IFE

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Transport and injection of CO_2 with impurities- When is corrosion an issue

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Emission 2017: 35 Gt CO_2

IEA CCS Roadmap (2 °C)

↓

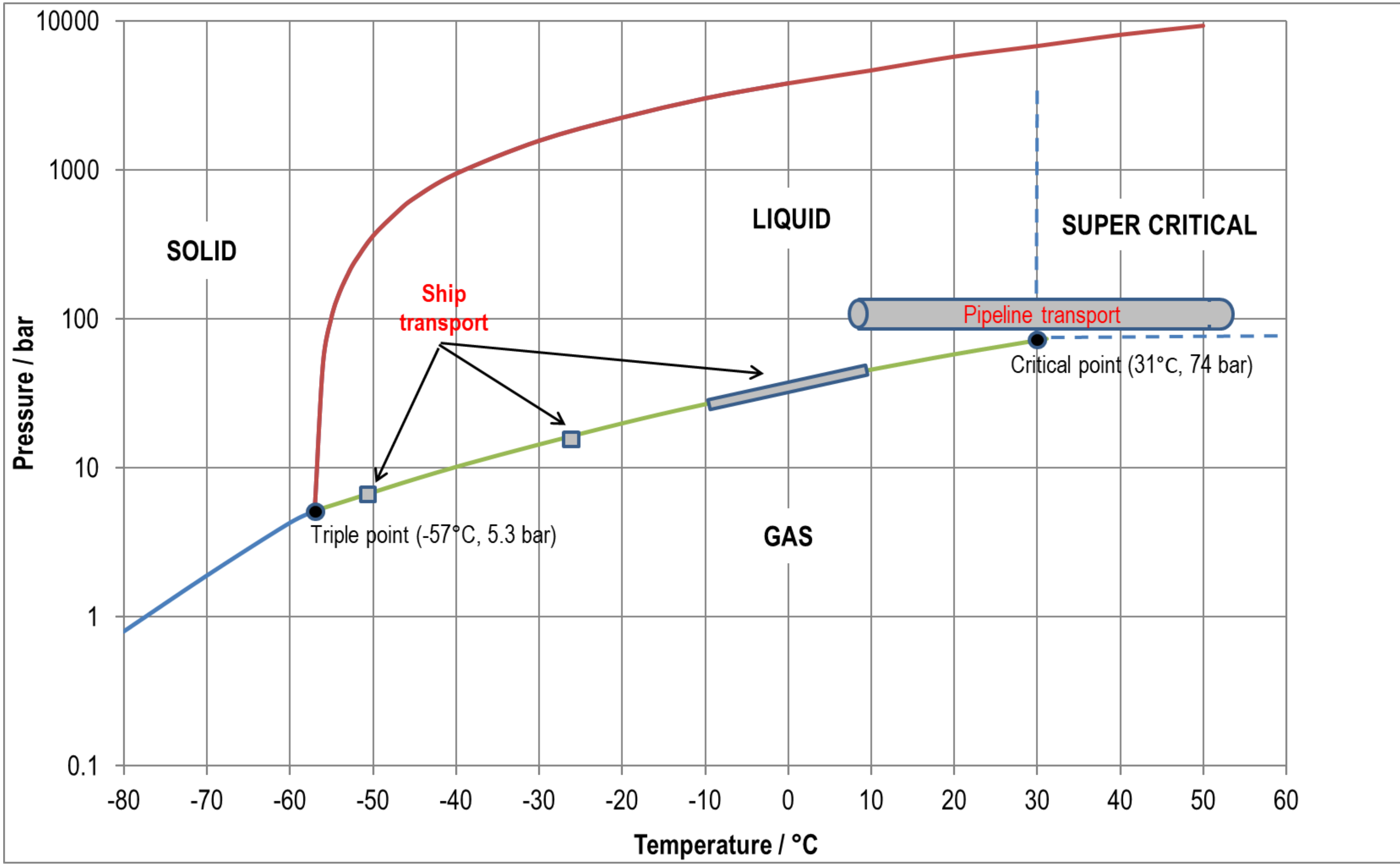
2050: transport and injection of 7-9 Gt CO_2

↓ (2-3x)

12” pipelines ~ 3 000
20” pipelines ~ 1 000
} **Flow velocity ~1.5 m/s**

Ship (loading)~ 800 000 } **10 kton**

Need to define the safe operation window before infrastructure and capture plants are designed and built!


10000
1000
100
10
1
0.1
Pressure / bar
-80
-70
-60
-50
-40
-30
-20
-10
0
10
20
30
40
50
60
Temperature / °C
SOLID
LIQUID
SUPER CRITICAL
GAS
Ship
transport
Pipeline transport
Critical point (31°C, 74 bar)
Triple point (-57°C, 5.3 bar)

CO_2 transport, State of the Art

- CO_2 injection for EOR > 35 years (USA)
- More than 100 installations, more than 5000 km pipeline
- **C-steel**: Good experience with clean and dry CO_2
- Reported corrosion when water accumulates
- CRA: ”Wet” CO_2, Sleipner, short distance
- Thousands of papers/corrosion studies for pCO_2 < 20 bar
  - Few studies for pCO_2 > 50 bar
  - Few studies presenting data with flue gas impurities

- Ship transport , food grade quality
  - Yara (200 kton/year)

CCS CO_2 transport challenges vs. previous CO_2 transport experiences

- New impurities (H_2O, H_2S, O_2, CO, SOx and NOx) might be present
  - How much is acceptable?
  - When will cross chemical reaction take place?
  - When will aqueous phases form
  - When will corrosion become a problem?

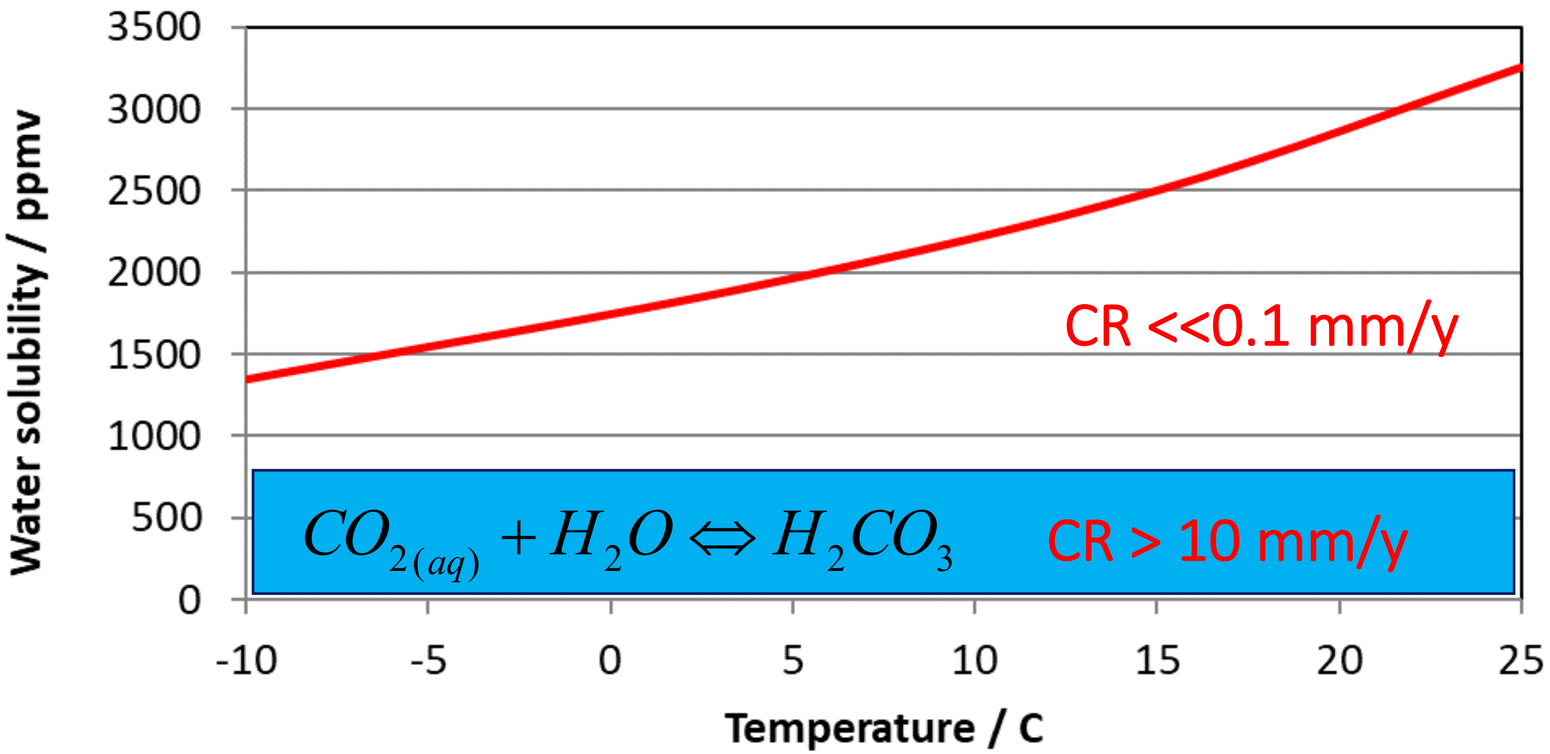
  } Safe operation window?
- Reuse of existing oil and gas infrastructure (13% Cr, soft material.....)
- Complex network
  - Compatibility of streams (monitoring)
  - Many point sources, more upsets?
- Subsea: shut down, pigging, depressurization and upset remediation
- Ship transport, low temperature (-25 C)-solubility, corrosive phases
- Use of flexible flowlines and risers

CO_2 composition recommendations/specifications

- Several recommendations, but lack of experimental verification
  - Based on: Corrosion issues, Health and safety, Reservoir/EOR
- The ISO transport standard (2016) gives no clear recommendation on CO_2 composition due to lack of data. ***"The most up to date research should be consulted during pipeline design"***
- Does ship transport require stricter specifications than pipeline transport?

Comp. ppmv	Dynamis 2008	NETL* (for design)		Goldeneye/ Peterhead 2014 (2016)	Northern Light 2018
		2012	2013		
H_2O	500	730	500	50	30
H_2S	200	100	100	0.5	9
CO	2000	35	35	10	100
O_2	<40000	40000	10	1 (5)	10
SOx	100	100	100	10	10
NOx	100	100	100	10	10

Water solubility in pure liquid CO_2



Impurities in CO_2 and possible reactions

H_2O, ppmv	500
H_2S, ppmv	200
CO, ppmv	35
O_2, ppmv	40000
SOx	100
NOx	100

Solubility in pure CO2:1000-3000

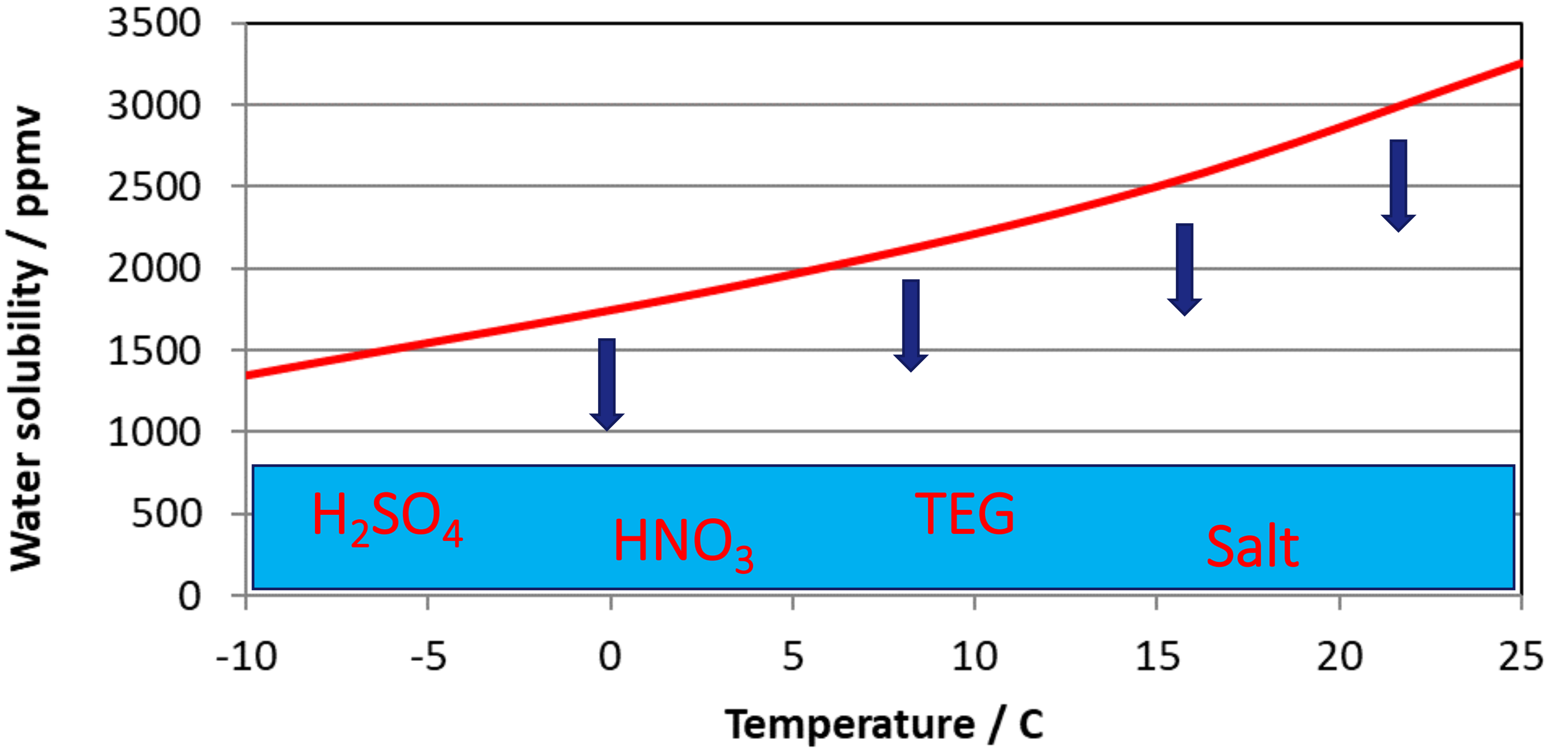
1.5 Mt/y
100 ppmv
100-200t/y

$$2\ H_2S + O_2 \rightarrow S_x + 2\ H_2O$$

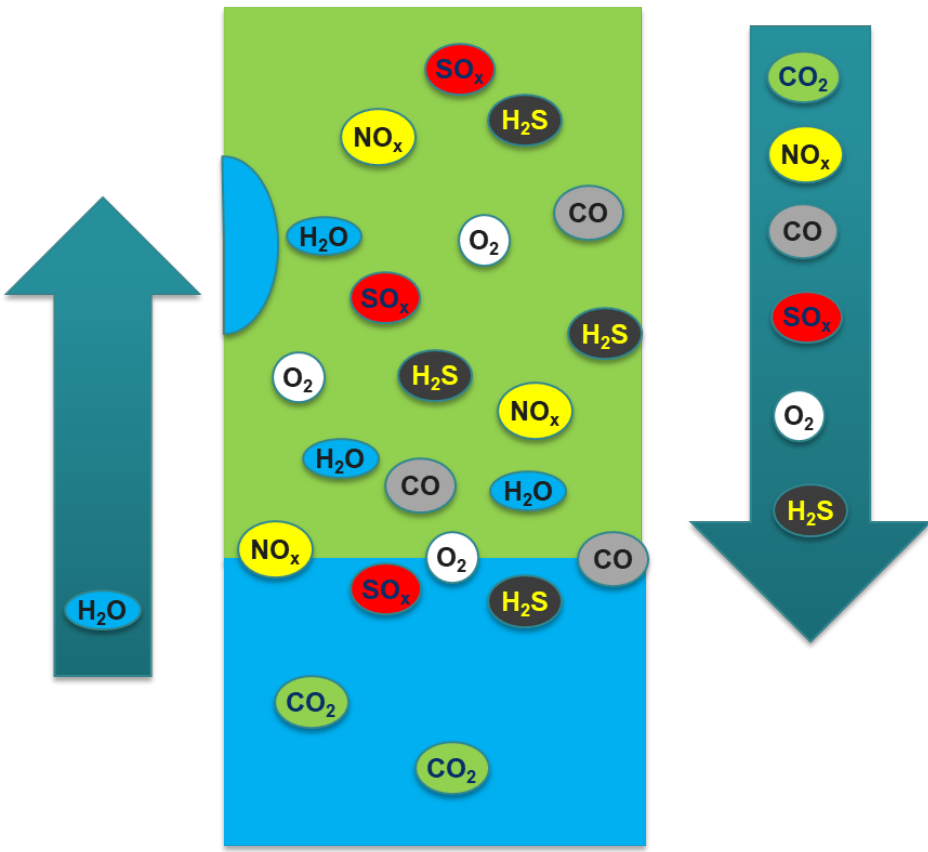
$$4\ NO_2 + O_2 + 2\ H_2O \rightarrow 4\ HNO_3$$

$$SO_2 + H_2O + \tfrac{1}{2}\ O_2 \rightarrow H_2SO_4$$

Water solubility in liquid CO_2 with impurities



Injection wells-
backflow of formation water



$$2\,H_2S + O_2 \rightarrow S_x + 2\,H_2O$$

$$4\,NO_2 + O_2 + 2\,H_2O \rightarrow 4\,HNO_3$$

$$SO_2 + H_2O + \tfrac{1}{2}\,O_2 \rightarrow H_2SO_4$$

V_{CO2}/V_{water} ratio

Testing of CO_2 specifications

Comp. ppmv	Dynamis 2008	NETL* (for design)		Goldeneye/ Peterhead 2014 (2016)	Northern Light 2018	Exp 25 C 100 bar
		2012	2013			
H_2O	500	730	500	50	30	122/90
H_2S	200	100	100	0.5	9	130/36
CO	2000	35	35	10	100	0/0
O_2	<40000	40000	10	1 (5)	10	275/70
SOx	100	100	100	10	10	96/30
NOx	100	100	100	10	10	69/32

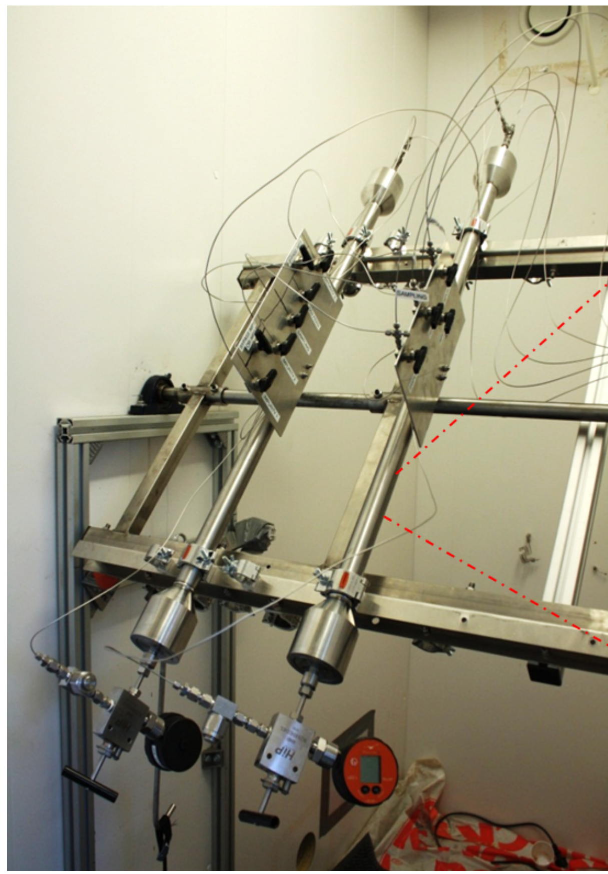
	H_2O ppmv	H_2S ppmv	NO_2 ppmv	NO ppmv	SO_2 ppmv	O_2 ppmv
IFE experiment. feed	122	130	96	0	69	275

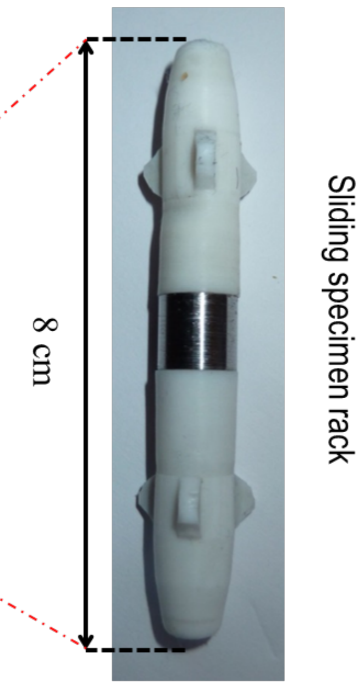
1 liter autoclave

200 ppmv H_2O

ONE!

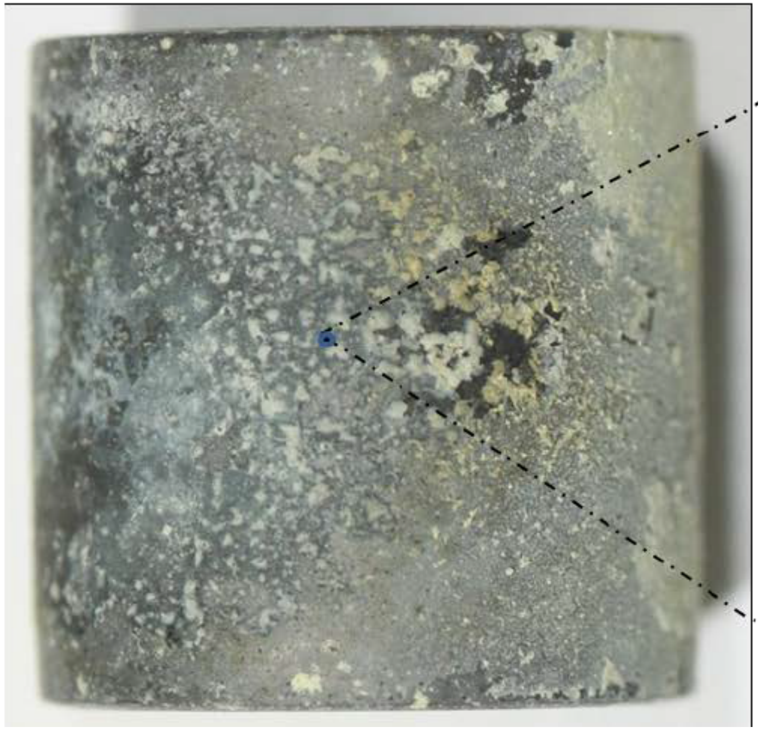
(< 0.1 ml)





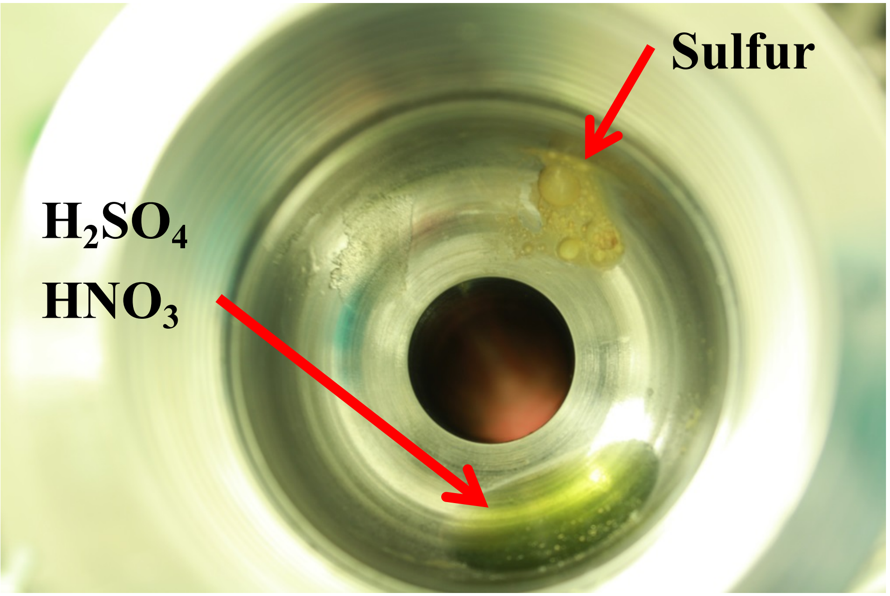
	H_2O ppmv	H_2S ppmv	NO_2 ppmv	NO ppmv	SO_2 ppmv	O_2 ppmv
Feed	122	130	96	0	69	275
Vented CO_2	<50	<10	<20	2-5	<30	Uncertain

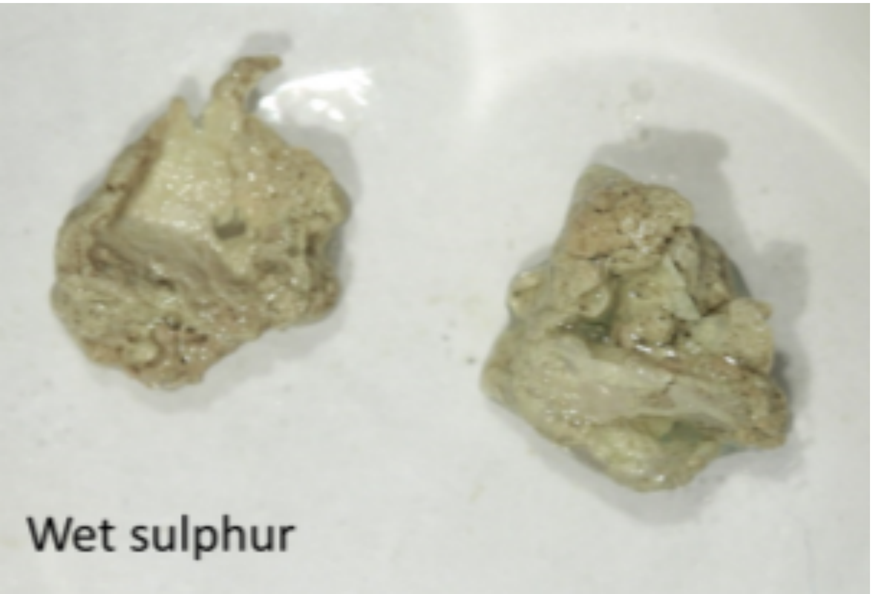
Not exposed



0.034 mm/year

	H_2O ppmv	H_2S ppmv	NO_2 ppmv	NO ppmv	SO_2 ppmv	O_2 ppmv
Feed	122	130	96	0	69	275
Vented CO_2	<50	<10	<20	2-5	<30	Uncertain





CO_2 1.5 Mt/y, > 200t/y

	H_2O ppmv	H_2S ppmv	NO_2 ppmv	NO ppmv	SO_2 ppmv	O_2 ppmv
Feed	122	130	96	0	69	275
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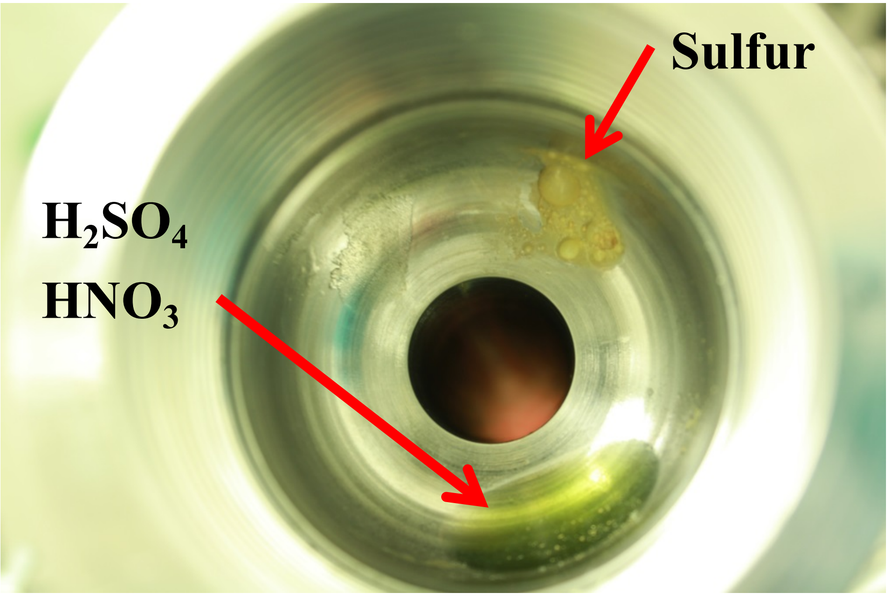

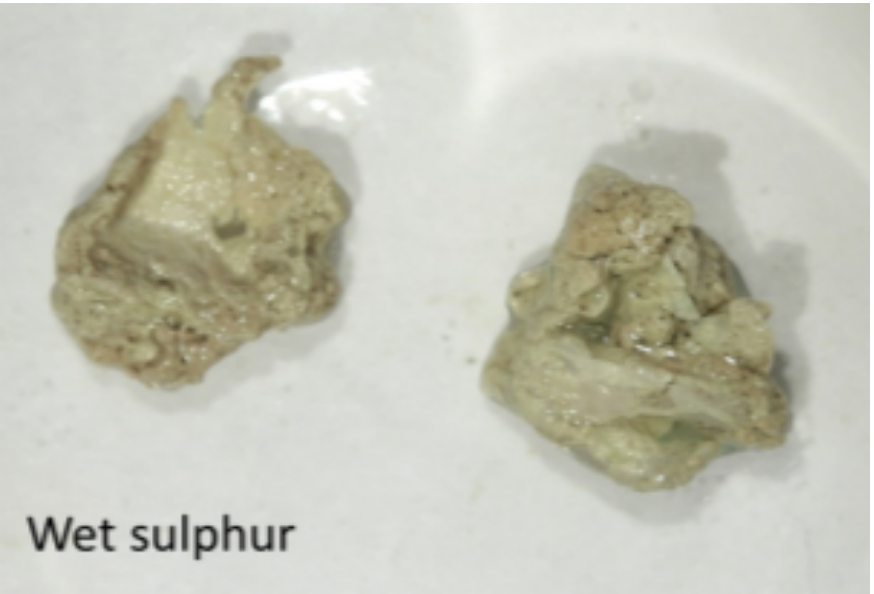

Is material selection a solution?

Conclusions/Challenges

- Free water and CO_2: high corrosion rates, >> 1 mm/y
- No aqueous phase, low corrosion rates, << 0.1 mm/y
- Developing models/tools to determine/predict "safe operation window"
  - Formation of corrosive phases
  - Formation of solids (sulfur, corrosion product)
  - Accumulation of impurities (depressurization)
- Generate experimental data for validation of models and tools required to design and operate CCS systems efficiently and at minimum cost.