Demonstration of a cost effective medium size Chemical Looping Combustion through packed beds using solid hydrocarbons as fuel for power production with CO_2 capture

(DemoCLOCK)

Dr. Shahriar Amini

Project Coordinator

SINTEF Materials and Chemistry, Norway

Content

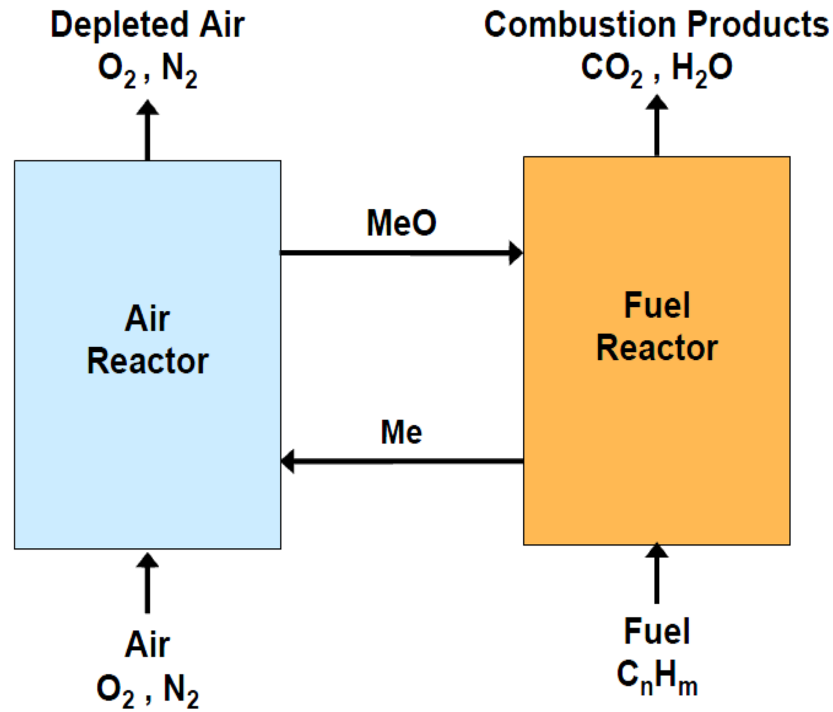
- Chemical Looping Combustion (CLC)
- Packed bed CLC
- Motivation for DemoCLOCK
- Objectives
- Consortium
- Work packages

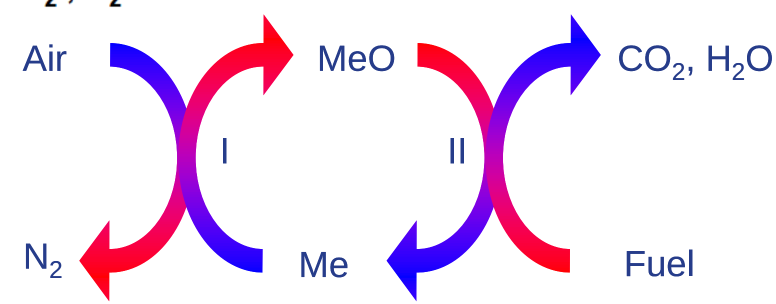
Chemical Looping Combustion

1. Air reactor: Reduced metal is oxidized with air. High temperature N_2 stream produced

2. Fuel reactor: Metal oxide (MeO) provides the oxygen for combustion in the fuel reactor. CO_2 is produced

3. Reduced metal (Me) is used again in step 1





I: $4\ Me + 2\ O_2 \rightarrow 4\ MeO\ (\Delta H < 0)$

II: $4\ MeO + CH_4 \rightarrow 4\ Me + CO_2 + 2\ H_2O\ (\Delta H > 0)$

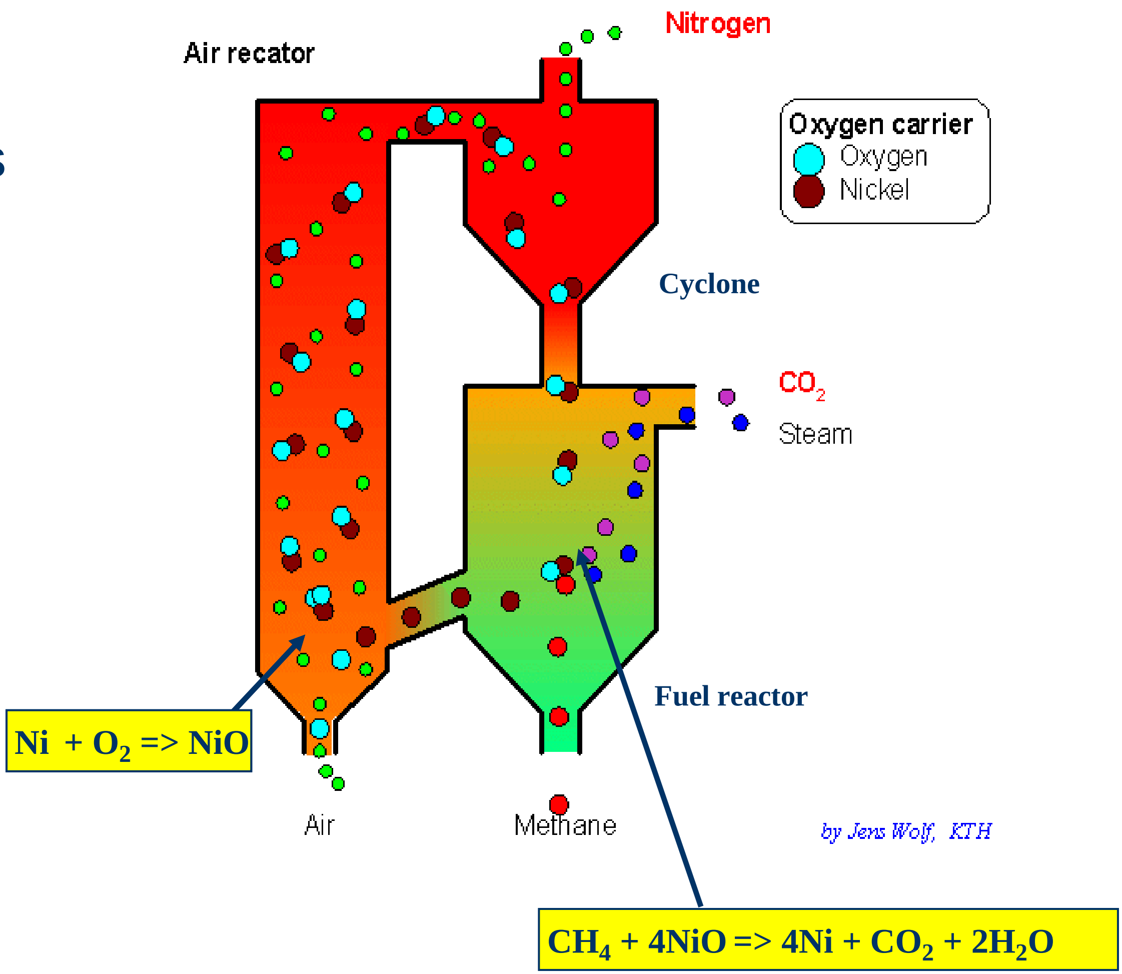
Advantages of CLC systems

- Power production with inherent CO_2 separation
- "No" energy penalty for separation of CO_2
- Potential for very high CO_2 capture efficiency
- No NO_x formation (no flame!)
- Direct contact between air and fuel is avoided

Process concepts (circulating fluidized bed)

- CFB system:
  - ➢ Recirculation of particles
  - ➢ Continuous operation
  - ➢ Proven technology

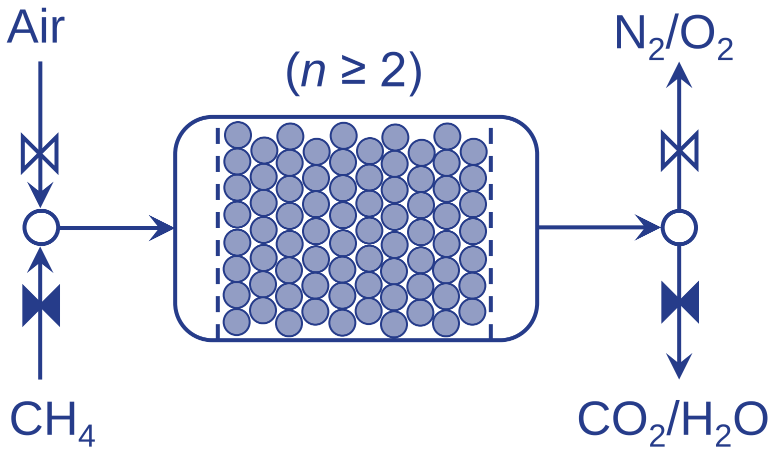
- Disadvantages:
  - ➢ Equipment erosion
  - ➢ Difficult to transport oxygen carriers
  - ➢ Difficult gas-solid separation (formation of fines → gas turbine)



Packed Bed Chemical Looping Combustion

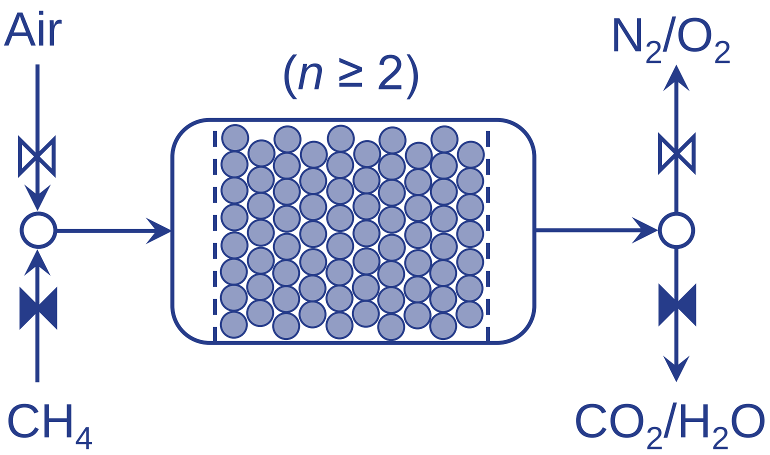
- An alternative reactor concept in which the recirculation of the particles is avoided

- Packed bed CLC:
  - Stationary solids
  - Periodic switching of gas flows
  - Dynamically operated parallel reactors for continuous operation
  - Proof of concept in laboratory scale by the research group at Technical University of Eindhoven, Netherlands



Advantages of packed bed system

- System is more compact and much easier to scale up on a technological basis
- Separation of gas from particles is intrinsically avoided to greatly simplify the system
- Better utilization of oxygen carrier



FP7 ENERGY - Efficiency Improvement of Oxygen-based combustion

Objective

- A sustainable solid hydrocarbon value chain with a focus on efficient and clean coal utilization

Expected impact

- Further development of oxygen-based combustion technologies with a view on the CO_2 capture process
- Demonstration in medium scale demonstration plant
- Focus of the activities: scalability of the results to industrial scale

Motivation for DemoCLOCK

- Fossil fuelled power plants are major emitters of greenhouse gases (GHG)
- Coal accounts for 40% of the electricity generated worldwide, while contributing to nearly 29% of all carbon emissions
- Carbon Capture and Storage (CS) is a way to reduce the CO_2 emissions from fossil based power plants
- The current techniques (i.e. post and pre combustion capture) are hampered with high cost for CO_2 capture
- There is a strong need to develop and demonstrate processes which are cost effective in transforming hydrocarbons into energy integrated with CO_2 capture

DemoCLOCK project

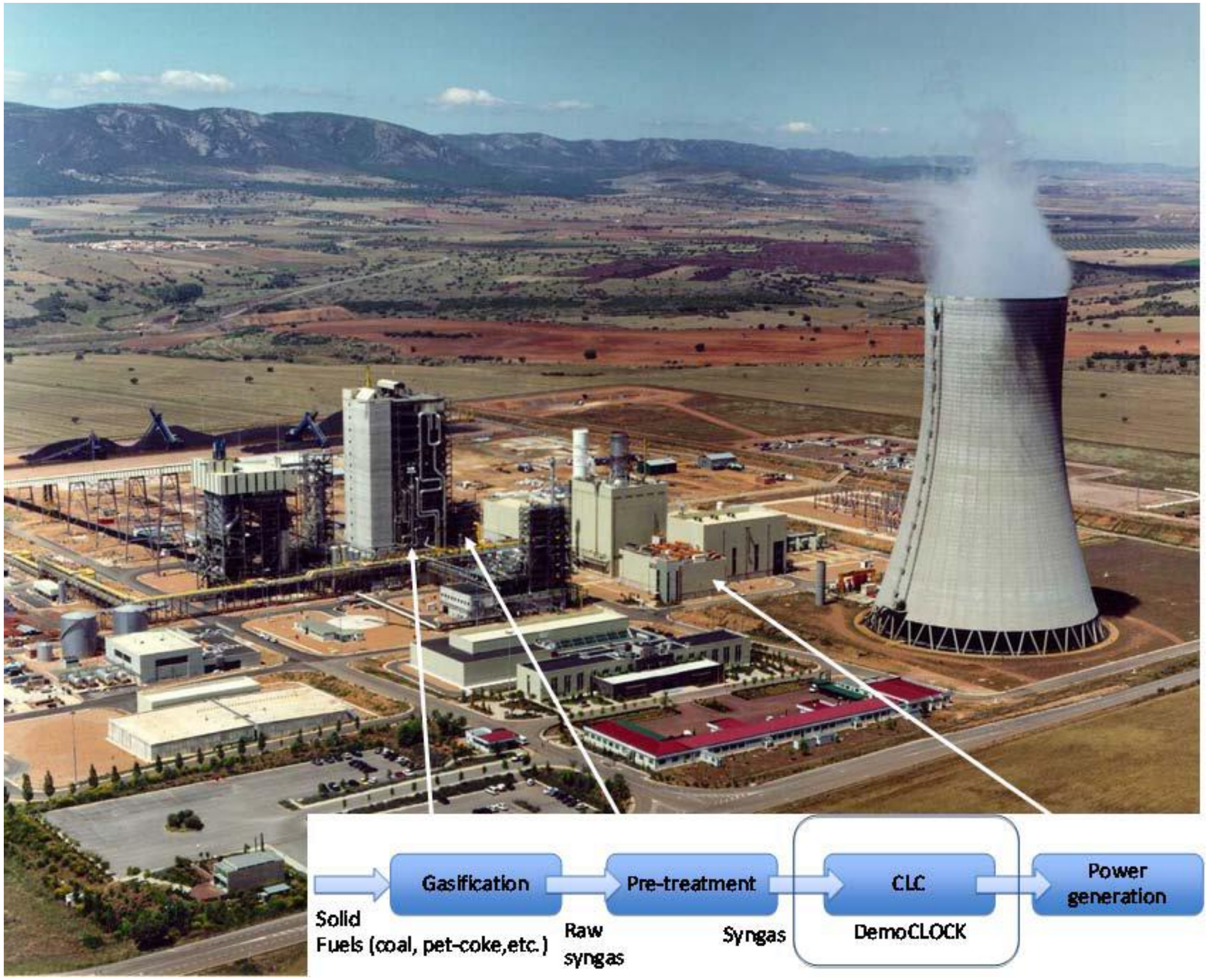
- **Duration**: 1 June 2011 - 1 June 2015
- **Funding**: FP7 ENERGY.2010.6.1-1 Efficiency Improvement of Oxygen-based Combustion
  Total budget: € 8,193,476
- 10 partners across Europe

Technical objectives of DemoCLOCK

The main objective: to demonstrate the technical, economic and environmental feasibility for implementing packed bed CLC in large-scale power plants.

- Demonstrate a medium sized packed bed CLC reactor (500 kW) for 3000 hours at IGCC facility at Elcogas (Puertollano, Spain)
- Convert gasified solid hydrocarbons (raw syngas) to energy at high temperature and pressure
- Technological implementation and integration of the process
- Reactor design for medium and large scale
- Selection of suitable minerals as oxygen carrier materials
- Environmental impact assessment and waste management
- Commercialization of the technology

Demonstration site: Elcogas Puertollano, Spain



DemoCLOCK - consortium

Technical work packages	Lead	Partners
WP1: Performance tests and manufacturing of oxygen carrier materials	vito vision on technology	SINTEF; TU/e Technische Universiteit Eindhoven University of Technology; CTI; ECN Energy research Centre of the Netherlands
WP2: Reactor Design & optimisation	SINTEF	TU/e Technische Universiteit Eindhoven University of Technology
WP3: Basic engineering & pre-commissioning	Array industries	ECN Energy research Centre of the Netherlands; ELCOGAS
WP4: Commissioning & Demonstration	ECN Energy research Centre of the Netherlands	Array industries; ELCOGAS
WP5: Technology implementation plan for a large-scale CLC power plant	Politecnico Milano	Foster Wheeler Engineering for a Better World; ECN Energy research Centre of the Netherlands; ELCOGAS
WP6: Environmental impact assessment and waste management	Instytut Ekologii Terenów Uprzemysłowionych Katowice	Politecnico Milano; vito vision on technology; SINTEF; Foster Wheeler Engineering for a Better World; ELCOGAS
WP7: Commercialization	Foster Wheeler Engineering for a Better World	Array industries; Politecnico Milano; SINTEF; Instytut Ekologii Terenów Uprzemysłowionych Katowice

WP1 - Performance tests & manufacturing of oxygen carrier materials

- **Goal**: selection and development of suitable oxygen carrier for operation in medium sized fixed bed CLC reactor (500kW)

- **Criteria**: O_2 transfer capacity, reactivity and kinetics, shape, pressure drop and packing density, mechanical strength, lifetime >20,000h, and sulphur poisoning resistance

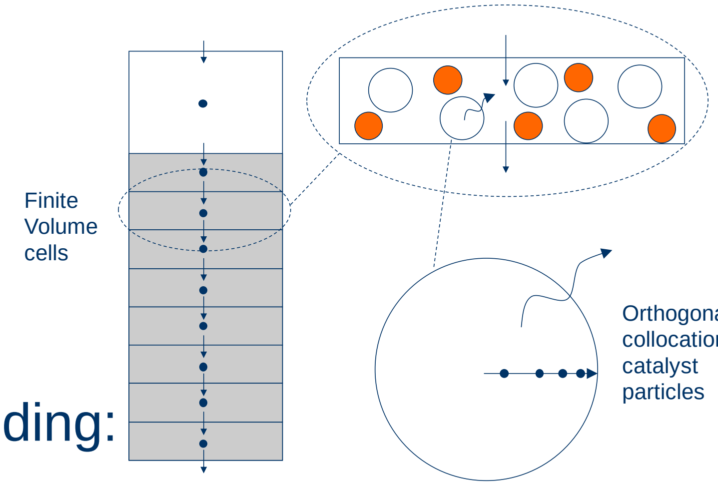
- **Deliverables and milestones**: selection of materials (SINTEF, TU/e), production of oxygen carriers (CTI), testing and evaluation in TGA and labscale reactors (Sintef, TU/e), sulphur tolerance (ECN), physico-chemical characterization including mechanical performance (VITO)

- The development of new oxygen carrier materials for fixed bed CLC operation is coming to an end in the project, and **has resulted in materials that can do the job**. The required amount of oxygen carrier material for the demo scale operation will be produced by CTI.

WP2 - Reactor design and optimization (SINTEF, TU/e)

- Objectives:
  - Establish design criteria for a fixed-bed CLC reactor
    - Reactor geometry and size
    - Catalyst size and shape
    - Establish operating conditions and cycle times
  - Establish necessary simulation models of the reactors
    - 1D reactor models for the actual design/operation simulations
    - Multiphase flow models for simulation of details → Input to 1D-model

WP2 - 1D reactor model



- Dynamic model of fixed-bed reactor based on Finite Volumes
- Simulates total operation sequence, including:
  - Oxidation
  - Reduction
  - Purging
- Predicts
  - Temperature in gas, temperature profile through catalyst particle
  - Gas composition (both in gas phase and inside catalyst)
  - Pressure drop

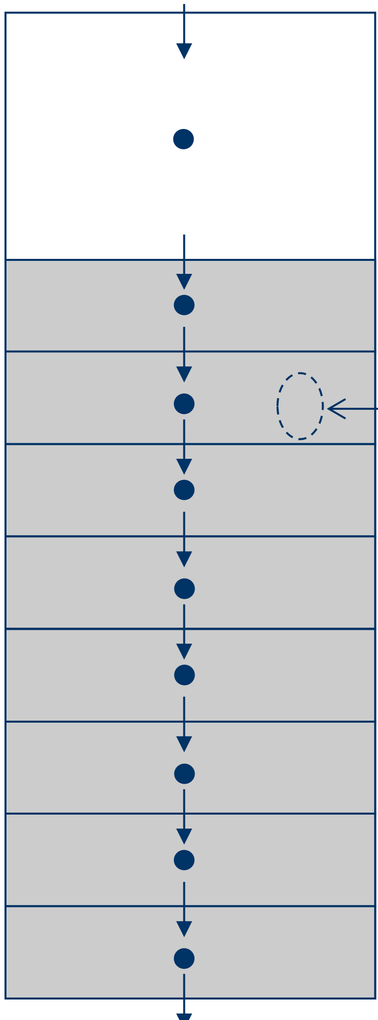
WP2 – Simulation-based engineering

1D

Computational Fluid Dynamics (CFD)

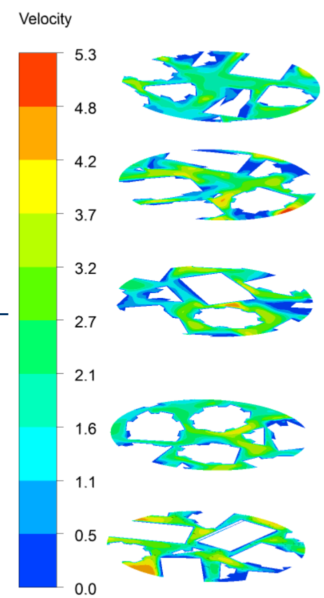
Discrete Element Method (DEM)

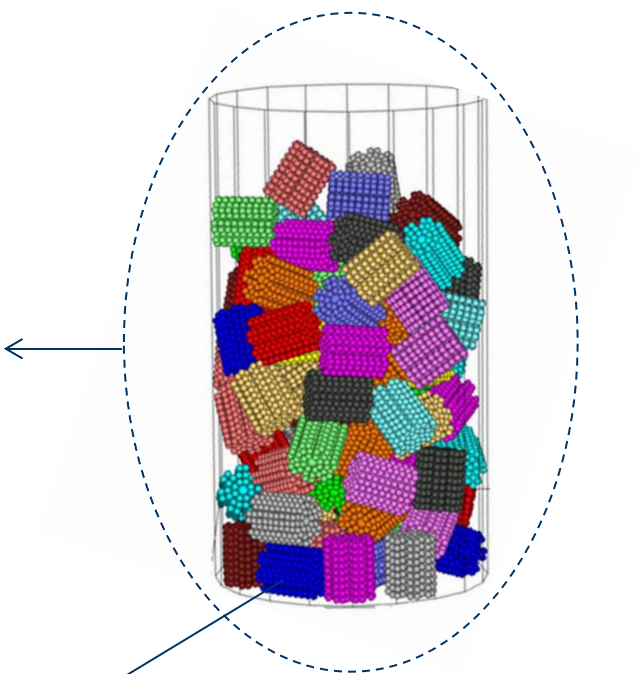
Finite Volume cells



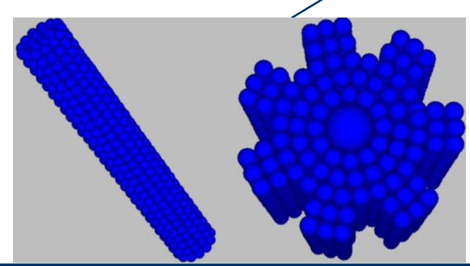
Δp, h, k,ϵ

Correlation for: pressure drop, mass- and heat transfer coefficients





A representable bed volume



WP3 Basic and Engineering design (Array, ECN)

Scope: Design, manufacture and commissioning of Demonstration plant

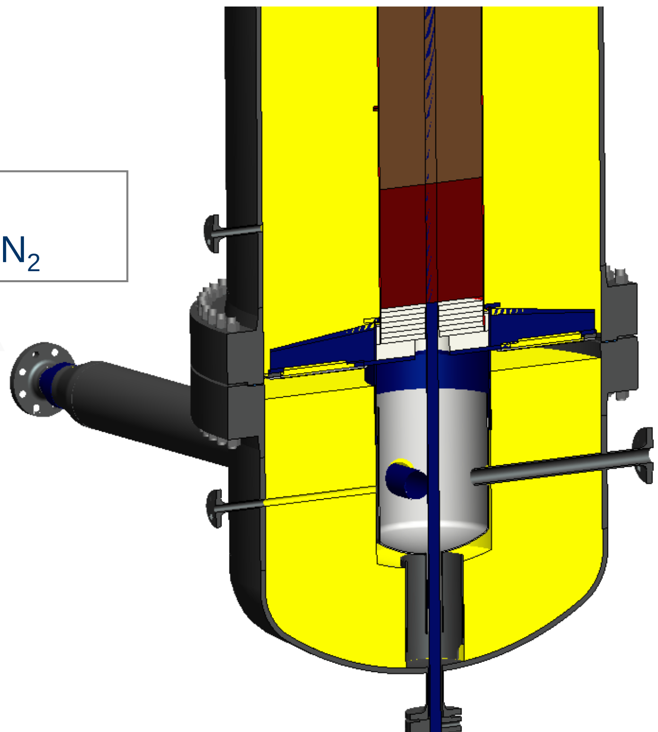
Design parameters

- pressure 26 bar (Elcogas syngas 19.8) – Reactor operating pressure 19 bar
- Reactor temperature: 1100° C

Demonstration Reactor (outside Diameter 1m, height 4m)

	Conditions
Internal Pressure	±19 barg
Catalyst	290 kg
Pressure difference	1.0 barg (OXY&HR)
Feed gas (preheated air)	450 °C, up to 500 °C during start of system
Reactor bed	1100 °C

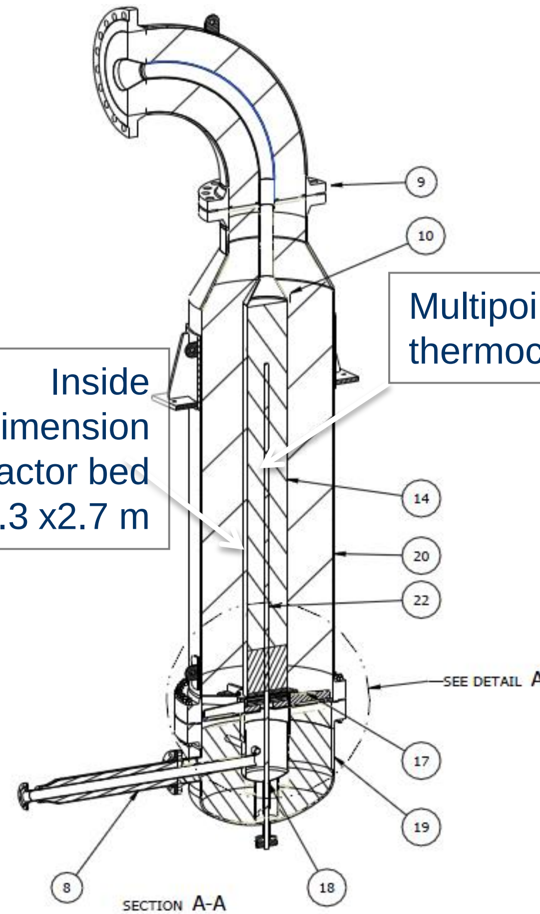
OXY: Air
PU1&HR: N_2



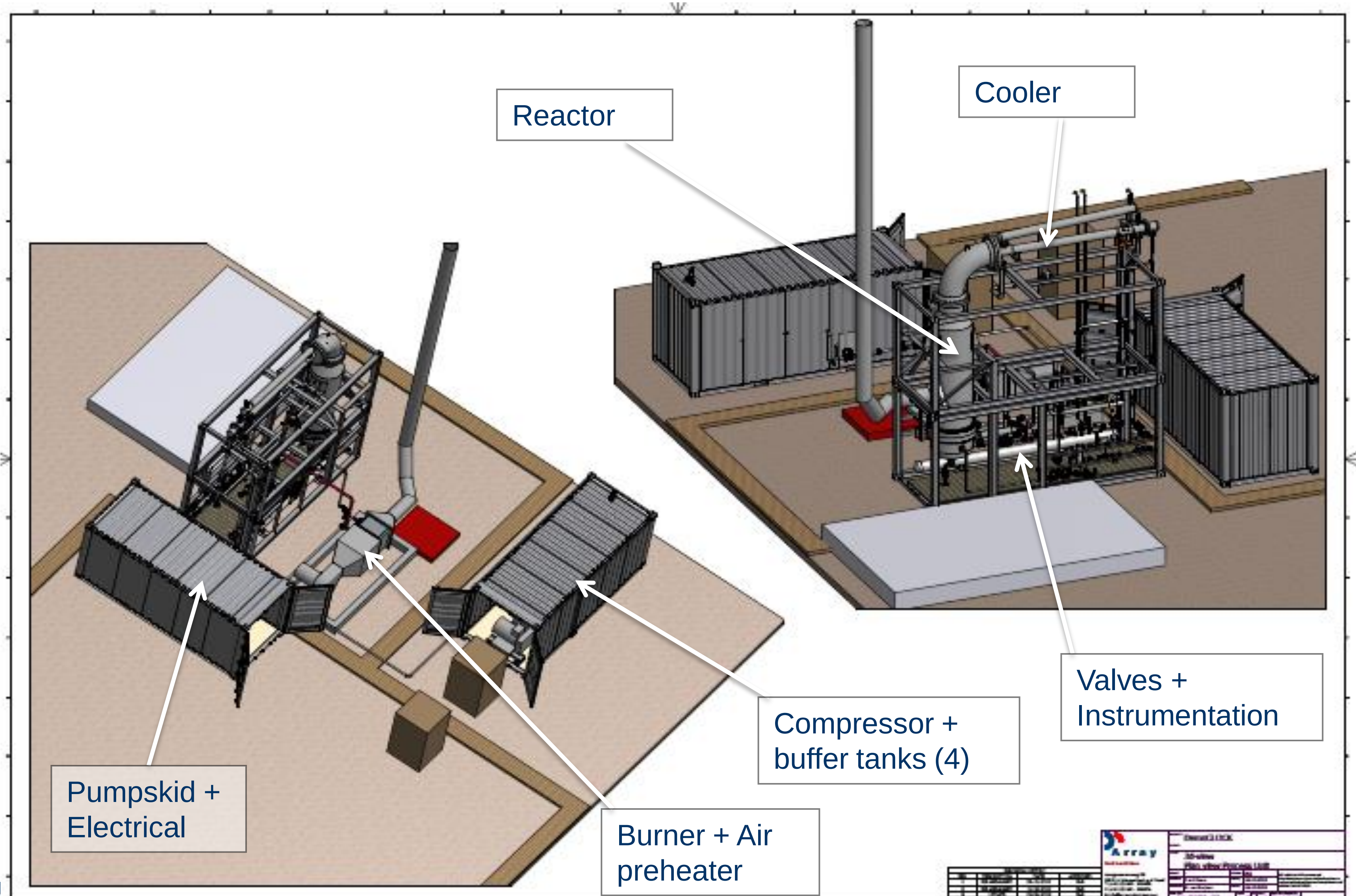
RED: Syngas+Steam
PU2: N_2

Inside dimension Reactor bed Ø0.3 x2.7 m

Multipoint (20) thermocouple



General layout of Democlock plant (L6, w 2.4, H 6m)



WP4 - Commissioning and Demonstration (ECN, Array, Elcogas)

Objectives

- Commissioning tests: testing outputs and reactor conditions during operation of the 0,5 MW demonstrator (***Site Acceptance Test***)
- Operating tests: optimization of operating conditions of the CLC reactor (***Determination of Operational Window***)
- Long term tests: Operation of CLC packed bed system to prove feasibility with 3,000 operating hours (≈3 months) (***Data Acquisition***)
  - Validation and improvement of system models: data input to WP2 (reactor design and scale up)
  - Provide input parameters for scale up of the process to industrial scale: data input to WP5

WP4 - Commissioning and Demonstration

- Activities:
  - Transport of containerized Democlock reactor from Array (NL) to Elcogas (ES)
  - Assemble at Elcogas and connect to Elcogas infrastructure
  - Tests (pressure, temperature, connections (gas/electricity) etc) to see wether everything is safety proof
  - Fill reactor with oxygen carrier (pre- or in-situ activated)
  - Test for operating window, cycle time, etc.
  - Determine optimal conditions and do a continuous test for 3 months.
  - Logged data will be used to refine models develloped in WP2 that will be used to design a full scale (GW) system in WP5

WP5 - Technology implementation plan for a large scale CLC-based power plant (Polimi, FWI, ECN)

Objective: Assessment of the potential of packed bed reactor (PBR) CLC configurations in the frame of coal fired, zero CO_2 emission power plants.

Achievements:

- Integrated Gasification Combined Cycle considered to exploit a PBR-CLC system for power generation
- Operating cycle of the PBR-CLC reactors
  - high temperature heat to a gas turbine based combined cycle
  - fully convert syngas to a pure CO_2 stream for storage
- Complete power plant mass/energy balance:
  - efficiency improvement of 4 to 5 % points can be achieved over comparable IGCCs with pre-combustion CO_2 capture based on commercial solvent absorption
- A tentative design of the large scale PBR-CLC:
  - string of 14 reactors, 5.5 m in diameters and 11 m long, is required to serve in a 350 electric MW power plant

WP6 - Environmental Impact Assessment and Waste Management (IEIA, VITO, Elcogas, FWI, Polimi, SINTEF)

Goal

- Assessment of safety and environmental impacts of packed bed CLC technology with special emphasis on wastes management

Objectives

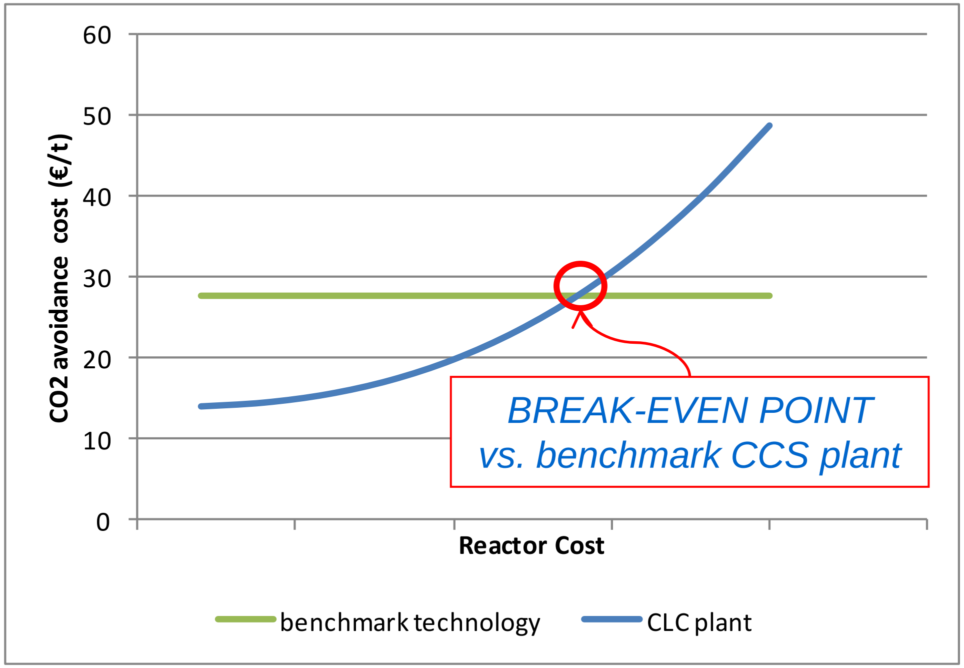
- Assessment of the health, safety and environmental issues inherent in medium size demonstration scale CLC technology
- Assessment of the health, safety risks and environmental impacts of commercial scale CLC technology

WP7 – Commercialization (FWI, Polimi (PDM), all other partners)

Task		Partners involved
7.1	Industrial feedback workshops	*IEIA, all*
7.2	Cost of electricity (COE) evaluation and comparison with alternative technologies	*FWI, PDM, all*
7.3.	Business plan	*Array, SINTEF, all*
7.4	Risk and mitigation	*FWI, PDM, all*
7.5	Overall feasibility study and evaluation of a full-scale packed bed CLC power plant with a view to the potential commercialization	*FWI, PDM, all*

WP7 - Financial modeling and sensitivity analysis

Example of the results



Thank you

http://www.sintef.no/Projectweb/DemoClock/