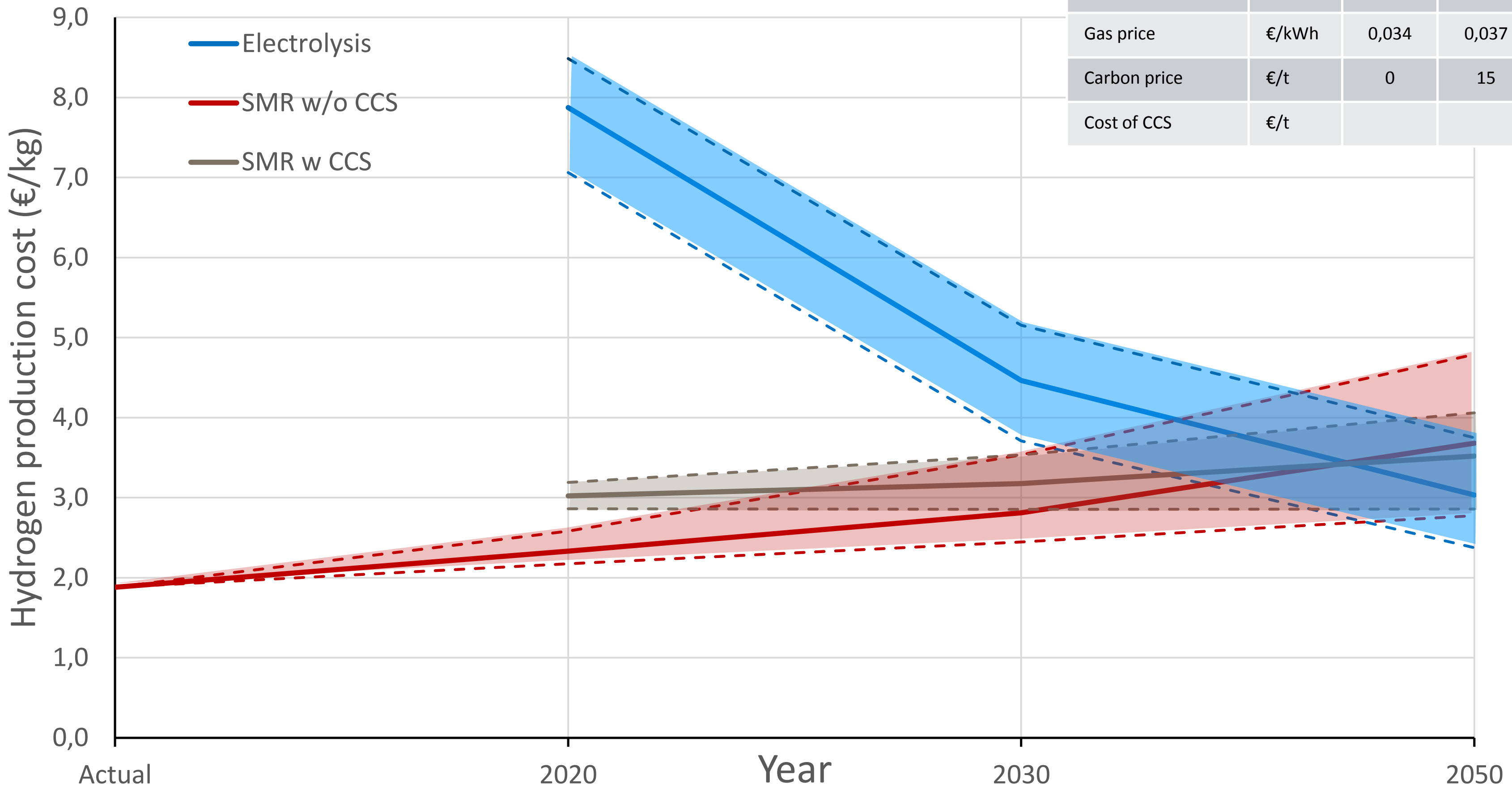


SINTEF

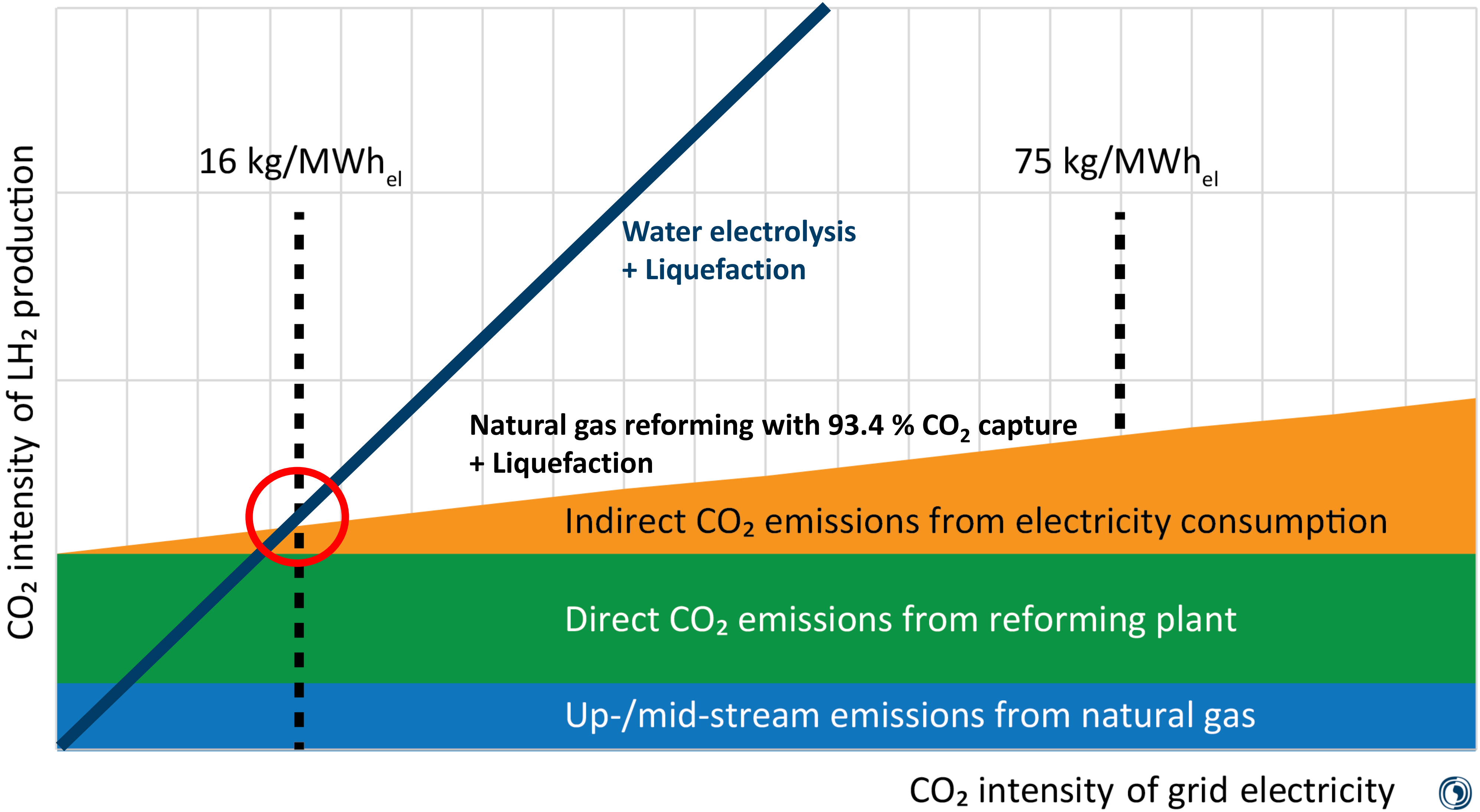
Hydrogen costs - comparison

Parameter	Unit	Actual	2020		2030		2050	
			Low	High	Low	High	Low	High
Cost of electricity	€/kWh	0,1	0,65	0,100	0,060	0,090	0,050	0,080
Operating time (electrolysis)	h/y		3500	3500	3750	4500	4000	6000
Gas price	€/kWh	0,034	0,037	0,044	0,041	0,054	0,044	0,068
Carbon price	€/t	0	15	25	30	80	50	150
Cost of CCS	€/t		100		80		60	

Hydrogen production cost comparison

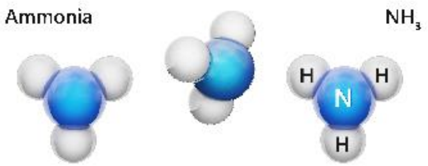


CO_2 intensity of liquid hydrogen product



SINTEF

Magnum and Leeds City Gate



Evaluating conversion of natural gas to hydrogen

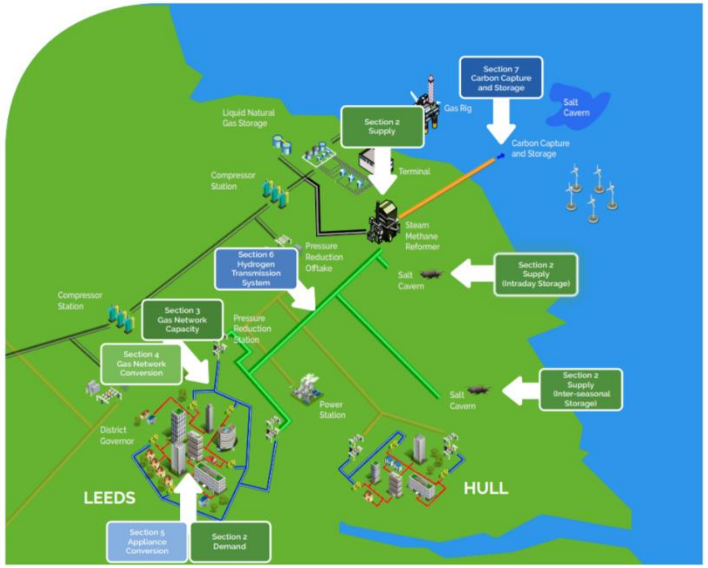
equinor

July 7, 2017 09:00 CEST

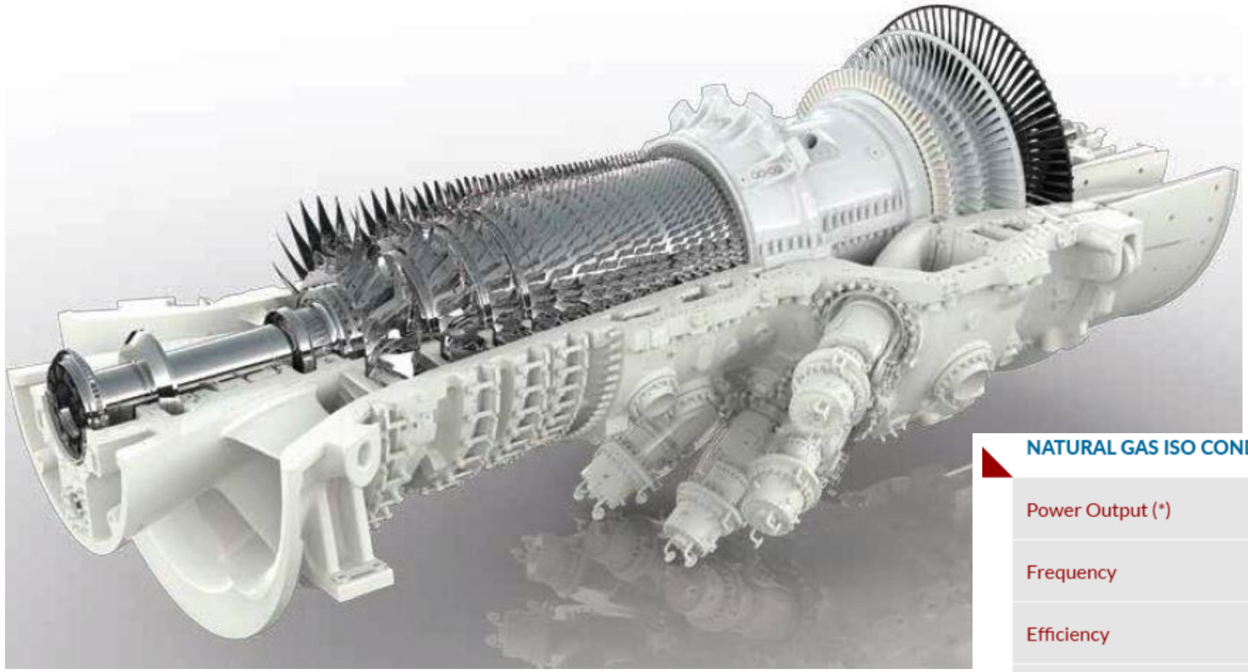
Vattenfall's gas power plant Magnum. (Photo: Koos Boertjens / Vattenfall)

H21 Leeds City Gate System Schematic

Northern Gas Networks



Turbulent combustion: a zero-emissions future



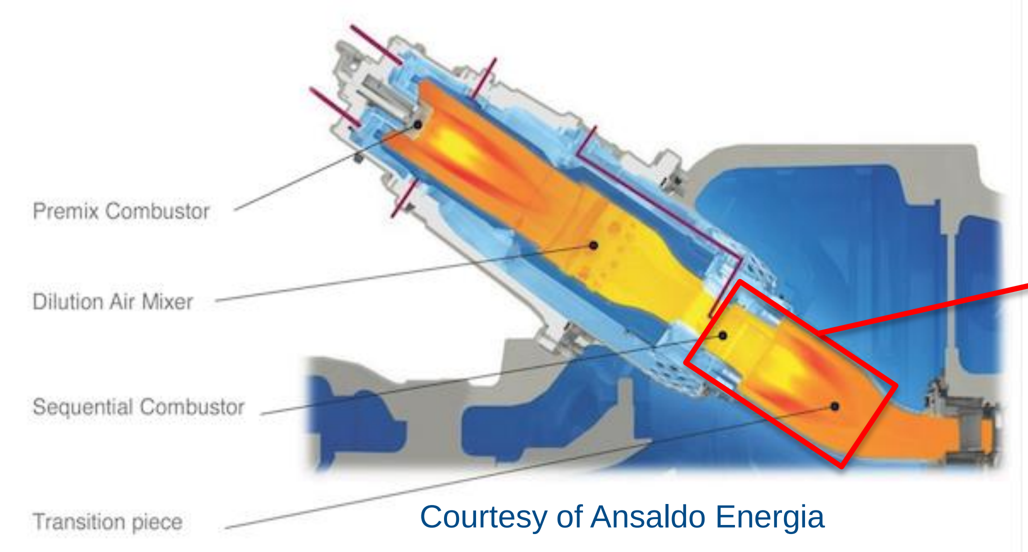
Ansaldo Energia GT36

NATURAL GAS ISO CONDITIONS		GT36 S5
Power Output (*)	MW	500
Frequency	Hz	50
Efficiency	%	41.5
Exhaust Mass Flow	Kg/s	1,010
Exhaust Temperature	°C	624

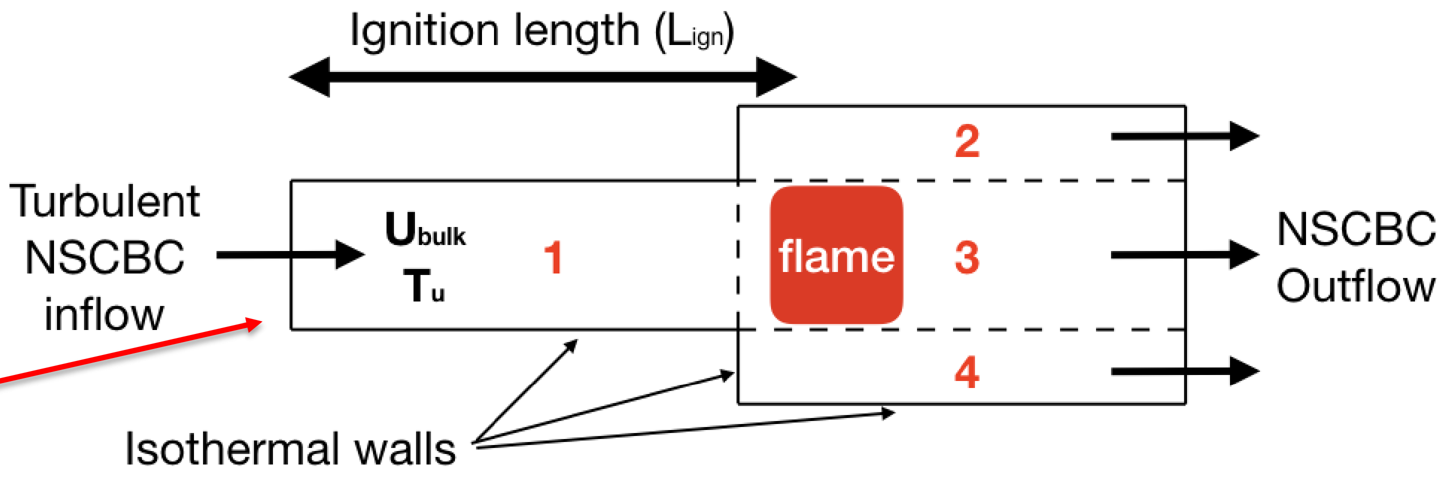
Ongoing HPC-based R&D with Ansaldo and Equinor to run on 100% hydrogen:

- Zero-emissions large-scale power generation
- One single GT36's power output is equivalent to the *global* installed fuel cell capacity (2017)...

DNS of reheat flame



Courtesy of Ansaldo Energia



$L_{ign} \sim U_{bulk} \times t_{ign} \sim$ 4cm

U_{bulk} = 200 m/s

Total grid ~ 1.25 billion

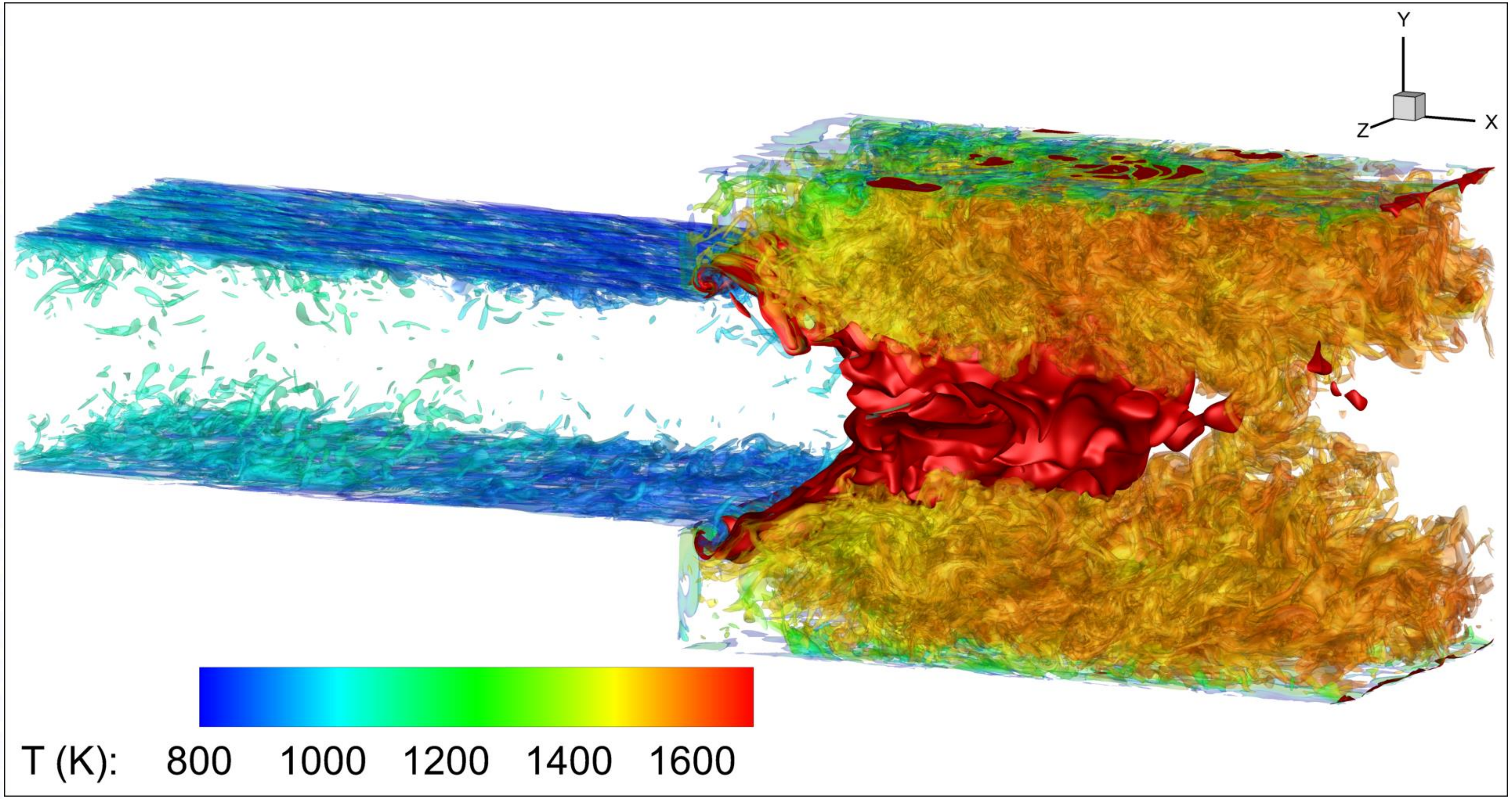
Reynolds number ~ 13000

- First ***ever*** Direct Numerical Simulation (DNS) of *geometrically simplified and downscaled* model of sequential combustor
- Aims to ***quantify of autoignition vs propagation***

Sandia National Laboratories

NCCS

DNS of reheat flame



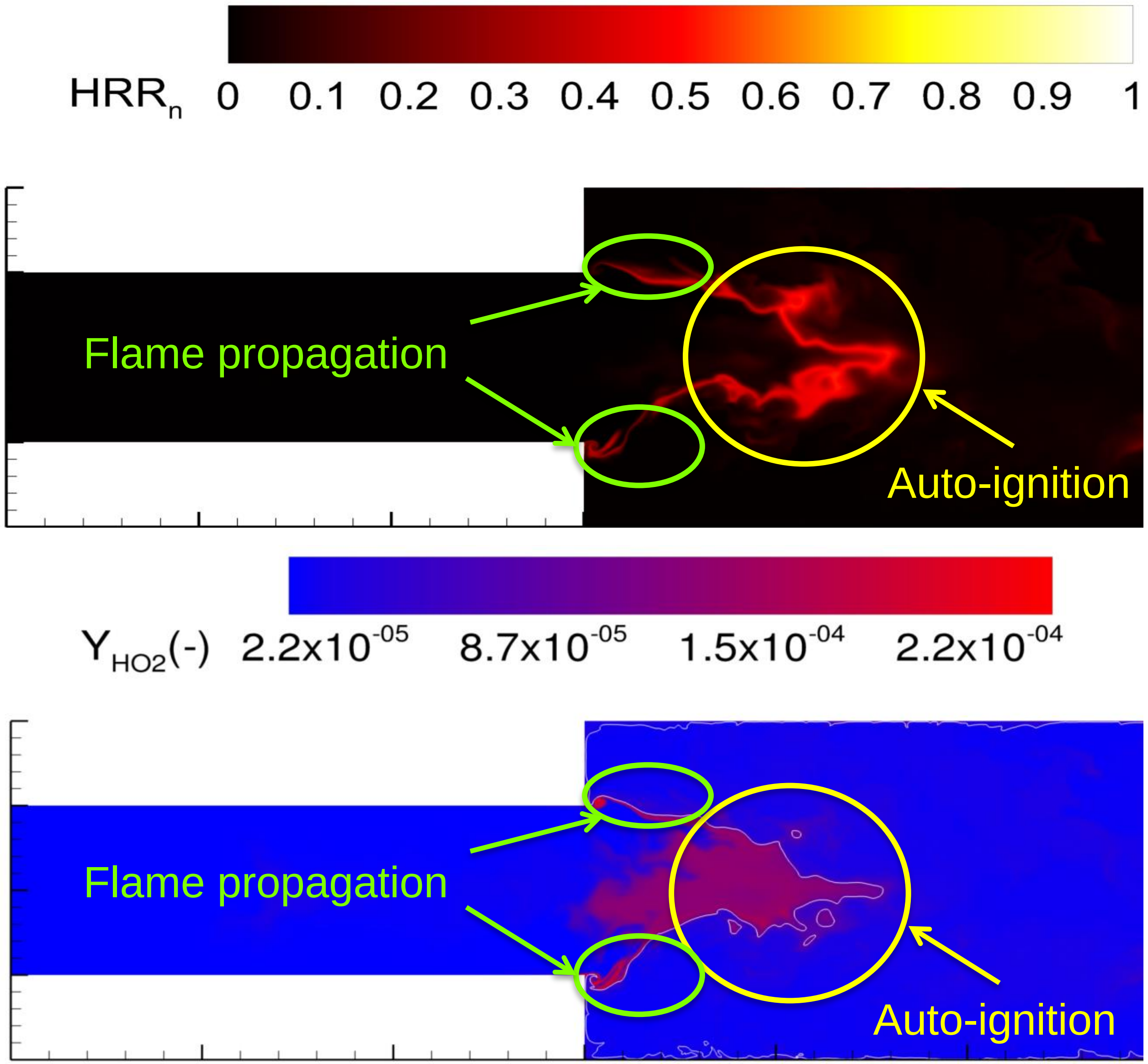
➢ **All time scales of chemistry and turbulence are resolved (model-free)!**

DNS results: flame auto-ignition vs flame propagation

ENCAP DECARBit

SIXTH FRAMEWORK PROGRAMME

SEVENTH FRAMEWORK PROGRAMME



Qualitative characterization:

- ***spatially thin structures → propagation***
- ***spatially distributed structures → auto-ignition***

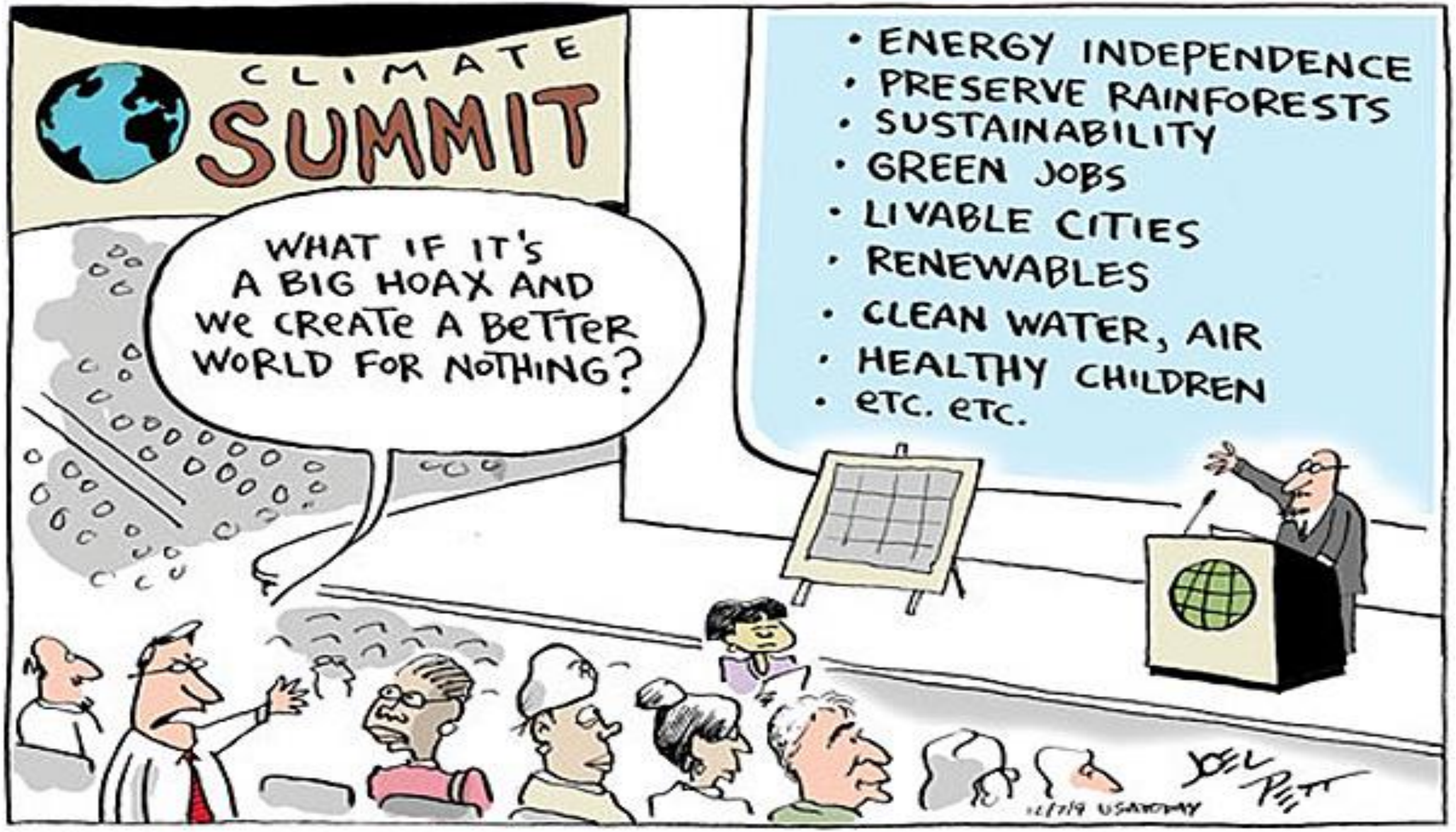
Summary

- We will need more power and more flexible power in the future- but we only need the power not the greenhouse gas emissions from the conversion process
- GT advanced cycles can address this by operating in post, pre or oxyfuel modes
- Hydrogen will be an important element to reach the well below 2 deg target, H_2 role largely underrated today as supply volumes and timing seen as major obstacle
- However, it can be produced sustainably from natural gas at large scale including CCS and be supplemented by hydrogen from renewables, enabling the hydrogen economy
- Important to support R&D in the GT area- optimal when industrial, EU and MS/AC R&D funding can work in concert

So GT's will be needed but they will cope with other fuels, oxidisers and inerts, pressures and temperatures!

SINTEF

Technology for a better society


CLIMATE SUMMIT
WHAT IF IT'S A BIG HOAX AND WE CREATE A BETTER WORLD FOR NOTHING?
• ENERGY INDEPENDENCE
• PRESERVE RAINFORESTS
• SUSTAINABILITY
• GREEN JOBS
• LIVABLE CITIES
• RENEWABLES
• CLEAN WATER, AIR
• HEALTHY CHILDREN
• etc. etc.

SINTEF