Towards demonstration of natural gas fired power plant with oxy-fuel capture

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Natural gas fired power plants with CO_2 capture

- Status gas turbine based power cycles
  - Post combustion absorption most mature
    - High excess air → low concentration of CO2 in exhaust
  - Pre-combustion capture:
    - Not competitive for NG
  - Oxy-fuel capture:
    - Competitive efficiency
    - Good potential for improvement through ASU technology development

Early Oxy-fuel Gas Turbine Cycle Concepts at SINTEF/NTNU

Energy Convers. Mgmt Vol. 33, No. 5-8, pp. 467-475, 1992

NEW CONCEPTS FOR NATURAL GAS FIRED POWER PLANTS WHICH SIMPLIFY THE RECOVERY OF CARBON DIOXIDE

O. Bolland and S. Sæther

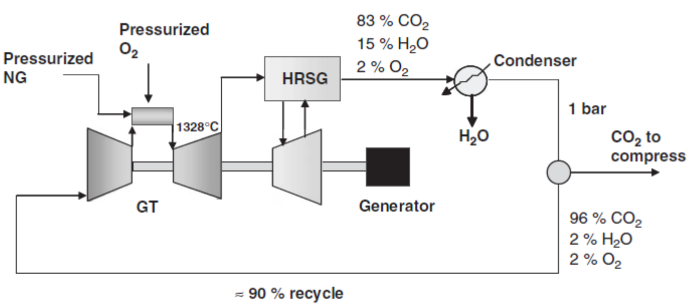


Fig. 1. Simplified PFD of the oxy-fuel CC concept.

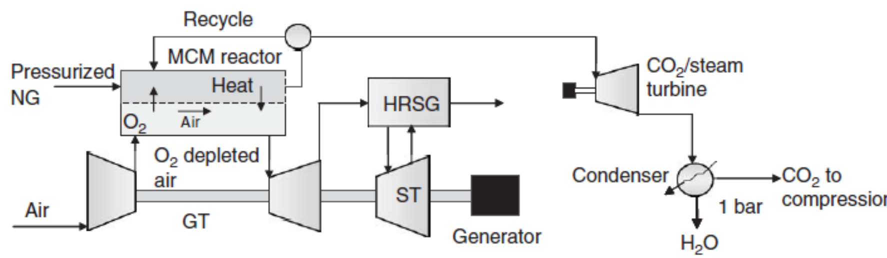


Fig. 4. Simplified PFD of the AZEP concept.

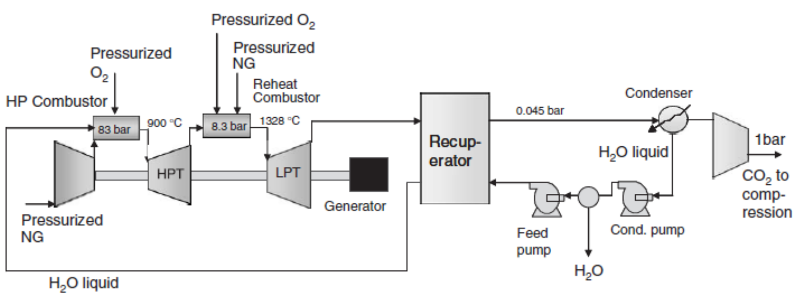


Fig. 2. Simplified PFD of the water cycle concept.

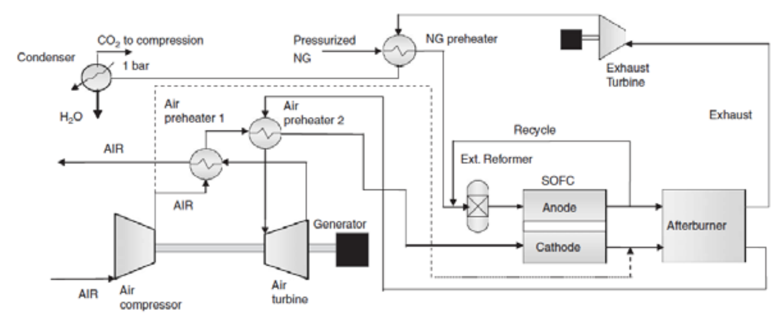
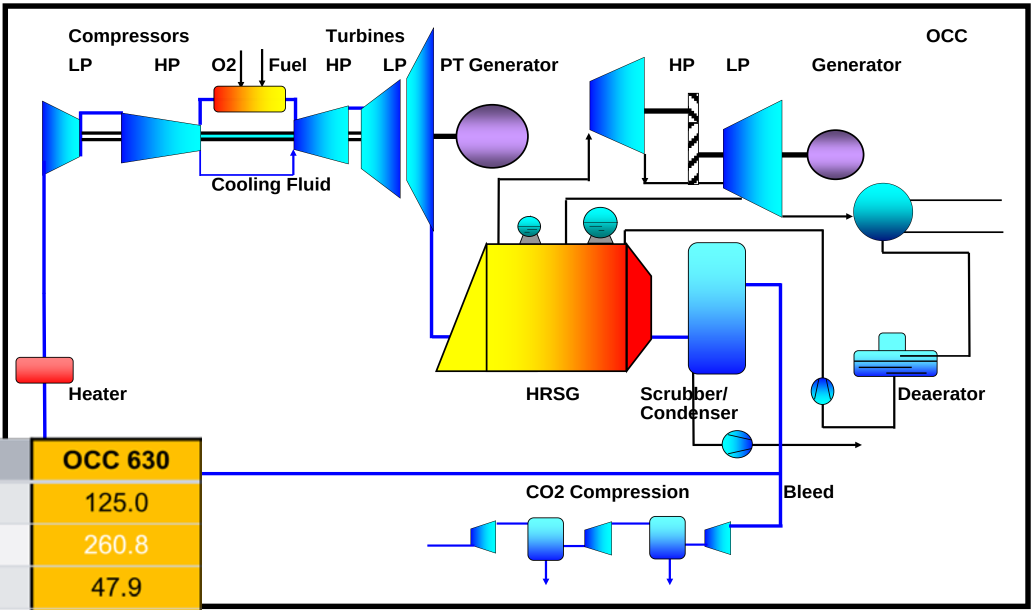


Fig. 5. Simplified PFD of the solid oxide fuel cell integrated with a gas turbine (SOFC + GT) concept.

Source: Kvamsdal et al, Energy, 2007

Natural gas fired power plants with oxy-fuel CO_2 capture

- CO2 as working fluid
  - Semi-closed oxy-fuel combined cycle (SCOC-CC)
  - MATIANT variants, ++

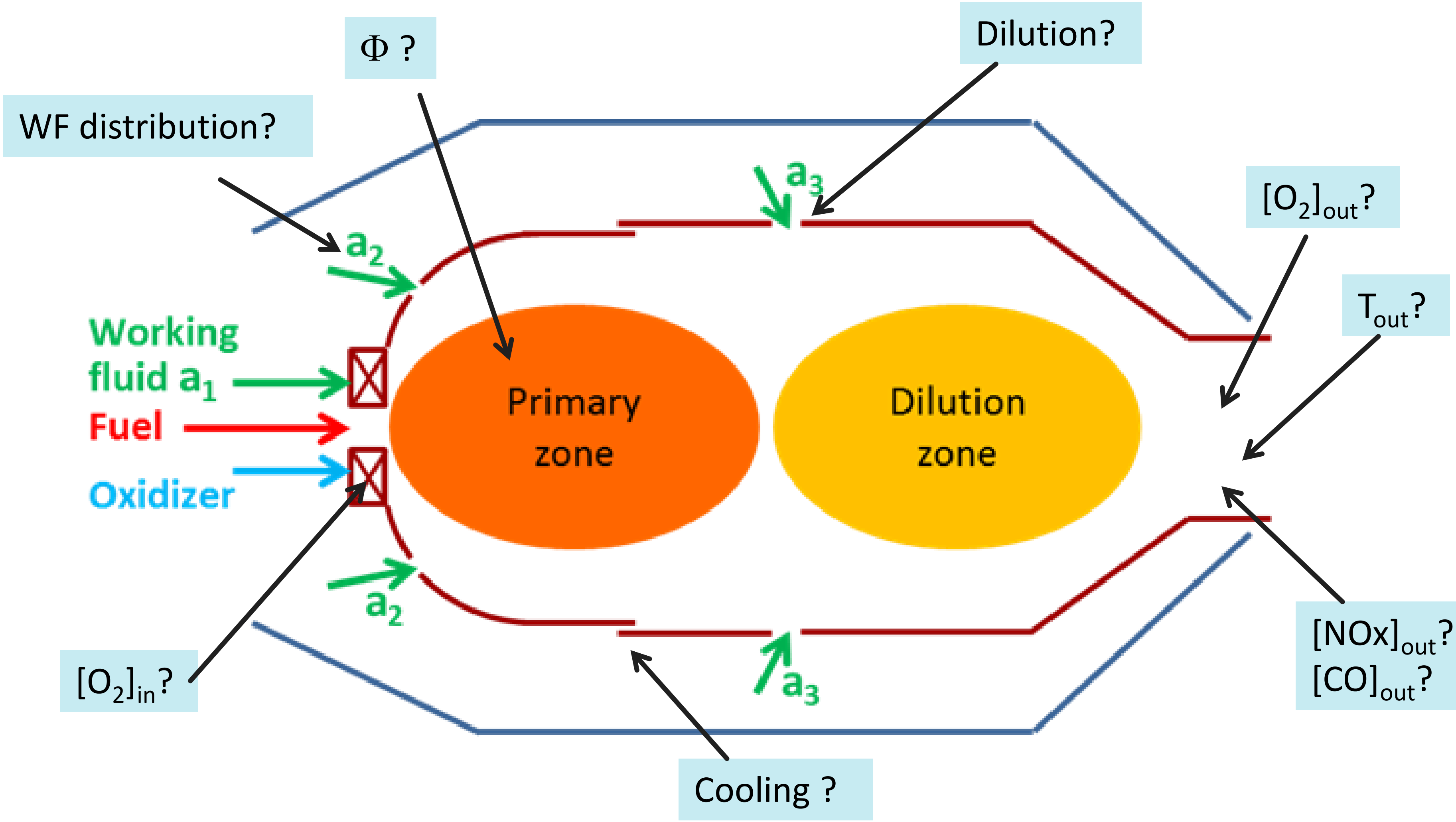


		HMOC	OCC 590	OCC 630
Net power output	MW_{el}	125.0	125.0	125.0
Heat input (LHV)	MW_{th}	298.7	259.8	260.8
Plant net efficiency	%	41.9	48.1	47.9
Pressure ratio	-	40.0	47.0	34.7
GT power	MW	98.5	106.6	101.0
ST power	MW	70.5	55.3	58.6
ASU	MW	17.6	16.7	16.7
O_2 compression	MW	11.8	14.1	12.3
CO_2 compression	MW	7.89	7.14	7.16

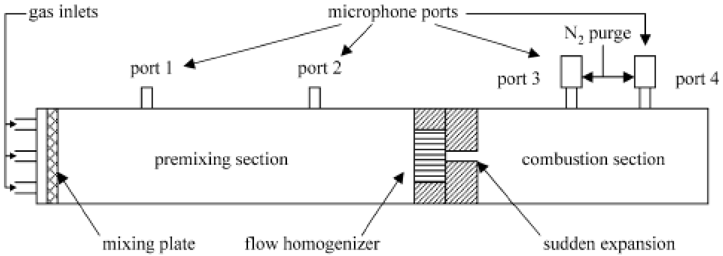
SIEMENS

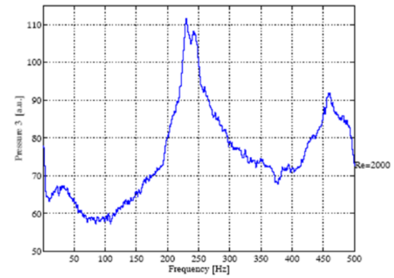
Source: OXYGT project,
Sundkvist et al, J. Eng. GT Power 136:101513, (2014)
Saanum et al., ASME Turbo Expo, GT2016-57142 (2016)

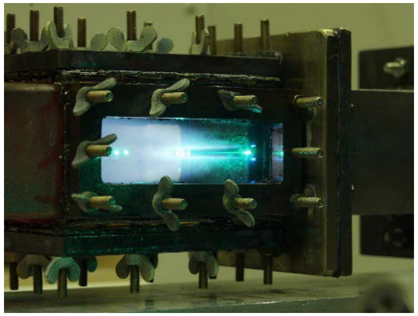
Challenges in oxy-fuel gas turbine combustion

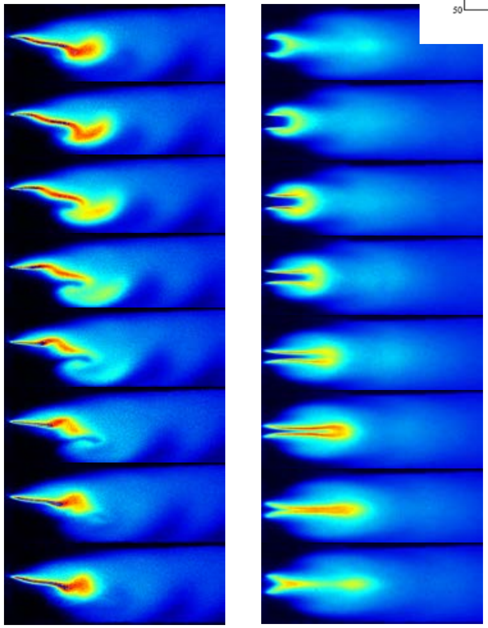


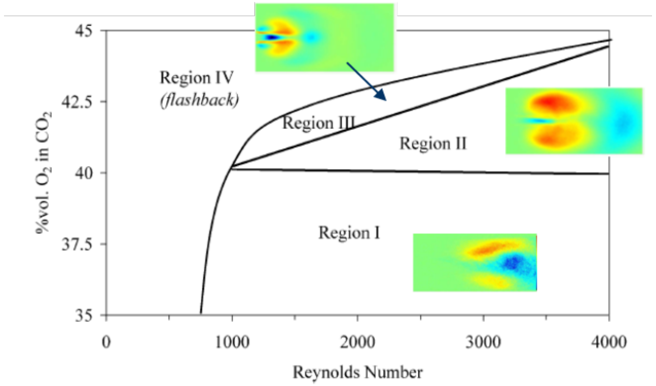
Oxy-fuel combustion fundamentals – Thermo-acoustic instabilities







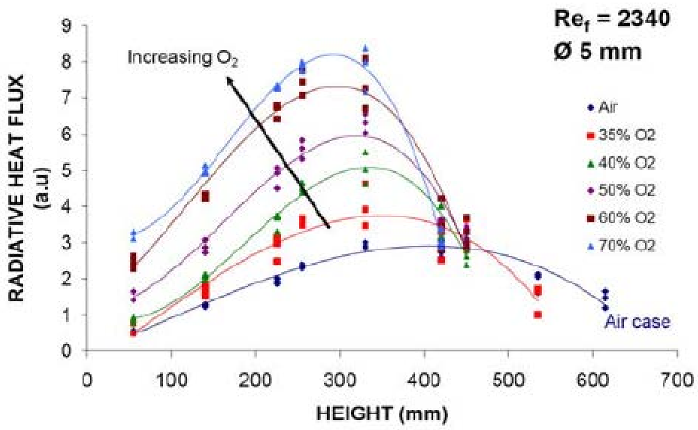


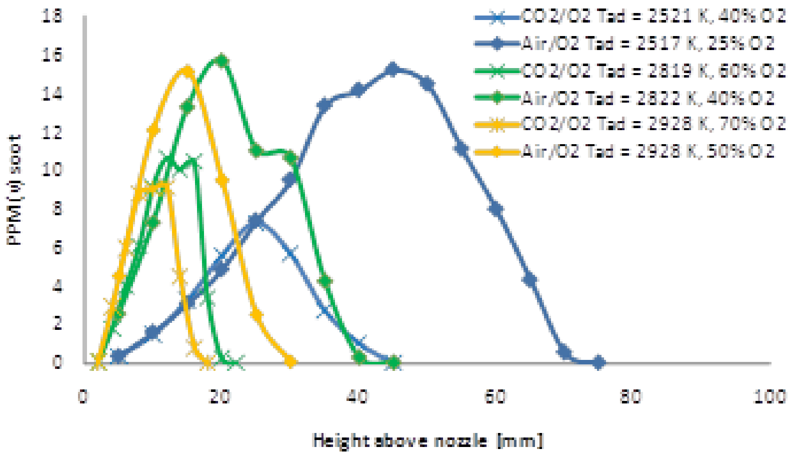


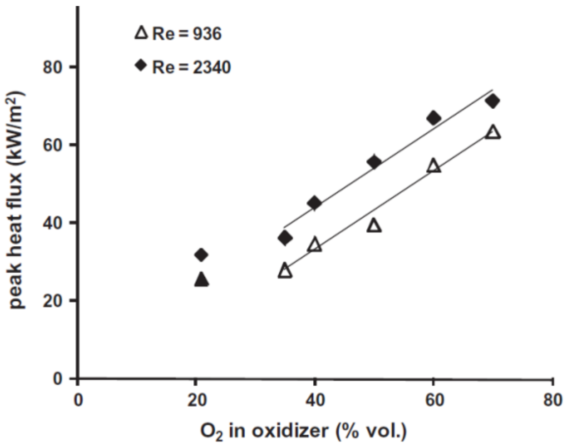
Source: Ditaranto et al, Comb. Flame 146, 2006

Oxy-fuel combustion fundamentals – Radiative heat transfer

- Increased radiative heat transfer
  - Higher local flame temperature
  - Higher flame emissivity
  - Soot





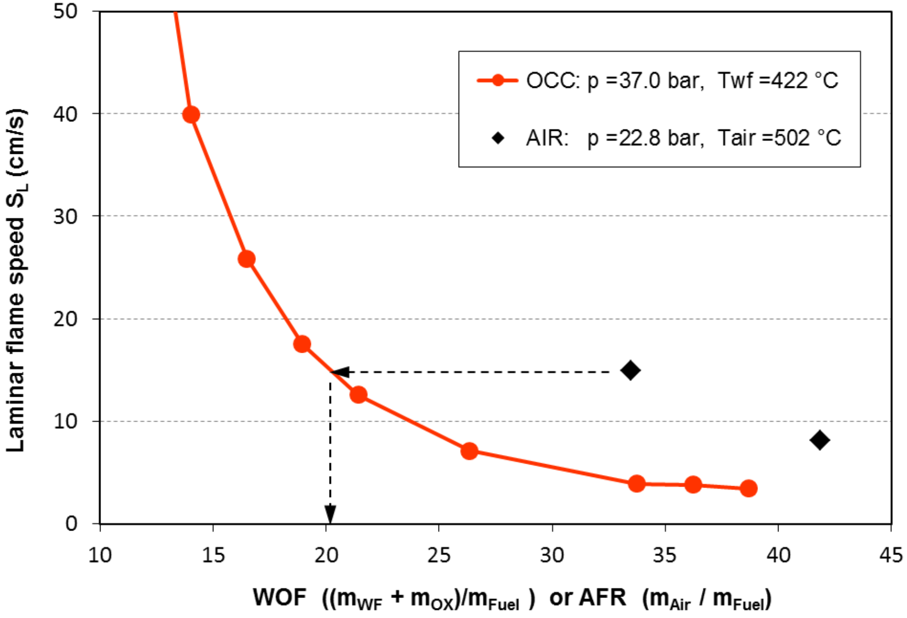


Source: Ditaranto et al, Exp. Therm. Fluid. Sci. 35 (2011)

Oxy-fuel combustion fundamentals – Flame speed

Primary zone strategy:
Keep the
same laminar flame speed
as in air case

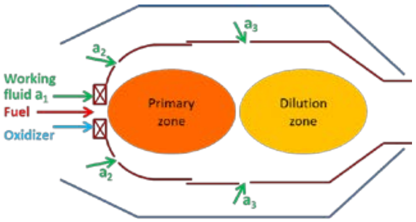
- Stability: Prio. 1 for a burner

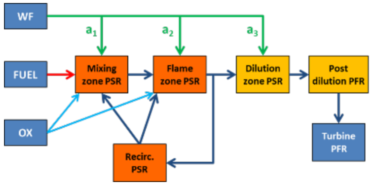


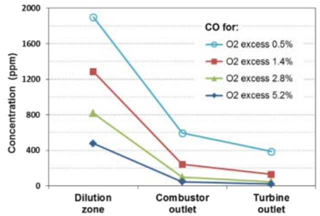
OXYGT project

- Feasibility of new combustion concept: OXY-FUEL GAS TURBINE

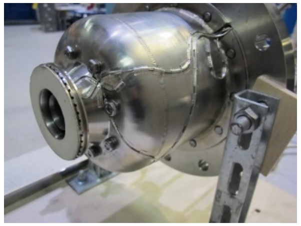
Concept study



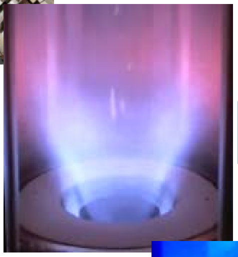




Burner design

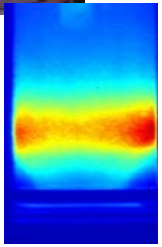


Pilot scale testing

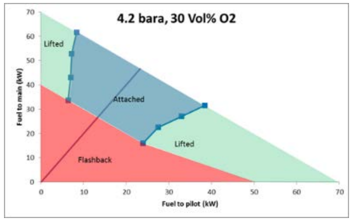


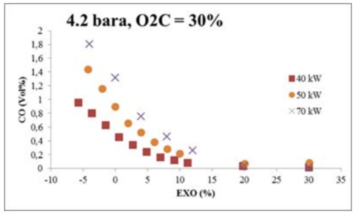
60 kW
7.1 bar
O2C = 27%
PFR = 28.5

OH* imaging



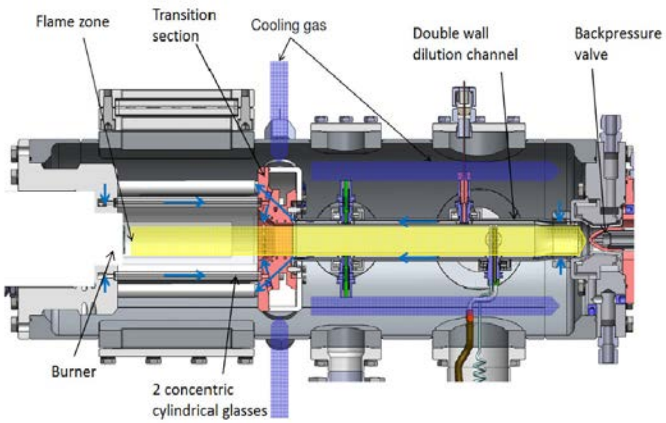
Learning and feedback

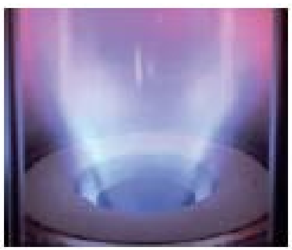




Sources:
Sundkvist et al. J. Eng Gas Turb Power 136(10):101513, 2014.
Saanum et al.. ASME Turbo Expo 2016, Paper # GT2016-57142

HIPROX facility





Oxy-fuel flame at 7 bar (source: OXYGT project)

Infrastructure financed by: The Research Council of Norway, CLIMIT

Specifications

Pressure vessel

- 15 bar
- 4 optical accesses

Combustor section

- 10 bar
- Double wall quartz flame section
- TBC coated dilution section
- Modular setup, 3 flame sections existing: 40X40 mm^2; Ø 50 mm ; Ø 90 mm

Fuel

- Max power 150 kWth
- Two feed lines 3 g/s (main) and 1.4 g/s (pilot) methane
- Storage: cylinder battery

Oxidizer

- Two independent heated feed lines PN 40
- Air 30 bar – 520 kg/hr - 300°C – Boosted network
- CO_2 15 bar - 300 kg/hr - 300°C - 6 m^3 liquid tank
- O_2 20 bar - 72 kg/hr - 20°C - Cylinder battery

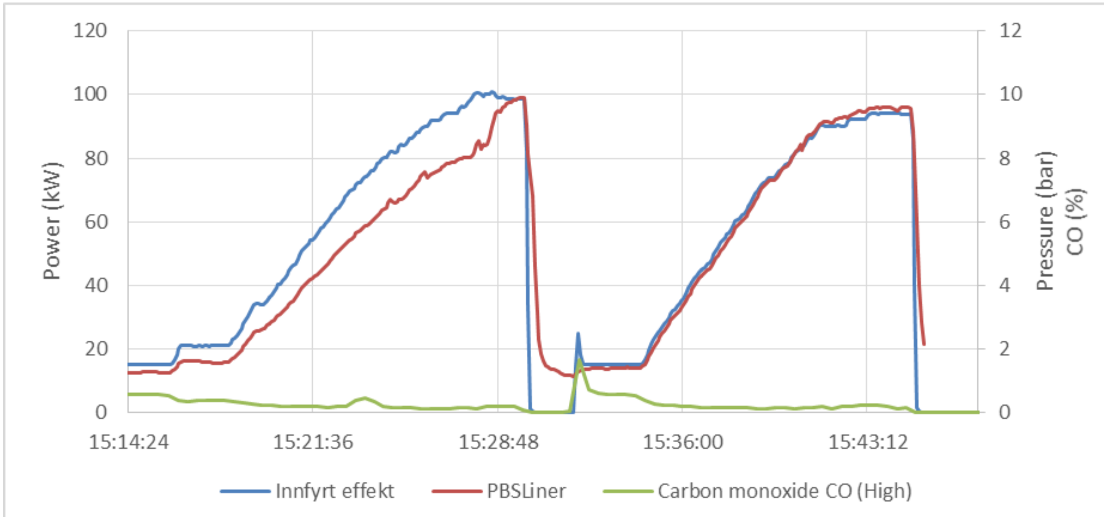
Measurement capabilities

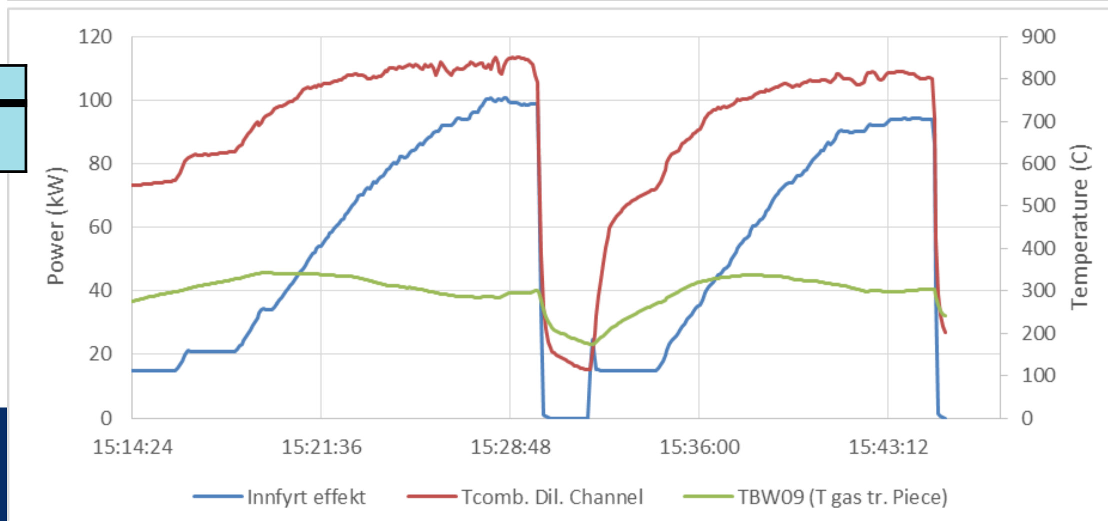
- Flame visualization (chemiluminescence, high speed)
- Multi-species emission (>15 species, FTIR)
- Temperature, heat flux
- Pressure (static and dynamic)

Pilot testing of oxy-fuel burner

- Testing to design conditions: 100 kW – 10 bar

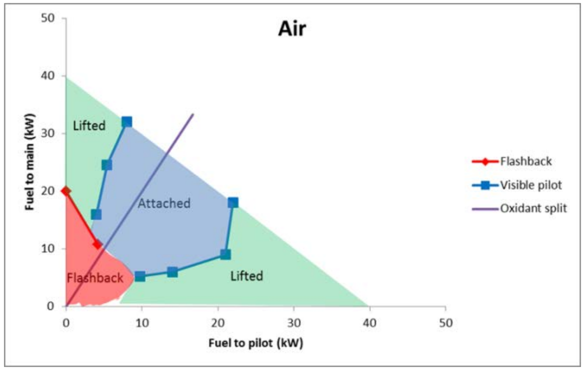
(left) 1 bar - 40 kW - 40% O_2
(right) 3 bar - 40 kW - 40% O_2

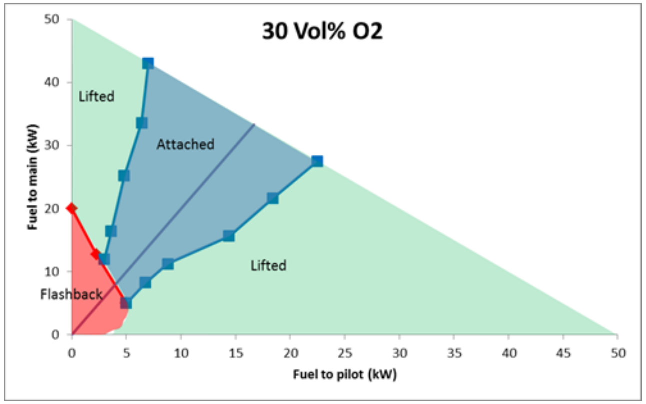


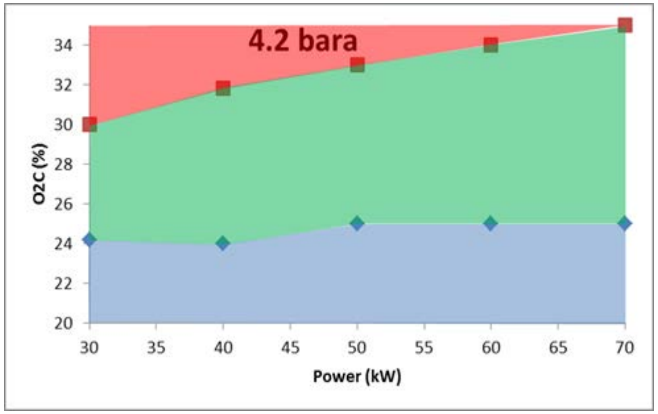


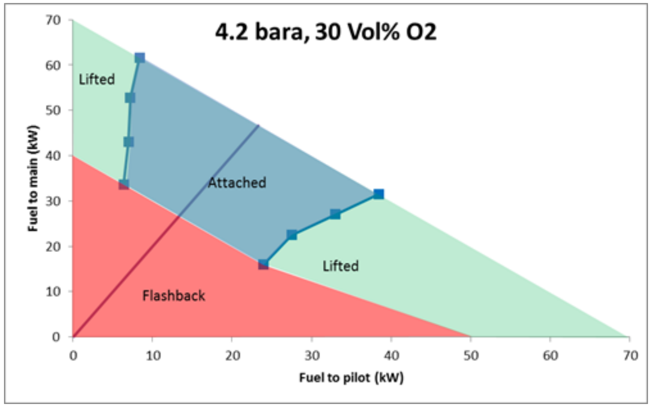
10 bar - 100 kW - 30% O_2

Pilot testing of oxy-fuel burner
Stability



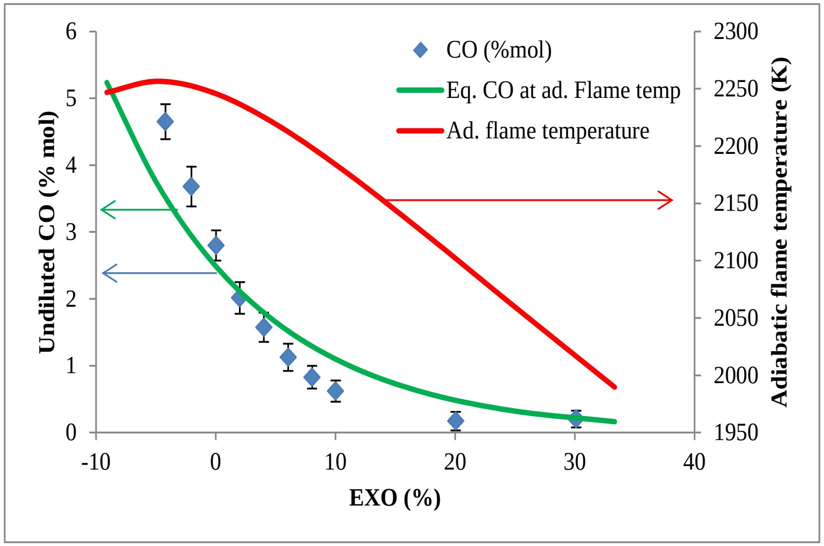






Pilot testing of oxy-fuel burner
CO burn out

- Kinetically CO is limited by:
  - $CO + OH \rightarrow CO_2 + H$
  - $CO_2 \leftarrow\rightarrow CO + ½ O_2$ (less important)
  - CO_2 inhibits CO oxidation
- Hardware dependent effect
  - Quenching of CO chemistry results in high CO



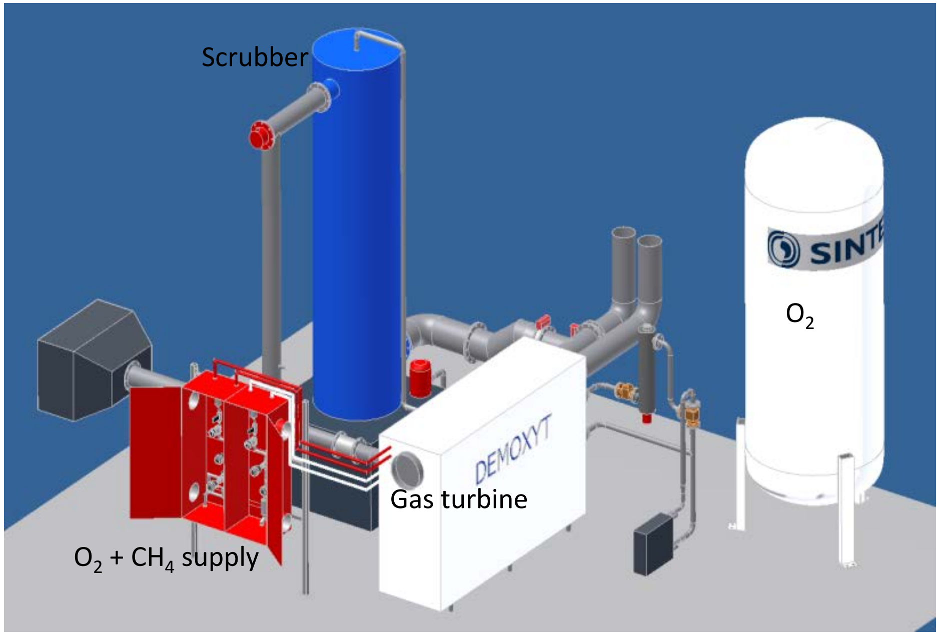
50 kW, 30 vol% O2, x bar

DEMOXYT: Oxy-fuel plant demo

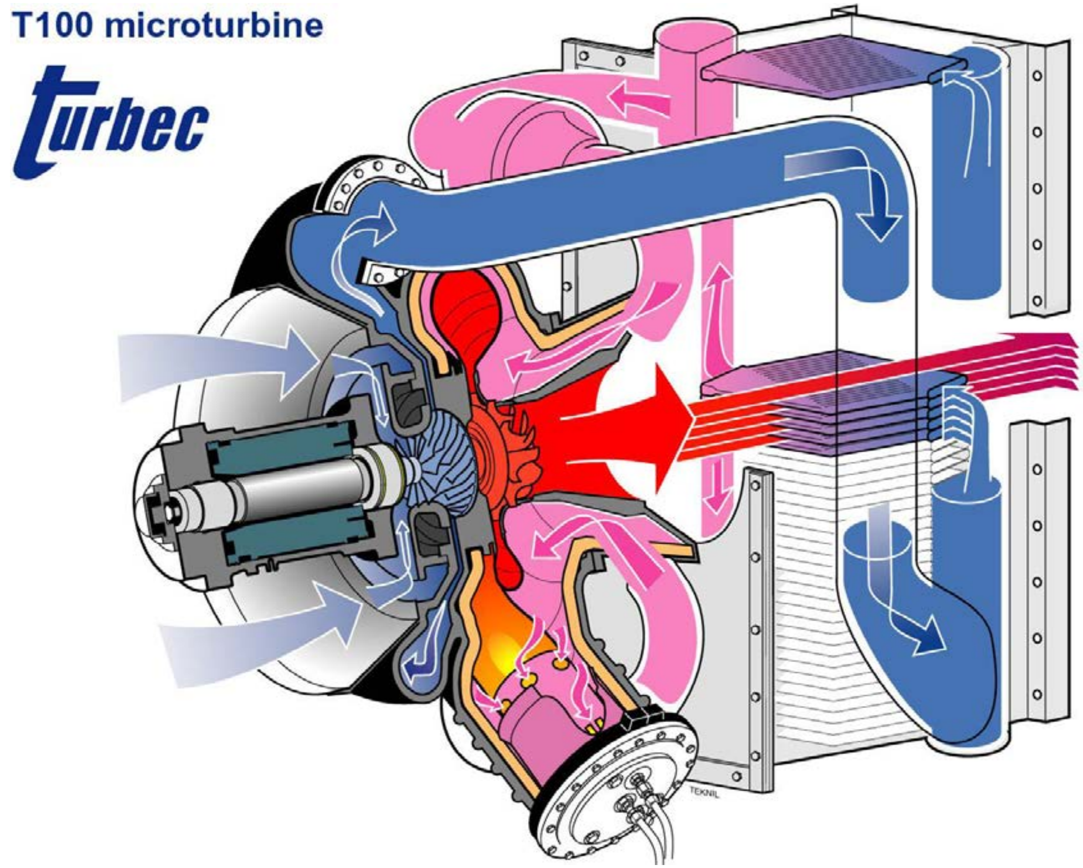
- Research Infrastructure funded by The Research Council of Norway
- Research Infrastructure part of eccsel
  - Open for funded transnational access

DEMOXYT

- SINTEF Energy Lab in Trondheim, Norway
- Based on Turbec T100 engine
- Oxygen and methane from tank
- Exhaust gas recirculation loop
- Exhaust cooling in scrubber



DEMOXYT



- Air mode operation
  - Power: 100 kWel
  - Pressure ratio: 4.5/1
  - TIT: 950°C
  - TOT: 650°C
  - Exhaust temp.: 270°C
  - Air flow: 0.8 kg/s
- Oxy-mode operation
  - Speed reduction
  - Mass flow increase
  - Pressure ratio reduction

-> Reduction in cycle efficiency

DEMOXYT: Oxy-fuel plant demo

- Installation period: commissioning in 2018
- Objectives
  - Demonstrate natural gas fired oxy-fuel power
  - Gain operational experience (start up, transients, mode shift, …)
  - Test bench for components development

Acknowledgements

- BIGCO2 project, RCN CLIMIT programme grants 178004/I30 and 176059/I30
- BIGCCS Centre, RCN FME grant 193816/S60
- OXYGT project, Gassnova CLIMIT programme grant 212784
- RCN Infrastructure grants 225868 and 245822

The Research Council of Norway

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