ENCAP SP4
Chemical looping combustion

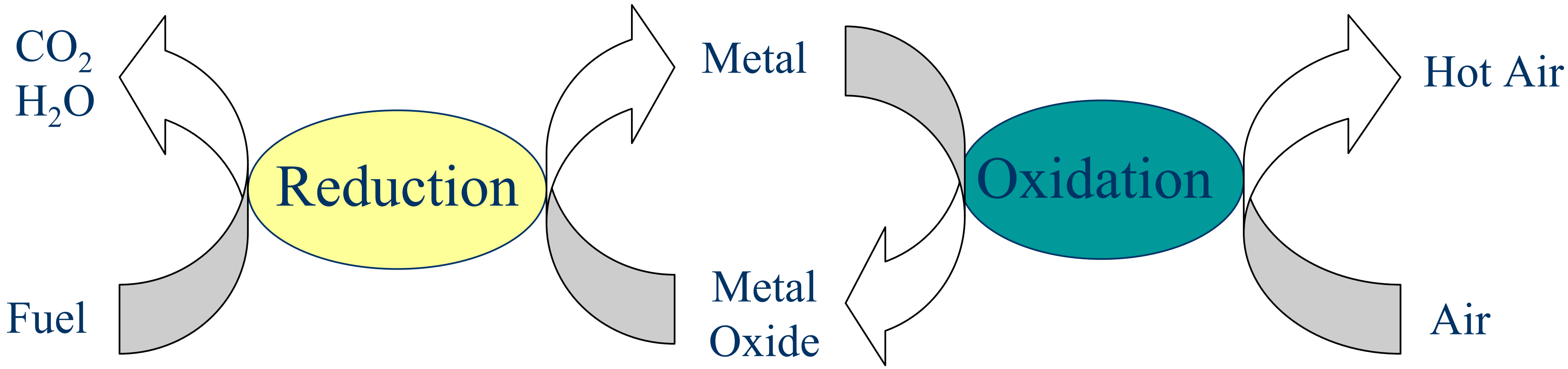
CASTOR-ENCAP-CACHET-DYNAMIS workshop

Thierry GAUTHIER, IFP

Content

- Background
  - Chemical Looping Combustion (CLC)
  - SP4 objectives
- SP4
  - Development of stable reactive materials for CLC
  - CFB design and scale-up
  - Innovative reactors development for gas turbine application
  - Process modeling, evaluation and optimization
- Conclusions

Chemical Looping Combustion Principle



- Process characteristics
  - full CO2 capture (100%)
  - no Air Separation Unit

No energy penalty for:
- oxygen production,
- for CO2 separation

⇒ One of the best candidate for 20 €/t_{CO2} target

SP4 objectives

- Chemical looping combustion applied:
  - to solid fuel boilers
  - gas turbine power cycles.
- Make available validated technologies, materials and process concepts for chemical looping combustion.
  - Develop CFB boiler for solid fuels CLC application up to pilot plant operation (1 MW_{th}).
  - Develop new concepts of CLC reactors adapted to gas turbine operation using natural gas.

SP4 Structure

Development of stable reactive materials for CLC
WP1
Chalmers
IFP
SINTEF

CFB design and scale-up
WP2
Alstom
Chalmers

Innovative reactors development for gas turbine application
WP3
IFP
TNO

Process modelling, evaluation and optimisation
WP4
NTNU
Alstom
Siemens
IFP
TNO

SINTEF
ifp Innovation Energy Environment
(SP leader)
ALSTOM

ENCAP

SP4 – Chemical Looping Combustion

PARTICIPANTS

AVANCEZ 1829
TNO
SIEMENS
NTNU
Norwegian University of Science and Technology

encap CO_2

Development of stable reactive materials for CLC 1/2

- Number of new material investigated
  - Natural ores
  - Industrial waste
  - Specific formulated and prepared materials with high oxygen content and reactivity
- Batch experimental work (O2 capacity & reactivity, fluidization)
  - Fluid bed fuelled with natural gas, syngas, coal and petroleum coke
  - Coated monoliths fuelled with natural gas
- Chemical and mechanical stability
- Scale up and selection of manufacture process

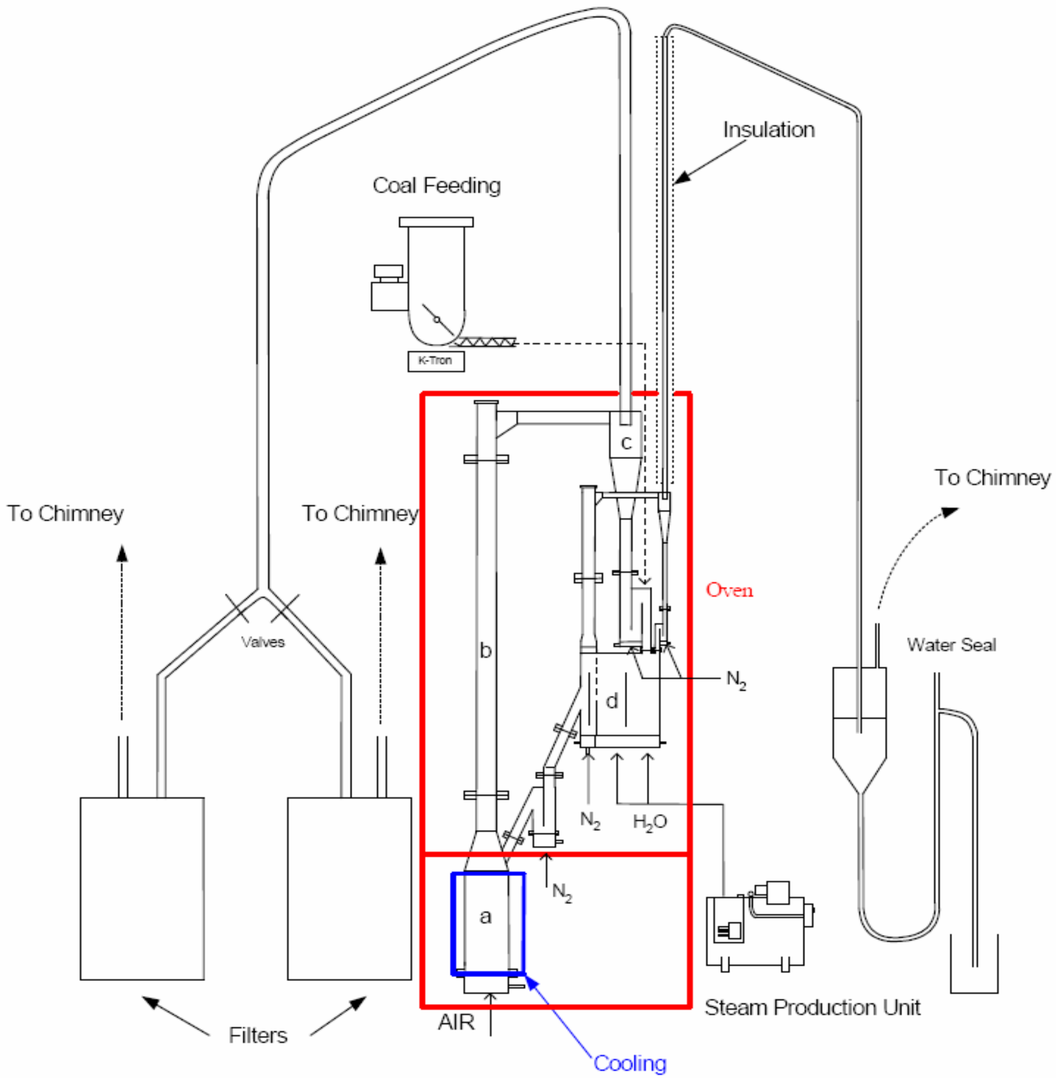
Development of stable reactive materials for CLC 2/2

- Proof of the concepts:
  - Solid fuel combustion with chemical looping in fluid bed
  - Natural gas combustion through chemical looping on monoliths

- Good performance with low cost oxygen carriers for hard coal and petroleum coke combustion

- Good stability of monolith coating during the experimental tests
  - Coke deposition exhibited on some materials

CFB design and scale-up 1/2



- Chalmers 10 kW_{th} CFB pilot built for solid fuels combustion testing
  - Validation of design through more than 140 hours operation
  - Stable conditions kept during hours
  - High capture and conversion rates achievable
  - CLC concept confirmed for solid fuels and suitable for low cost oxygen carriers (ilmenite)

CFB design and scale-up 2/2

- Evaluation of plant feasibility and design of 455 MW_e CLC boiler unit
  - Reactor design
  - Heat & material balance
  - Efficiency study
  - Preliminary risks review (Failure Mode Analysis).

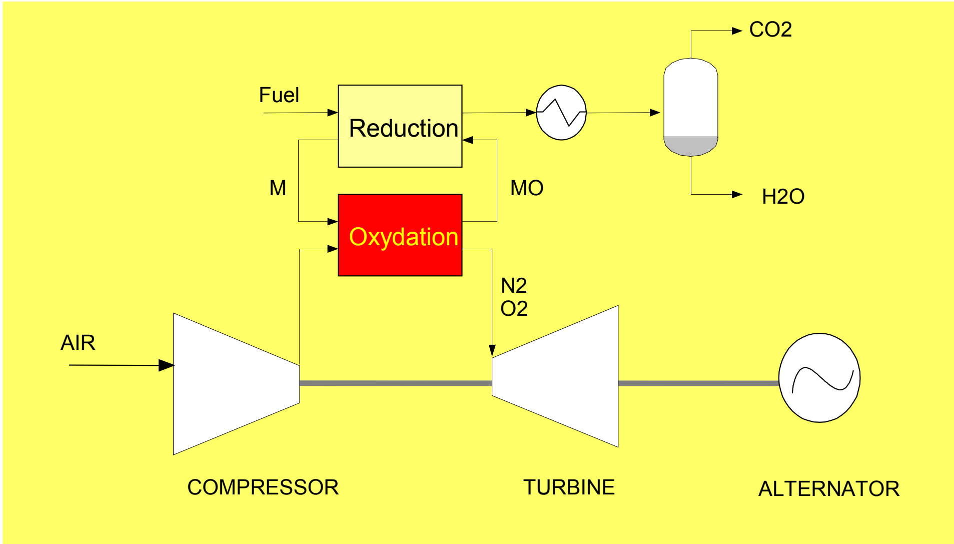
- Low cycle efficiency penalty
  (Δ=2%, mainly CO_2 compression)
- CO_2 mitigation cost lower than 10 €/ton_{CO2}

Innovative reactors development for gas turbine application 1/3

- Particule free reactor concepts for gas turbines

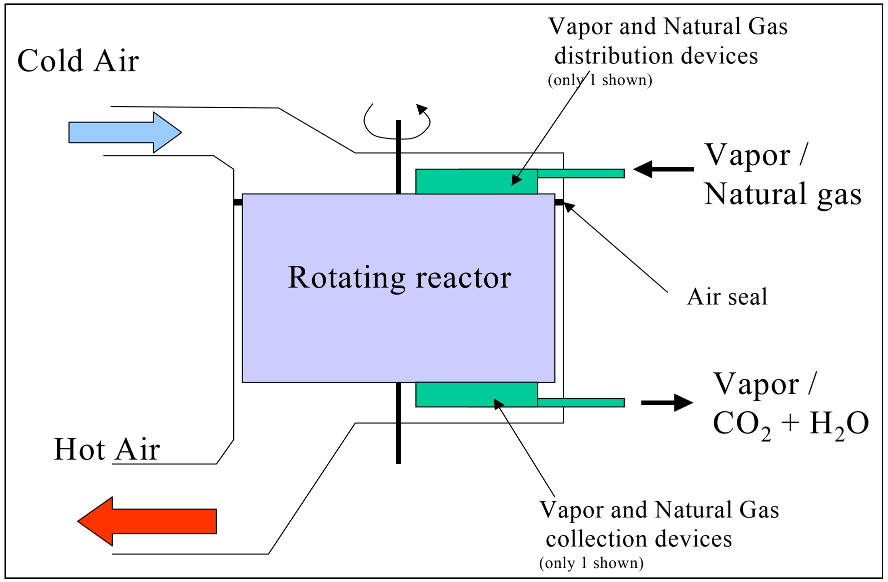
- Concepts
  - Rotating reactor
  - Membrane assisted reactor

- Reactor development
  - Testing and modeling
  - Scale-up , economic evaluation



Innovative reactors development for gas turbine application 2/3

- Rotating reactor concept



- Based of rotating Heat exchanger technology with
  - Natural gas and Air sections
  - Steam sealing and flushing
- Continuous operations

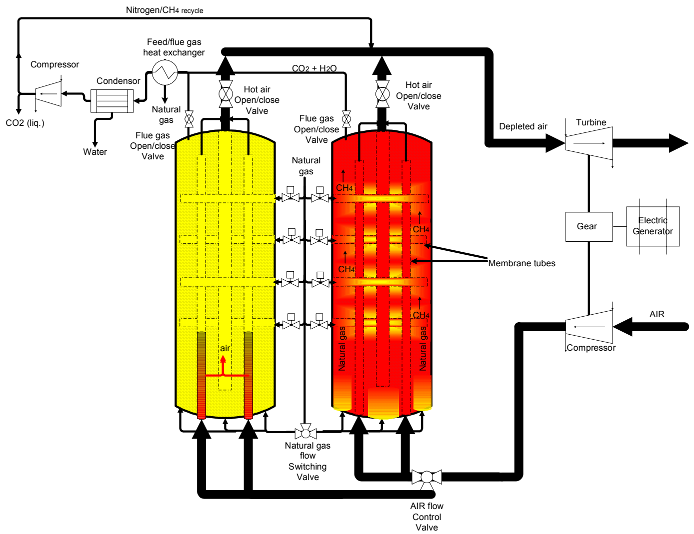
- Experimental work:

  Natural gas tests on different coated monoliths in a batch reactor
- Reactor modelling based on experimental data
- Scale-up and cost estimate for a 350 MW_e process scheme

- No technological barrier identified
- Further studies needed

Innovative reactors development for gas turbine application 3/3

- Membrane assisted reactors



- Packed bed reactors
- Gas distribution through porous ceramic membranes

- Bench scale setup (in progress)

- Low pressure drop
- Continuous operation using reactor switching
- Stable temperature and pressure operation
- Very efficient turndown ratio
- Long catalyst lifespan

➢ First results in fixed bed CLC show good promise; more research needed for optimalisation. Focus on methane slip.

Process modeling, evaluation and optimisation

- Definition of common basis for fair comparison to benchmark the different concepts and SP1 reference case
- Efficiency analysis + Heat & Material balances for a 350 MW_e plant considering:
  - CLC reactors
  - Air and CO_2 turbines
  - Steam cycle
- Technical and economic evaluations of CLC cycles
- Identification of promising process options for CLC
  - ➢ Double reheat required to achieve a unit efficiency up to 52%

Conclusions 1/2

- Solid fuel combustion with CLC
  - concept proven
  - Suitability of low cost materials (natural ores) in CFB reactors confirmed

- CFB development
  - Chalmers fluidized bed reactor system (10 kW_{th}) for solid fuels operated successfully
  - Design concept for solid fuels CFB boiler 455 MWe with Low cycle efficiency penalty and CO_2 mitigation cost lower than 10 €/ton_{CO2}

Conclusions 2/2

- Gas Turbine Power Cycle application :
  - Rotating reactors concept investigated and assessed
  - Test of membrane assisted reactors in progress
  - Turbine application : CLC combined cycle efficiency 52% with double reheat process

- In progress : Quality approval and fabrication of new material for testing at IFP, Chalmers and TNO
  - Optimized formulation (Perovskite) for stable and reactive materials
  - Material delivery to partners for testing
  - Industrial production cost of optimized material
  - Tests of this new material in pilot units

Thank you for your attention

ENCAP - SP4 Team

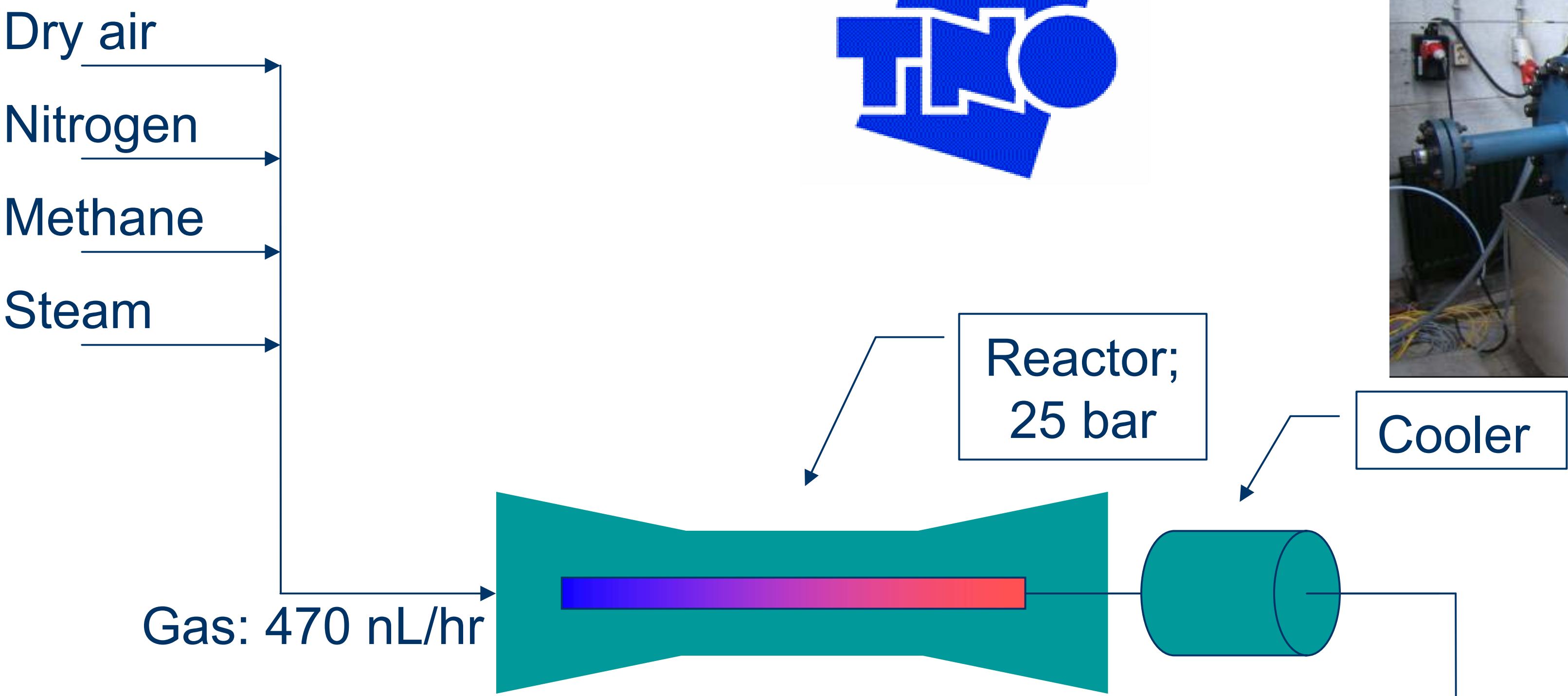
(SP leader)

ENCAP

SP4 – Chemical Looping Combustion

PARTICIPANTS

TNO



Gas analyses

CH_4
CO_2
CO
O_2
H_2

Catalyst material 0.39 mole/74.5 grams:

encap CO_2