IMPACTS: IMPURITIES IN THE CCS CHAIN

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REPRESENTING THE IMPACTS TEAM

TNO innovation for life

IMPACTS
The impact of the quality of CO_2 on transport and storage behaviour

IMPACTS OF IMPURITIES IN CO_2

(INCOMPLETE LIST OF CONCERNS)

- Capture
  - Cost of capture plus treatment of CO_2 vs quality of CO_2
- Transport
  - Corrosion: H_2O removal vs liners, alloys
  - Integrity: H_2 removal vs stronger pipes
  - Transport system: purification CO_2 vs higher-pressure system
  - External safety: H_2S content vs larger safety distances
- Storage
  - Injection system: higher compression requirement vs purification
  - Loss of storage capacity: purification vs ETS 'budget'

IMPACTS: study trade-off between CO_2 quality and system design, system performance

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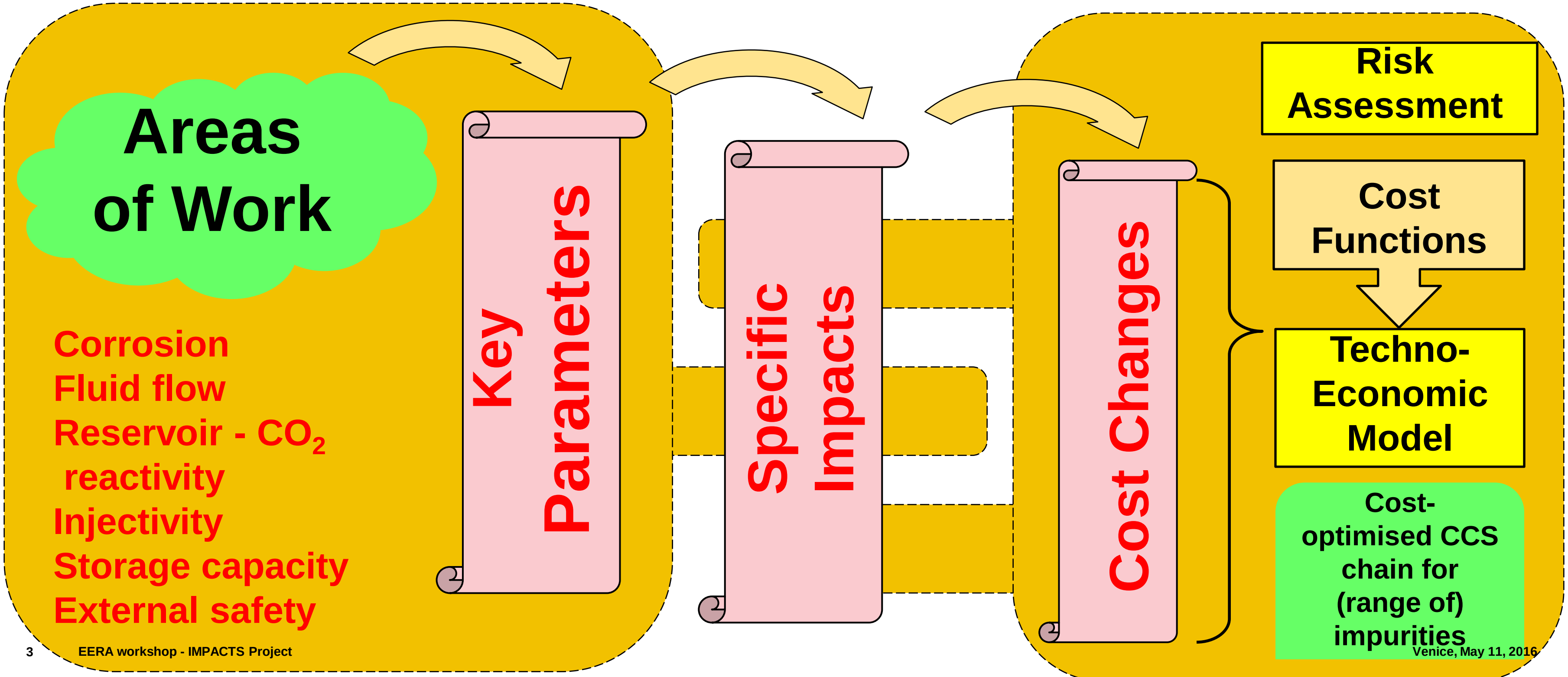
PROJECT DATA FLOWS

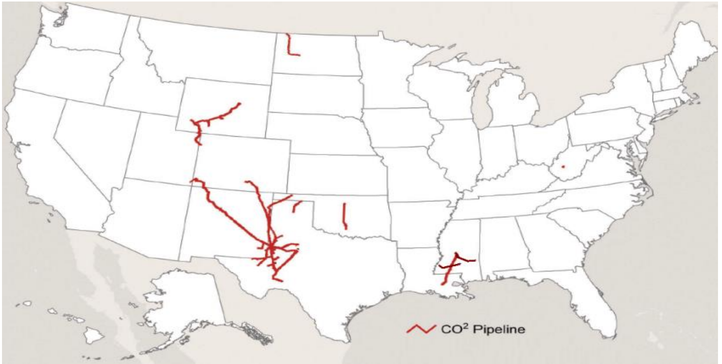


ARE THERE CO_2 QUALITY GUIDELINES CURRENTLY AVAILABLE?

- Industrial practice and recommended practice for CO_2 infrastructure exist.
- Often based on estimates and assumptions about the system.

- Fit-for-purpose: Direct use of CO_2 transportation experience is not always possible due to the difference in CO_2 mixtures.

- A specific know-how has to be developed to cover the lack of knowledge in the specific European applications.



DEFINING THE CO_2 QUALITY – KEY CRITERIA

Historically dependent on the source, transportation and usage

- CO_2 pipelines have been based upon standards for Natural Gas (NG) and were constructed with standard carbon steel (CS), hence ….
- …. critical to keep the CO_2 dry to avoid formation of carbonic acid

(Image courtesy of Kinder Morgan, 2006)

- Image shows internal view of a carbon steel pipe that has been transporting CO_2 for more than 20 years. When maintained dry there is no indication of any corrosion.

So many questions…

- In which part of the chain should impurities be removed? Should they?
- Is it cheaper to purify the stream before transport?
- Will CO_2 quality affect EOR?
- Is "overwhelmingly" CO_2 strong enough criteria to ensure safe transport and storage?
- How do CO_2 impurities affect storage pH?
- Is using stainless steel instead of carbon steel cheaper than adding purification processes?
- How accurate do the models need to be?
- Will pipelines corrodes if impurities are present?
- How does CO_2 stream quality affect compression?
- What conditions are needed to avoid hydrates in the chain?
- How will CO_2 quality affect the equipment/ operations along the chain?
- Will impurities affect depressurisation of pipelines?
- Will pipeline thickness need to be adjusted to handle impurities?

WORST COMBINATIONS

- Six combinations that produce the highest levels of impurities
  - [CO_2] above 95%
- Water content not included
  - Defined by customer, not by capture process
- Desulphurisation included

CO_2 source / Capture technology	Coal-fired power plant / Amine-based absorption	Coal-fired power plant / Ammonia-based absorption	Coal-fired power plant / Selexol-based absorption	Coal-fired power plant / Oxyfuel combustion	Natural gas processing / Amine-based absorption	Synthesis gas processing / Rectisol-based absorption
CO_2	99.8%	99.8%	98.2%	95.3%	95.0%	96.7%
N_2	2000	2000	6000	2.5%	5000	30
O_2	200	200	1	1.6%		5
Ar	100	100	500	6000		
NO_x	50	50		100		
SO_x	10	10		100		
CO	10	10	400	50		1000
H_2S			100		200	9000
H_2			1.0%			500
CH_4			1000		4.0%	7000
C_2+					5000	1.5%
NH_3	1	100				
Amine	1					
	Post	Post	Pre	Oxy	Amine	Amine

CO_2 MIXTURE PROPERTIES TREND 2.0

- TREND 2.0
  - Model for thermodynamic properties of CO_2 rich mixtures
  - Excel tool provided as interface
- Work done by Ruhr University (Bochum, GE), SINTEF (NO), Tsinghua University (China)

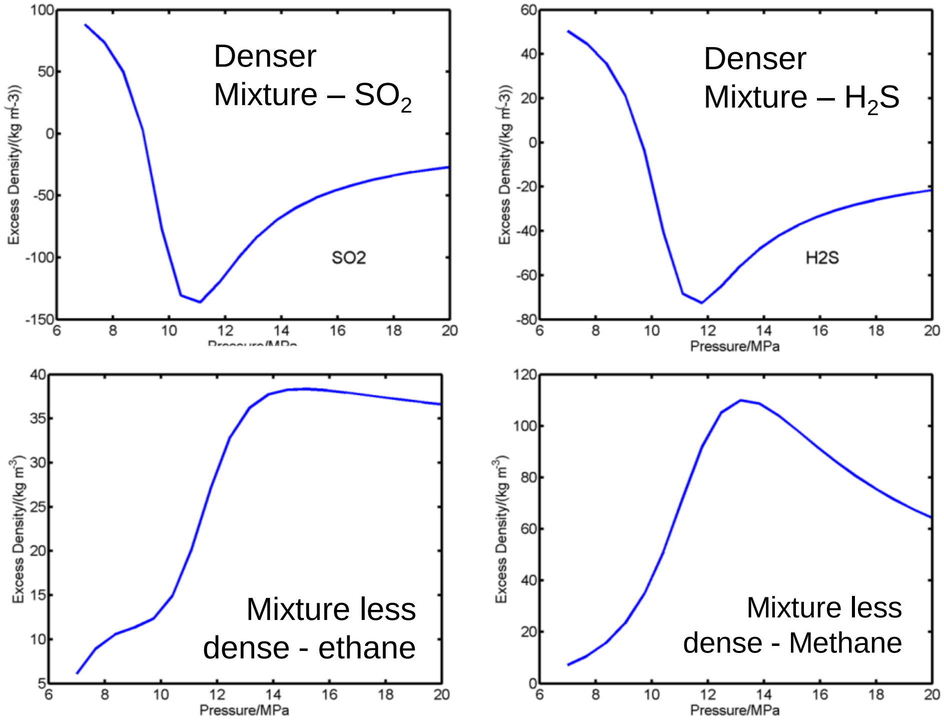
		chlorine	hydrogen chloride	diethanolamine	monoethanolamine	sulphur dioxide	hydrogen sulfide	methane	hydrogen	carbon monoxide	argon	oxygen	nitrogen	water
major components	carbon dioxide	LB	LB	lin	lin	red								
	water	LB	lin	red	red	red								
	nitrogen	lin	LB	lin	lin	red								
	oxygen	lin	lin	LB	LB	red								
	argon	lin	lin	lin	lin	lin								
	carbon monoxide	lin	LB	lin	lin	lin								
	hydrogen	lin	lin	lin	red	lin								
	methane	lin	LB	lin	lin	red								
minor components	hydrogen sulfide	LB	LB	lin	lin	LB								
	sulphur dioxide	red	LB	red	LB									
	monoethanolamine	lin	lin	red										
	diethanolamine	lin	lin											
	hydrogen chloride	red												
	chlorine													

- EOS-CG model of *Gernert and Span (2015)*
- GERG-2008 model of *Kunz and Wagner (2012)*
- red New model, reducing parameters fitted
- lin New model, linear combination rule
- LB New model, Lorentz-Berthelot combination rule

CO_2 MIXTURE PROPERTIES

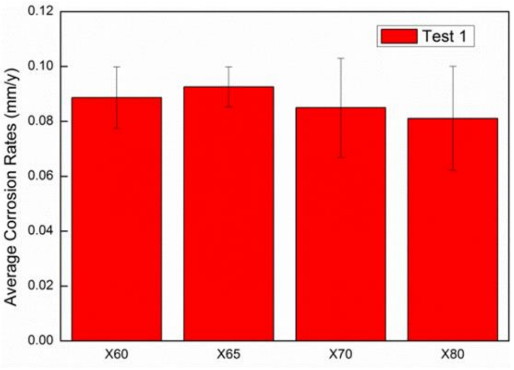
- Insights into effects of various impurities on mixture properties. Example: density

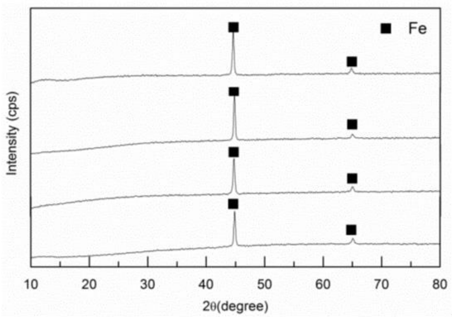
  - Effect on density
    - 'Excess density' curves show change in density of mixture when 10% impurity is added
    - Positive values (for ethane, methane) indicate decreasing density of mixture
    - Negative value (SO_2, H_2S) indicate that adding these to the CO_2 *increases* the density
      - Smaller compressors…
      - Larger storage capacity…

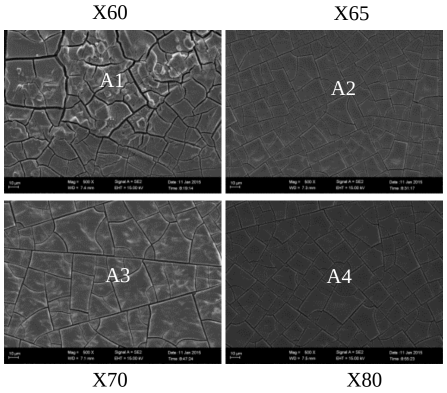


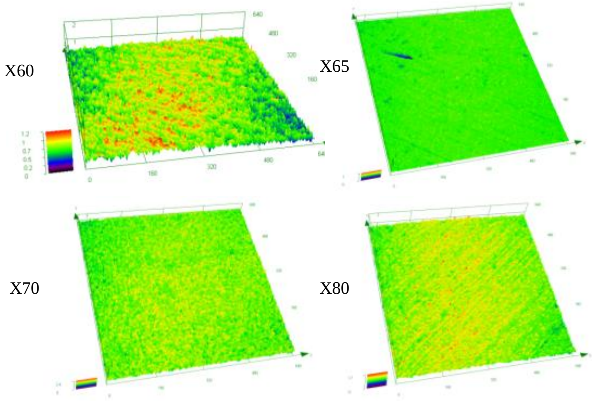
CORROSION EXAMPLES

- Examples of results from corrosion experiments
  - Examples show corrosion rates for several steel grades
  - (Much) more detail in reports









STORAGE CAPACITY

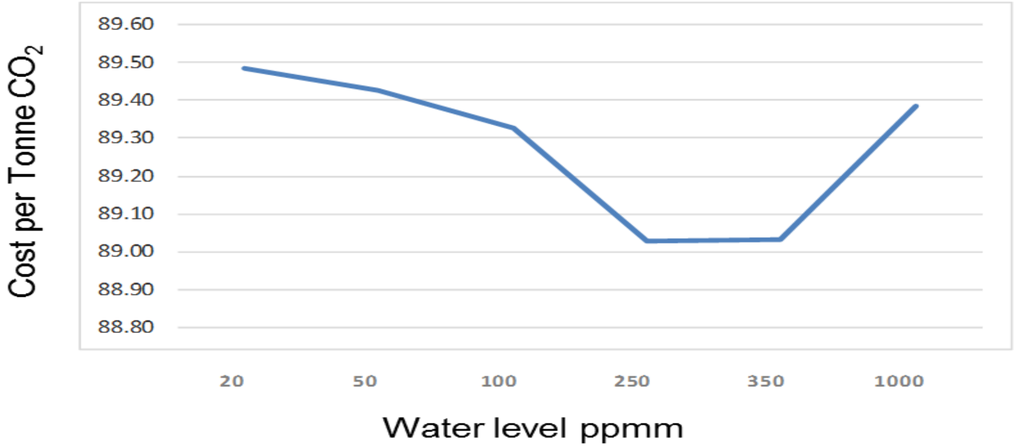
- Example shows effect mixture properties on storage capacity
  - Several real (!) mixtures
  - Effects can be significant

	Coal-fired power station Amine based adsorption	Coal-fired power station Post combustion ammonia	Coal-fired power station Selexol based adsorption	Coal-fired powerstation Oxyfuel combustion	Natural gas processing Amine based adsorption	Synthetic gas processing Rectisol based adsorption	Cement Industry	'Ketzin' injection
Storage type	Oil field	Aquifer	Oil field	Aquifer	Oil field	Oil field	Oil field	Aquifer
wt % impurities	0.24	0.05	0.21	1.28	0.93	0.41	4.99	7.37
Depth								
800 m	-2.8	-0.5	-5.3	-16.0	-15.1	-9.7	-53.0	6.6
900 m	-2.0	-0.3	-4.1	-11.4	-11.0	-7.4	-41.3	5.0
2000 m	-0.7	-0.2	-1.7	-4.4	-4.2	-3.1	-12.2	-1.5
3400 m	-0.7	-0.2	-1.2	-3.2	-3.1	-2.2	-7.5	-3.3

IMPACTS RESULTS – WATER CONTENT

Techno-economic model:

Insight into possible impurity level trade-offs when capture cost curves included



Example:

Classic "bathtub" curve for moisture level with a short onshore pipeline (Benchmark Case B)

- Increasing water level requires cost of higher grade steel for pipeline
- Reducing water level requires costly additional processing
- Hence sweet spot at 250 – 350 ppmm

CHAIN-WIDE RESULTS

- Summary of impact of impurities
- If water content is sufficiently low, most entries in table will become ‘small’

Table 4: Summary of possible main impurities and their expected impacts

Potential impurity	Possible impacts		
	Health and Safety	Physical Properties	Chemical properties
Amines*	Small	Small	Small
Ammonia	Medium	Small	Small
Ammonium salts	Small	Small	Medium with low water
Antimony	Small	Small	Small
Chlorine and chlorides	Medium	Small	Medium with low water
Carbon monoxide	Medium	Small	Small
Carbonyl sulphide	Medium	Small	Medium with low water
C2+ compounds	Small	Small	Small
Heavy Metals	Small	Small	Small
Hydrogen	Small	Medium	Small (if low O_2)
Hydrogen cyanide	Medium	Small	Small
Hydrogen fluoride	Small	Small	Medium with low water
Hydrogen sulphide	Medium	Small	Medium with low water
Methane	Small	Small	Medium with low water
Methanol*	Small	Small	Small
Nitrogen	Small	Significant	Small
NOx and SOx	Medium	Small with low water	Small
Oxygen	Small	Significant	Medium if low H_2 & H_2O
Particulate	Small	Significant	Small
Polyethylene Glycols*	Small	Small	Small
Sulphur trioxide	Small	Small	Medium with low water
Water	Small	Significant	Significant

*Present as carry-over from ‘wet’ CO_2 removal processes

IMPACTS Recommendations on the need for upstream conditioning

It is generally more economic to clean up the CO_2 stream at capture (upstream) than to deal with significant downstream effects.

Justification:

- Higher quality stainless steel pipelines are expensive
- High costs of replacing storage capacity at a higher than expected rate due to reduced density of the CO_2 stream
- Corrosion by-products need to be handled

IMPACTS Recommendations on the need for upstream conditioning

A general cost-optimal level of nitrogen is 0.5%, or lower if naturally so (advanced amine is below 1000 ppmm)

Justification:

- This avoids excessive downstream effects due to, e.g., density reductions. However, reducing the nitrogen levels below this at source is not economic.

IMPACTS Guidelines on reaction during the mixing different of CO_2 qualities in a multi-user transportation system

Reactions between impurities in (mixed) streams are unlikely to happen

Justification:

- IMPACTS cases have O_2 concentrations and levels of potential fuels such as H_2 that are too low for burning / oxygenation to take place.
- Other reaction possibilities are extremely endothermic and/or below the flammable limit

IMPACTS: WRAP-UP

- Available on IMPACTS website: *www.sintef.no/projectweb/impacts*

  - IMPACTS reports, recommendations
    - Detailed technical (public) reports, overview & summary reports

  - IMPACTS Toolbox (http://www.sintef.no/globalassets/sintef-energi/impacts/d3-2-2-impacts-toolbox-.ppsx)
    - Provides overview of IMPACTS results, tools, recommendations, …
    - Quick introduction into areas covered by IMPACTS project
    - Provides links to IMPACTS reports on each topic or highlight


CO_2 leaking from truck
Netherlands, 1960s

ACKNOWLEDGEMENTS

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Partners:

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THANK YOU FOR YOUR ATTENTION

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SEVENTH FRAMEWORK PROGRAMME

http://www.sintef.no/projectweb/impacts/

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