ZEP NWT
FUTURE CCS TECHNOLOGIES

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NWT FUTURE CCS TECHNOLOGY REPORT MOTIVATION & OBJECTIVES

- Update of previous ZEP publication on ”Recommendations for research to support the deployment of CCS in Europe beyond 2020”, started in 2010
- There are currently 15 large-scale CCS projects in operation worldwide, capturing about 28 Mtpa across a range of sectors with more to come in the next 2-3 years
- Use the commercial & performance data of these large-scale plants (1st generation CCS technology) as benchmark for the assessment of the potential of emerging CCS technologies
- Provide an overview of evolving 2nd and 3rd generation CCS technologies and their technical maturity (TRL based)
- Assess 2nd and 3rd CO_2 capture, transport & storage technologies under the premise of cost reduction (CAPEX/OPEX), performance improvement and best suitability/most promising for various applications in power and industry, such as cement, iron & steel, refineries etc.
- Use existing references on future CCS technologies (journals, database and IJGGC, IEA GHG, Global CCS Institute and ZEP reports)

CO_2 capture technology - Technology Readiness Level (TRL)

Full Commercial Application	9	Actual system proven in operational environment (competitive manufacturing of full system, at scales of several 100s of MW_{th} or around 1MtCO_2/a stored)
Demonstration	8	System complete and demonstrated at industrial scales of 10s of MW_{th} or 0.1 to 1 MtCO_2/a stored
Pilot	7	System prototype demonstrated in operational environment (industrial pilots operating at 10s of MW_{th} and/or separating 10s of kt CO_2/a)
	6	Technology demonstrated in relevant environment (steady states at industrially relevant environments: pilots in the MW_{th} range and/or separating 1 to 10 kt CO_2/a)
Small Pilot	5	Technology validated in relevant environment (pilots operated at industrially relevant conditions at 0.05–1 MW_{th}) and/or less than 1 kt/a captured/stored
Lab/Bench	4	Technology validated in the lab (continuous operated pilots at lab scale <50 kW_{th})
	3	Experimental proof of concept (pilot testing of key components at small bench scale)
Concept	2	Technology concept formulated (basic process design)
	1	Basic principles observed

CO_2 capture technology - Definitions

1st generation CCS technologies:

- CO_2 capture technologies that can be categorised as commercially available or near-commercial technology today. These technologies have been tested or operated as demo- or widely deployed in various commercial applications. In the near or medium term, it is expected that these technologies would likely involve further development to achieve incremental improvement.

2nd generation CCS technologies:

- Emerging CCS technologies which can be demonstrated at pre-commercial scale and may become commercially available in the coming decade (i.e. between 2020 and 2030). 2nd generation CCS technologies are likely to be based on the scale-up of technologies which are assessed today with a TRL in the range of 3-6, likely achieving the TRL of 6 or 7 in the next five year (i.e. by 2020), including refinements of the 1st generation CCS technologies.

3rd generation CCS technologies:

- Emerging CCS technologies which may become commercially available during the next two decades (i.e. beyond 2030). 3rd generation CCS technologies are likely to be based on the progress of technologies which are today assessed with a low TRL in the range of 1-3, including likely refinements of the 2nd generation technologies.

CO_2 capture technology – TRL

Separation Process	TRL 2005	TRL 2015	Reference
Precipitating solvents	3	5	[25, 26]
Biphasic solvents	3	4-5	[27, 28]
Catalysed enhanced solvents	4	5	[29, 30]
Vacuum Pressure Swing Adsorption (post combustion)	2	5	[31, 32, 33]
Temperature Swing Adsorption (post combustion)	2	3-4	[34]
CO_2 liquefaction/partial condensation	2-3	6	
Chemical looping combustion of solid fuels	3	6	[35]
Calcium looping, post combustion	2	6	[36]
Metallic membranes for H_2	3	4-5	[37, 38]
Polymeric membranes for CO_2	3	5-6	[39]
Ceramic membranes for O_2	4	4	[40, 41]

CO_2 capture technology – Assessment

- Cost reduction potential (Capex & Opex),
- Energy efficiency or efficiency penalty reduction,
- Operational flexibility,
- Health, Safety & Environment (HSE),
- Retrofitability,
- Materials Availability.

CO_2 capture technology – Assessment

Process	**Solvent based processes**	**Solid sorbent processes**	**High temperature solid looping systems**		**Membrane systems**		
Separation Technology / Assessment criteria			Chemical looping	Calcium looping	Polymeric (post)	Ceramic (Oxy)	Metallic (pre)
Cost CAPEX					2)		
Cost OPEX							
Efficiency penalty (thermodynamics, T- and P-level)							
Degradation solvent, sorbent, membrane							
Operational flexibility (on/off)					2)	2)	2)
HSE (waste, toxicity)	1)	1)					
Retrofitability[3)]					2)		
Materials availability (abundance, manufacturing chain)							
FOAK cost							
Applicability, most suitable to	Power, NG processing, Steel, Refineries, other	Power (pre combustion), Steel, Refineries	Power (solid fuels), Refineries	Power (post combustion, solid fuels), Cement	Power, NG processing, Cement, Steel	Power (oxy and pre combustion)	Power (pre combustion), Refineries

1) All solvents or solids containing amino-groups might show due to operation conditions disamination reactions which can lead to nitrosamine formation or degradation.
2)Depends very much on process integration of the membrane system. For example the retrofitability of polymeric membranes in a post-combustion configuration in general is possible, however, the feasibility in a detailed set-up which might require several membrane stages, compressors or vacuum pumps has to be individually assessed.
3)The retrofitability criterion is a yes or no criterion, therefore only green or red

CO_2 capture technology – Assessment

- Nearly all emerging capture technologies claim a reduction potential with respect to CAPEX required by 1st generation capture technologies. Although there are inevitable underlying uncertainties, **chemical looping shows currently the highest CAPEX reduction perspective**.
- Technologies involving **solid sorbents, looping processes and polymeric and metallic membranes** show a legitimate potential to improve operational cost (OPEX) compared to 1st generation solvents.
- With respect to process efficiency, most of the technologies assessed show an improvement potential. **Chemical looping appears most promising and polymeric membranes show potential** as they are already commercially applied to other boundary conditions, i.e. in natural gas processing.
- **Polymeric membranes might be a good alternative for natural gas or other clean flue gas post-combustion applications**, compromising on other process parameters, such as CO_2 capture rate or in combination with other technologies (hybrid systems).
- **Degradation of functional material appears to be a problem** of almost all emerging technologies over time with calcium looping being the only exception.
- **Promising emerging capture technology with respect to operational flexibility are polymeric membranes and likely solid sorbent processes (VPSA, PSA)**, conditional to the integration of these technologies in the overall process configuration.
- **With respect to HSE and waste disposal, solid sorbents, calcium looping and membranes bear an advantage** against current aqueous amine solvents. This is due to the volatility of amines requiring additional efforts/technical equipment to avoid amine emissions.
- With regards to retrofitability, chemical looping is not retrofitable as it is a new concept substituting a boiler or gas turbine in contrast to calcium looping which is applied as post-combustion capture technology. The same applies any oxy-combustion related process e.g. oxy-ceramic membranes which require the recirculation of flue gas, difficult or too complex to be integrated to existing configurations without high investment.
- Finally when it comes to availability, **chemical looping as well as oxy-ceramic and metallic membranes might be the technologies that face the most critical challenges today**.

TRANSPORT

- Pipeline transport: established technology, commercially available
  - Minor issues around relation between CO_2 composition and flow in pipelines and into wells
    - Knowledge base being developed to accurately describe physical properties of CO_2 mixtures
  - Large-scale networks: CO_2 quality management, network management to be developed
    - Expect this to be developed as networks evolve

- Ship transport: established technology, but developments required
  - Port-to-port: scaling up of existing ships and loading / unloading facilities
  - Port-to-offshore:
    - Develop ship and offloading facilities design
    - R&D into effects of batch-wise injection
    - Offloading technology requires development (flexible hose)

STORAGE

Storage is established technology, but developments remain necessary

- R&D into flexibiltiy of transport and storage networks
- Expand operational envelope of injection wells and subsea equipment
  - R&D on effects of repetitive cycles of pressure and temperature
  - Include both saline formations and depleted fields
- Develop effective storage portfolio management
- Develop pressure management techniques to maximise use of pore space
  - E.g., water / brine production
- Continue development of low(er)-cost monitoring and remediation techniques
- Develop dedicated (i.e., low-cost) well abandonment methods

FUTURE CCS TECHNOLOGIES
MEMBERS

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- Sylvain Thibeau, Dominique Copin (Total)
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- Chris Gittins (TAQA)
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Reviews from

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- SCCS / Edinburgh University
- Politechnico di Milano
- ETH Zurich
- Imperial College
- Eindhoven University of Technology