IMPACTS

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

Techno-economic Analysis of CO_2 Quality Impact on CCS Chains

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Agenda

- What is a Techno-economic analysis?
- How we have approached this in IMPACTS
- Use of cost functions - outline
- Derivation of cost functions
- Examples of cost function results
- TE Model – overview
- Techno-economic trade-offs in CCS chains
- Absolute Limits (Red Lines)

Techno-economic analysis

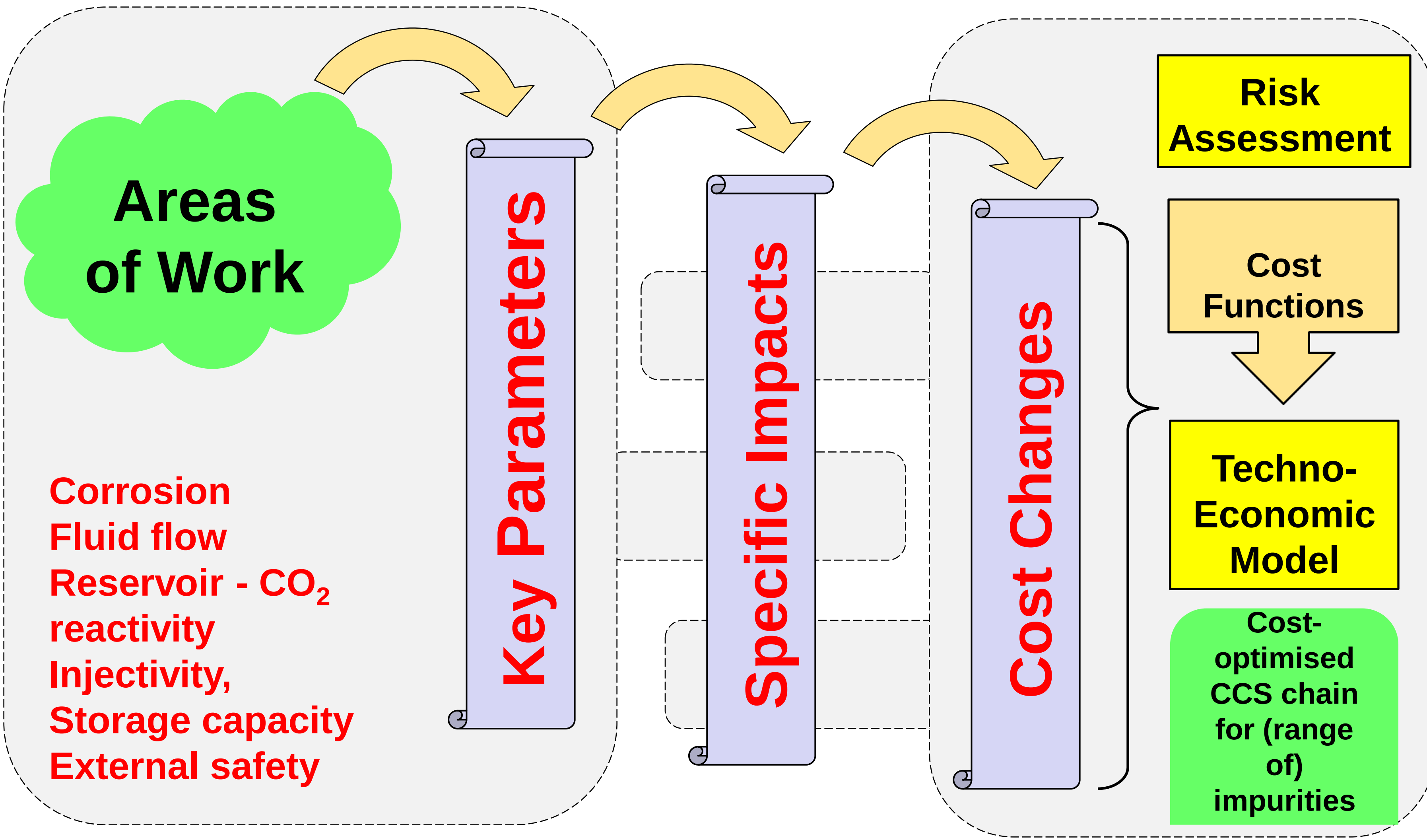
A Techno-economic Analysis is usually performed to provide insight into cost-benefit decisions about projects and involves two basic elements:

- The technical requirements to achieve a defined outcome
- The economic changes that this implies

These two elements can be combined into a standard project financial model with the capability to:

- model the technical issues
- vary the assumptions to look for optimal solutions

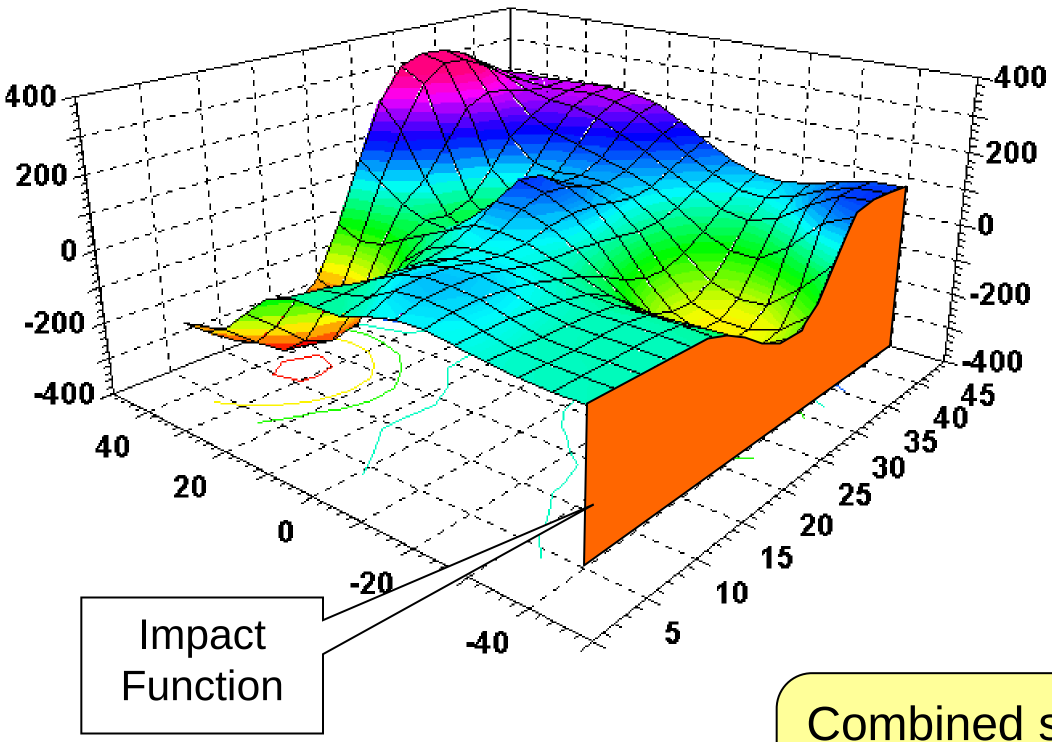
IMPACTS Project Data Flows



Use of Cost Functions - outline

Multi-variant influences

The cross-influence challenge:



- Many impurity impacts will actually be a multi-dimensional surface (more than 3D shown here)
- Individual impact functions are sections through this surface
- Cross-influences can be important, caused either by:

Combined species physical or chemical impacts

Process equipment with multiple species impacts

Capture Cost Function

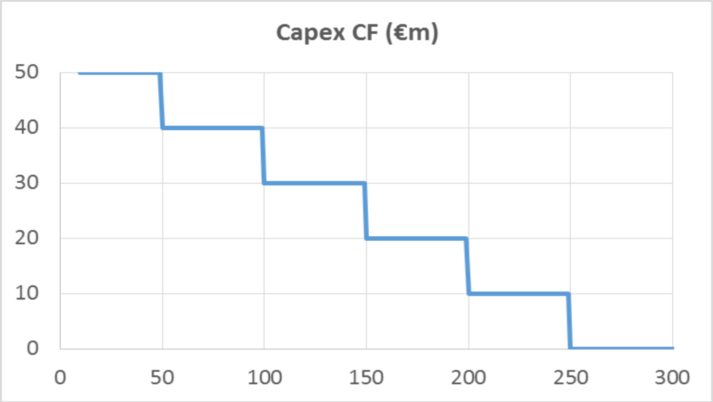
Example: Reducing water content using methanol drying

Capex

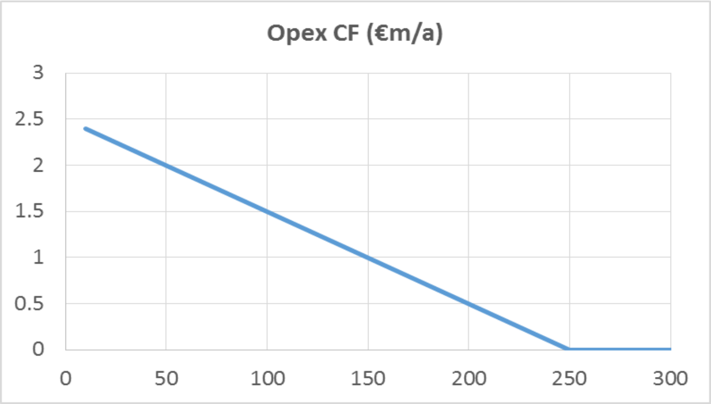
H_2O ppmm	CF (€m)
2000	0
250	0
249	10
200	10
199	20
150	20
149	30
100	30
99	40
50	40
49	50
10	50

Opex

H_2O ppmm	CF (€m/a)
2000	0
250	0
10	2.4



Water content ppmm



Water content ppmm

Capex is a series of steps of €10m per100ppmm

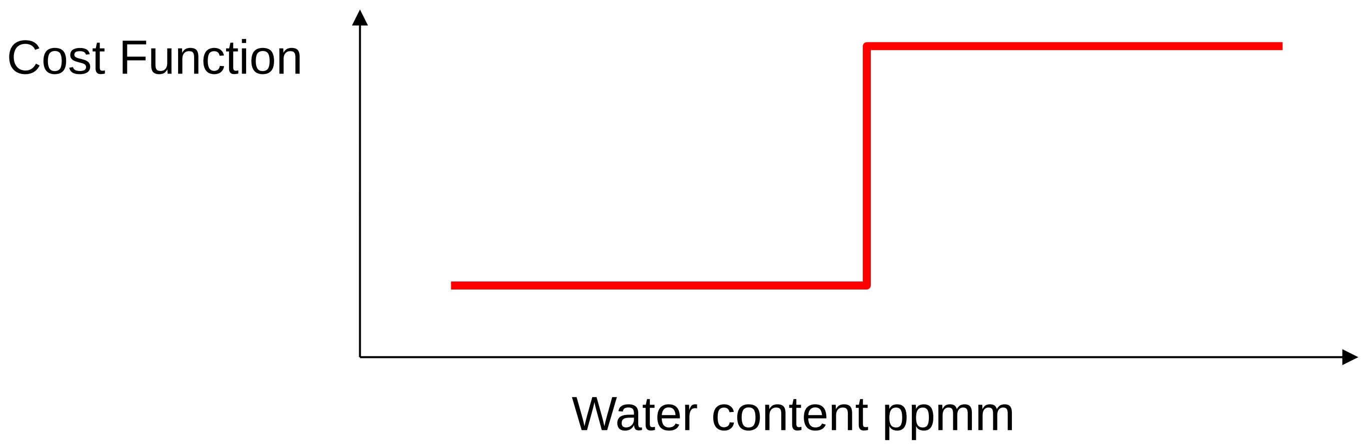
while the Opex is a smooth linear relationship with decreasing ppmm.

Pipeline Steel Cost Function

Example: Using Stainless Steel to avoid corrosion

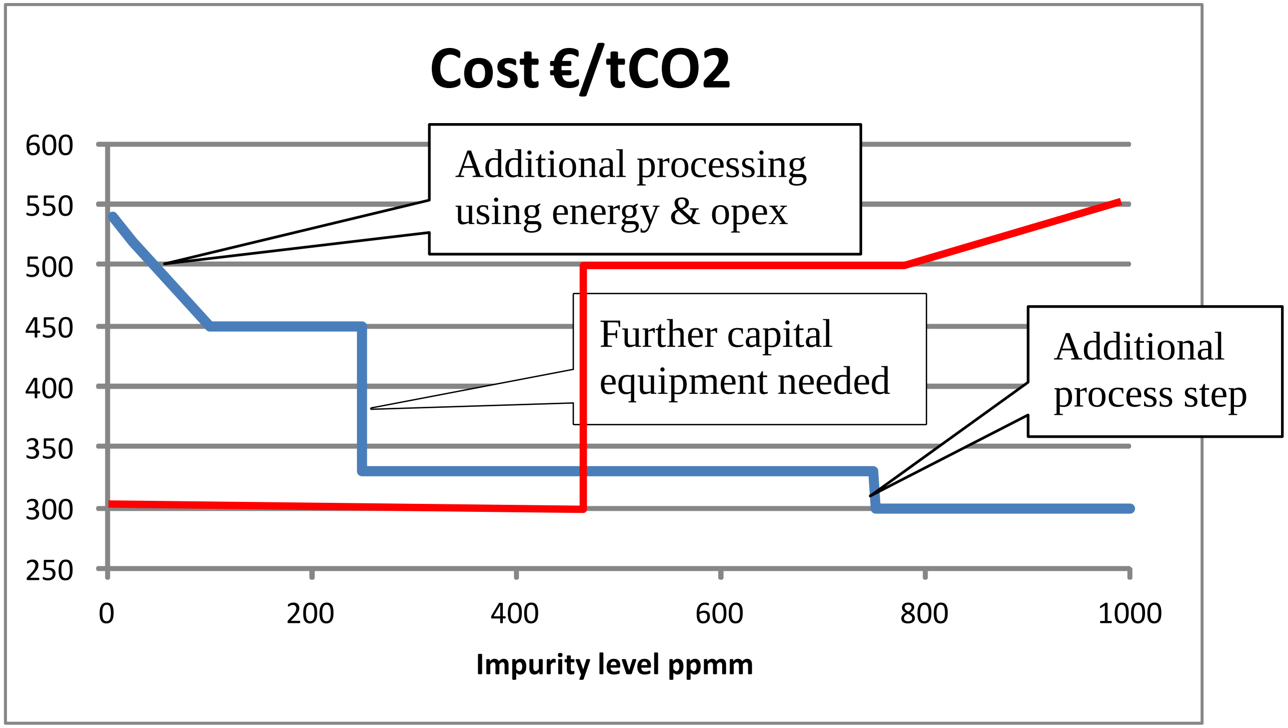
Capex is a single step change in cast due to more expensive material.

In this case a factor is used so as to be able to apply it to the calculated material cost of the chosen pipeline



Overall Cost Function Build-up

Influence of changing purity: Cost Function



Blue line shows cost of increasing purity at source

Red line shows changing downstream T&S costs with changing ppm

Optimum position is at minimum total cost (450ppm here)

Derivation of Cost Functions - examples

Cost Functions – Capture Plant

What are the key impacts on cost of capture in an IGCC (Capex and Opex) when:

- tightening the specification
- relaxing the specification

from the standard Benchmark plant? Expressed as % change to allow for re-sizing.

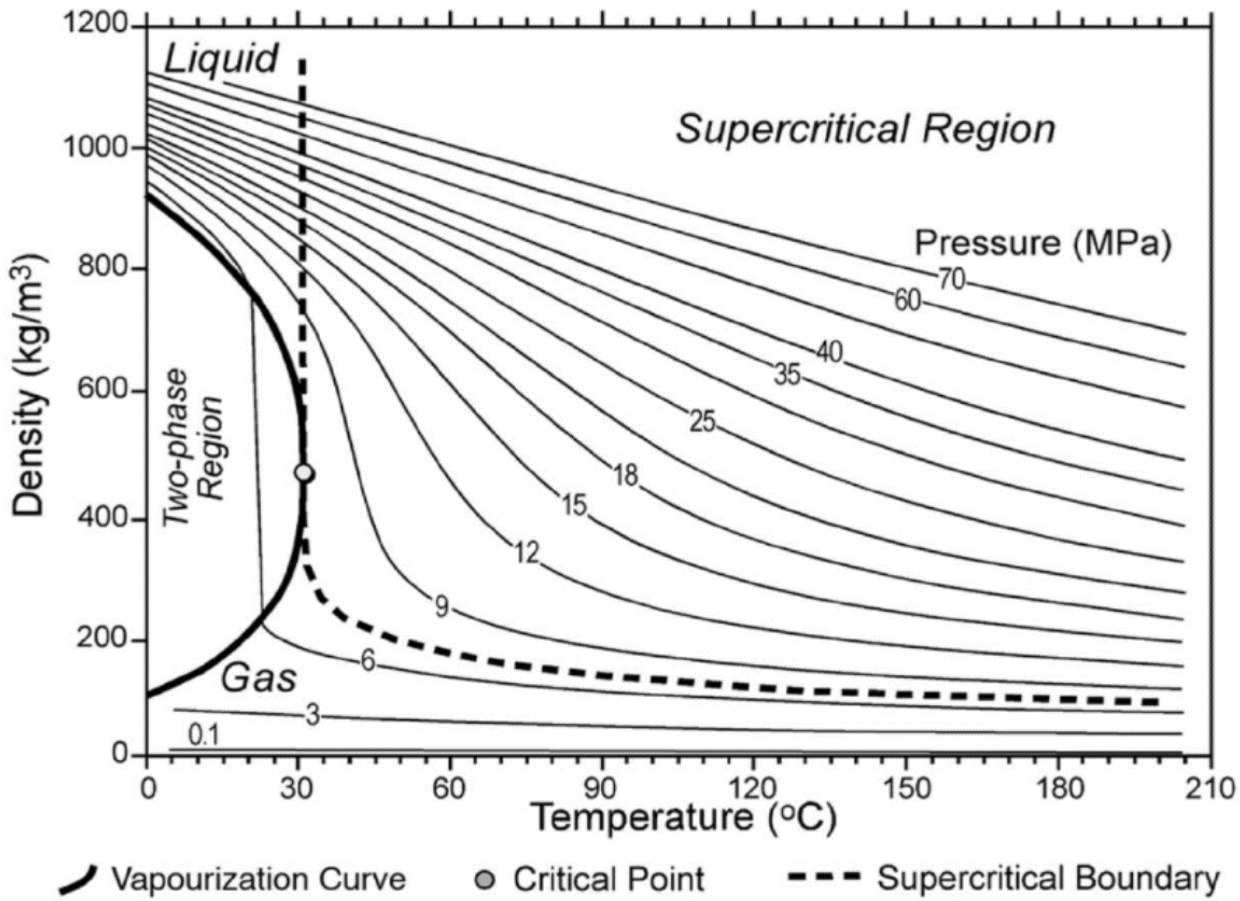
Capex **800€m**

Opex **21€m/a**

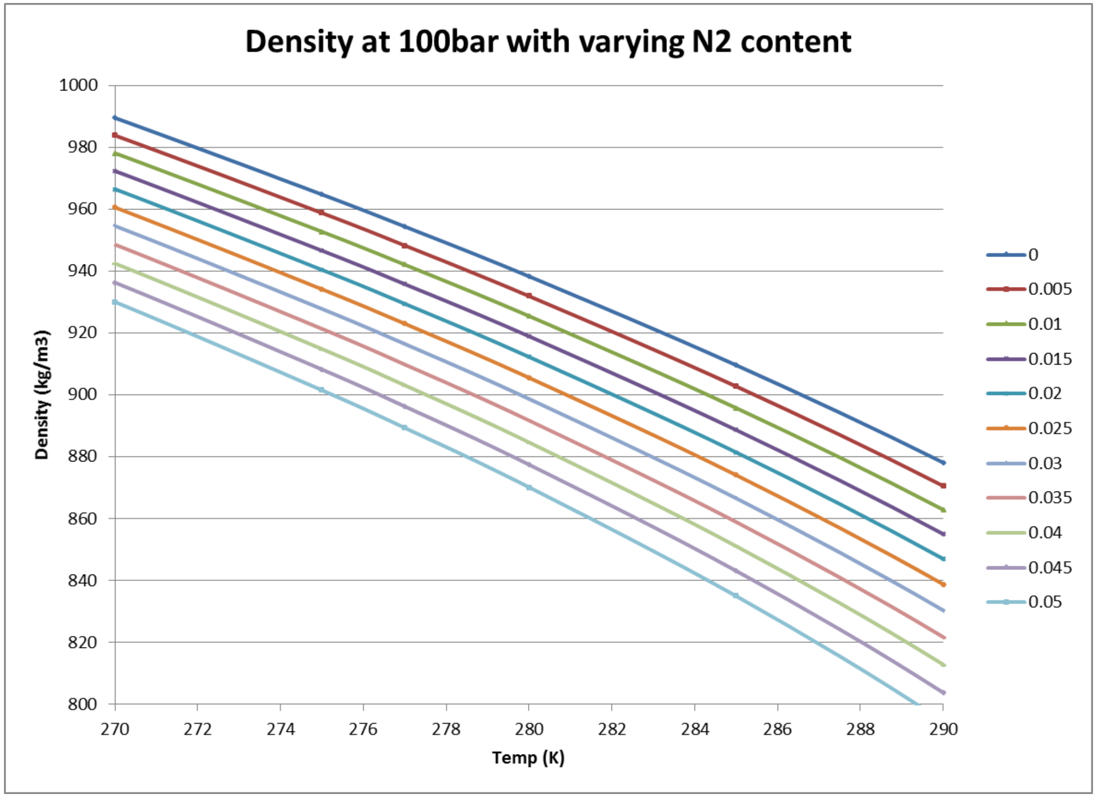
Refinement				
Impurity	**Δ ppm**	**Capex %**	**Opex %**	**Process**
H_2O	<250	5	0	Methanol wash
N_2	<2%	1	2	Use CO_2 lock hoppers
O_2	<10	1.5	1	Liquid scavenger (and methanol)
Ar	<200	2.5	2	Refine ASU separation level
H_2S, H_2	<100	5	1	Refine the DMEPEG wash
CH_4,C_2+, NH_3	<500	0	0	Use entrained flow gasifier
Cl-	<5	0	1	NaOH wash
Relaxation				
Impurity	**Δ ppm**	**Capex %**	**Opex %**	**Process**
N_2, Ar	>250	-2.5	-2.5	Cheaper ASU design

Variation in density with N2 content

Pure CO_2 has interesting characteristics:



Variation in density with N2 content



Data from TREND 2.0

Developed by RUB for the IMPACTS project

So an approximation for the density of the mixture can be derived as follows:

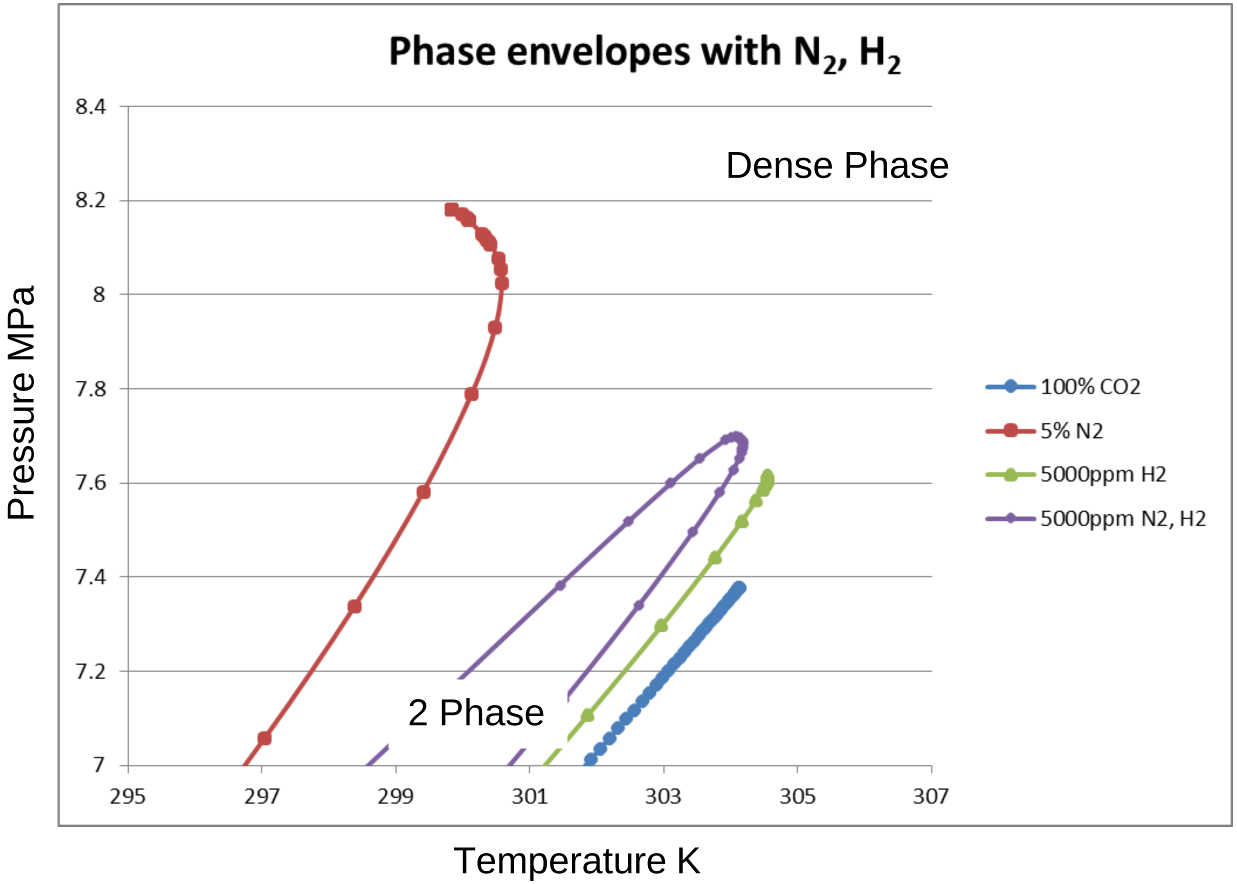
$$\rho = 938-1360N+0.72(P-100)-6(T-280)$$

where N is the N2 fractional content

P is the pressure in bar

T is the temperature in K

Variation in Bubble Point with Impurities



Data from TREND 2.0

Developed by RUB for the IMPACTS project

Need to raise chain pressure to avoid two-phase flow (around 8bar)

IMPACTS T-E Model

IMPACTS Techno-Economic Model

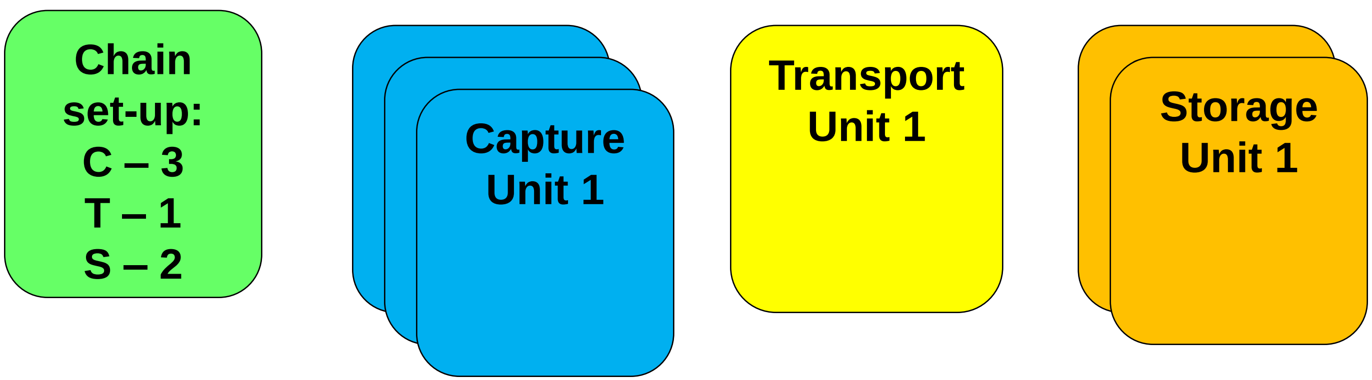
The Techno-Economic Model is

- Designed to be flexible to allow different chains to be modelled
- Built in Excel to be user-friendly
- Using a data table to flex impurity level from designated capture plant
- Providing user-specifiable economic measures
- Kept as simple as possible where standard

Techno-Economic Model

Set-up of Benchmark Chains

IMPACTS Tool v0.2				Component Module Coordination Sheet					
				6	100	100	100	10	11
Components in use	Capture	3		6	10	11			
	Transport	1		**Chain Components**					
	Storage	2		1	2	3	4	5	6
Use pull-down menu type and name to attach the required component sheets	Type of module			Capture	Transport	Storage	Storage	Capture	Capture
	Worksheet name			Capture 1	Transport 1	Storage 1	Storage 1	Capture 2	Capture 3
	Component name			Pre-Combustion	Pipeline	Oil Field	Oil Field 2	Post-Combustion	Post-Combustion
Chain Structure		Group		1	2	3	3	1	1
	Chain Connection type			Join	Series	Branch	Branch	Join	Join



Techno-Economic Model

Overview of Connections

IMPACTS Tool v0.4	Logic Module	Connections			
Connection Diagram	This sheet provides a visual representation of the connected CCS chain				
	Components Group 1	**Connections**	**Components Group 2**	**Connections**	**Components Group 3**
Group Type	Join		Series		Branch
	IGCC 1		Pipeline 1		Oil Field 1
	Amine PC 1				Oil Field 2
	Amine PC 2				

Techno-Economic Model

Capture Module input

Capture Impurity Specification	Uses User Input or Data Table from Main			
Overall CO2 purity	99.6%			
	Used		User Input	
Impurity	**ppmm**			
H2O	100		100	
N2	2000		2000	
O2	100		100	
Ar	20		20	
NOx	100		100	
SOx	100		100	
CO	20		20	
H2S	100		100	
H2	50		50	
CH4	500		500	
C2+	1000		1000	
Cl	5		5	
NH3	50		50	

Fill in all boxes marked yellow		
wer Station Parameters	1	
ctrical output MW gross	460	MW
-site Loads	116.4	MW
ctrical output MW net	344	MW
t overall efficiency	31%	%
el Type	Coal	
el calorific value (LHV)	26600	MJ/kg
el Carbon content	66.9%	%
2 capture rate	91.7%	%
2 produced	337.4	t/h
	3.0	Mt/a
ailability (typical)	87.5%	
tput Pressure MSL	210	bar
mpression load	80.7	MW

Techno-Economic Model

Model Components contain cost function influences:

Resulting Component outputs:
- Costs
- Availability
- Efficiency
- Change in Power

Input of whole plant costs and individual affected components

Call up Cost Functions and calculate influence factor

Module Output								
		To[illegible]ures			Changes due to Impurities			
							Power	
		Capex	Opex	Opex	Avail	Efficiency	onshore	offshore
		€M	€M/a	€/tCO2	%	%LHV	MW	MW
		944.5	22.6	0.0	0.0	0.0	0.0	0.0
Base Parameters		Capex	Opex	Opex	Avail	Efficiency	onshore	offshore
		€M	€M/a	€/tCO2	%	%LHV	MW	MW
Plant Items								
Whole Plant adjusted		821.3	22.6	0.0	0	0	0	0
Contingency /owners costs	15%	123.2						
Cost / Other Adjustments		**Resulting Cost Values**			**Resulting other parameter changes**			
AGR		75.9	1.9	0.0				
SRU and TRT (Claus)		21.3	1.1	0.0				
CO2 compression & conditioning		19.4	0.5	0.0				
Pressure Swing Adsorption		2.6	0.1	0.0				
Additional Drying								
Efficiency Net LHV		0.0	0.0	0.0				

Benchmark Costing Values fr[illegible]abook					
Values for the whole plant					
Capex	Opex	Opex	Ref Size	Year	
€M	€M/a	€M/tCO2	t/h CO2	basis	**CEPCI**
821.9	22.6	0.0	324.0	2013	1
Costings adjusted for year and size					
821.4	22.6	0.0			
Standard Costs for Benchmark Size			**year**	**CEPCI**	
75.9	1.9		2013	1	
21.3	1.1		2013	1	
19.4	0.5		2013	1	
2.6	0.1		2013	1	

	Cl	5		5				
	NH3	50		50				
Size								
Adjustments	Formula	Factor	Apply					
Size factor	(B/A)**size factor	0.9994	0.9994					
Adjustment Factors to be applied								
Actual Size		**Factor**	**Apply**		**Impurity Cost Function**	**Name**	**Factor**	**Apply**
Size factor		0.9994	0.9994					1.000
Size factor		0.9994	0.9994					1.000
Size factor		0.9994	0.9994					1.000
Size factor		0.9994	0.9994					1.000
			1.0000					1.000
			1.0000					1.000
			1.0000		H2O reduction	PREH2O		1.000
			1.0000					1.000
			1.0000					1.000
			1.0000		Efficiency effect			1.000
			1.0000					1.000
			1.0000					1.000
			1.0000					1.000

Techno-Economic Model

Tables of Cost Functions

Name and using Module

Criterion

Interpolation routine

Table of values

Transp 1		Capture		Transp 1	
TSSH2O	100	**PEFFN2**	-1.8	**DENSN2**	2000
Impurity <100	Impurity >=100	Impurity <-1.8	Impurity >=-1.8	Impurity <2000	Impurity >=2000
10	100	-5	5	1000	5000
1	1	0.975	1.025	1016	1010
1.00		0.99		1014.48	
Impurity	Value	Impurity	Value	Impurity	Value
10	1	-5	0.975	10	1017
100	1	5	1.025	1000	1016
200	1			5000	1010
350	1			10000	1004
351	4.13			50000	949
500	4.13				
1000	4.13				

Flex arrangements – Data Table

Source and nature of flexing can be set by user

Impurity Elasticity calculations

Vary the composition from

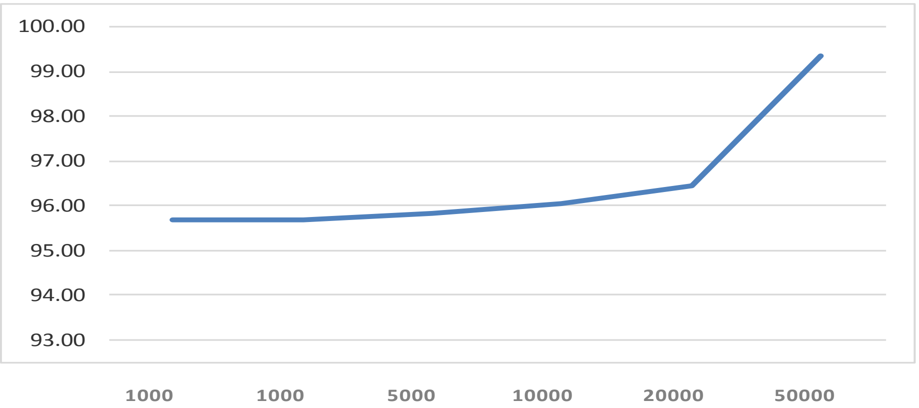
Capture 1	Capture 2	Capture 3	Capture 4	
TRUE	FALSE	FALSE	FALSE	FALSE

Data Table used here for variation of the measure against ppm

to be completed

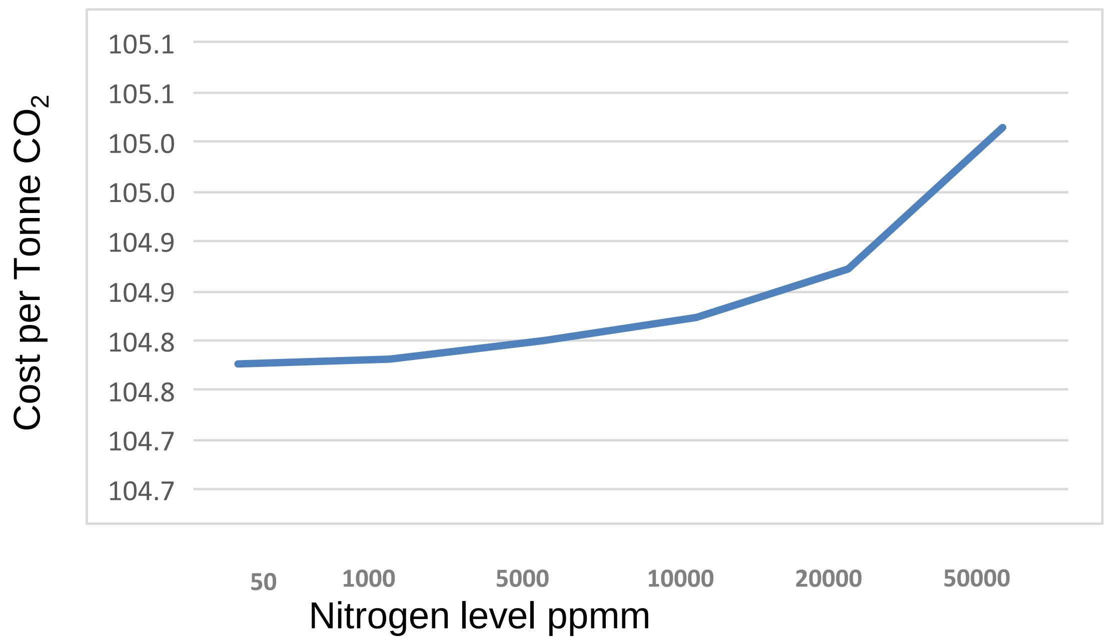
	Base			Variants:									
	ppm	€/t/ppm	€M/a/ppm			€/t							
	Capture 1				Graph	base	20	50	100	250	350	1000	ppm
H_2O	100	0.96	4.24			95.71	95.87	95.81	95.71	95.42	95.42	102.35	
							1000	1000	5000	10000	20000	50000	ppm
N_2	2000	0.05	0.21		1	95.71	95.68	95.68	95.83	96.03	96.46	99.34	
							3	10	20	100	500	1000	ppm
O_2	10	9.57	42.44			95.71	95.86	95.71	95.71	95.71	95.72	95.72	

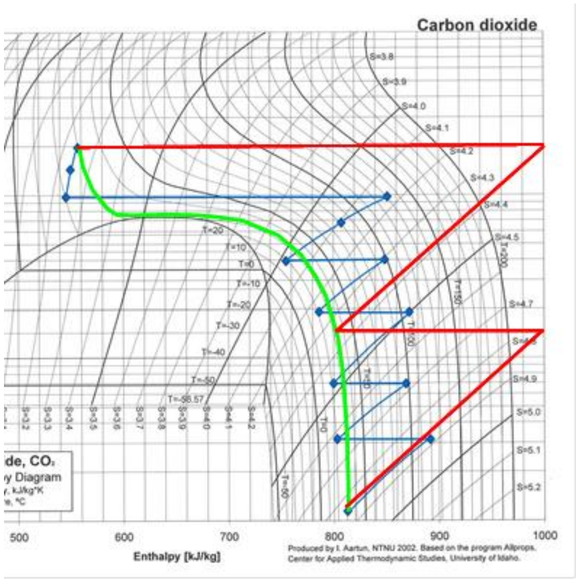
Tabular and graphical output as defined by user in addition to standard project cash flows and returns



IMPACTS Sensitivities – typical outputs

Effect of Nitrogen on Multi-stage Compression Efficiency





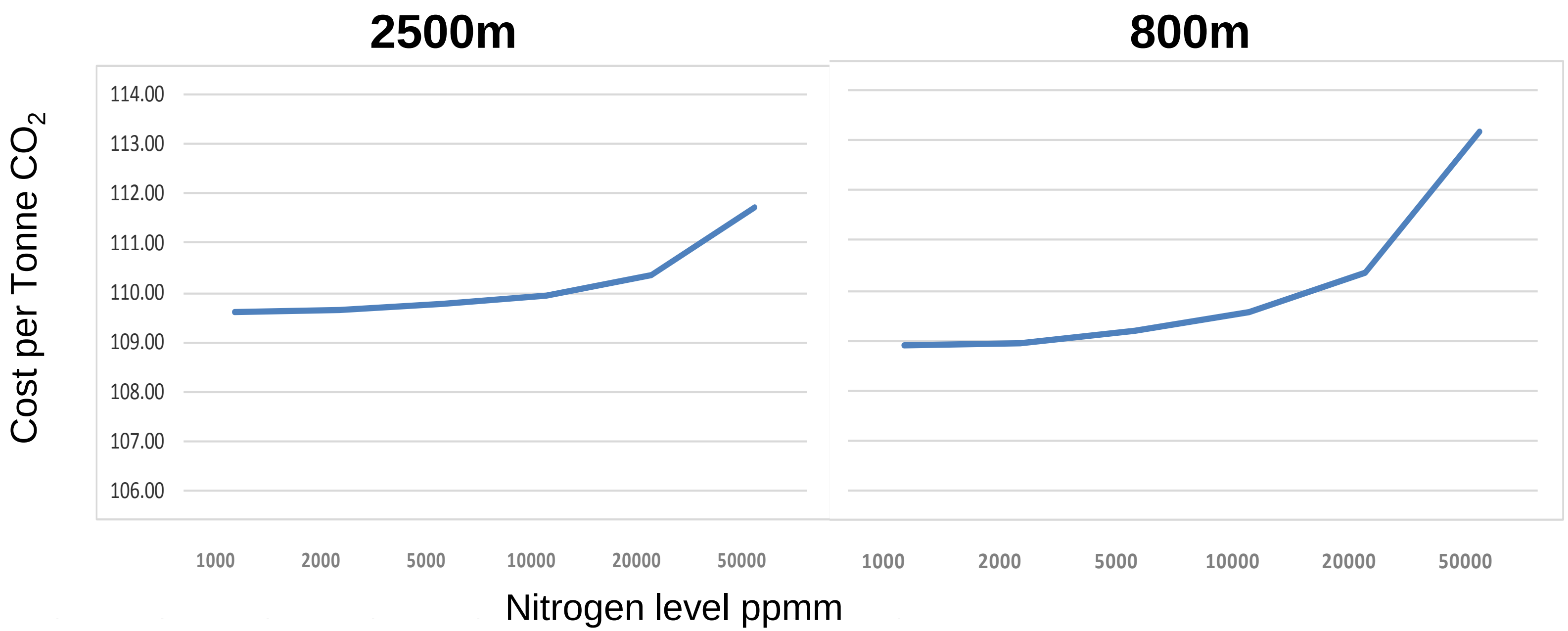
Empirical formula derived from multiple runs of TREND2 and ProMax: 0.5% change in energy consumption per 1% N_2 content

Applied to Capture module and hence energy usage in CCS chain

Graph created using model flex facility

IMPACTS Sensitivities

Effect of Nitrogen on CCS chain storage capacity with depth

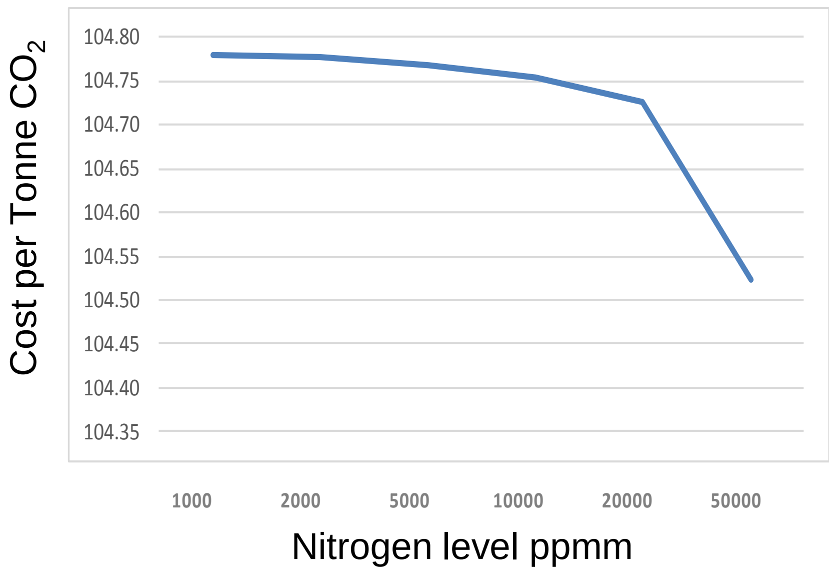


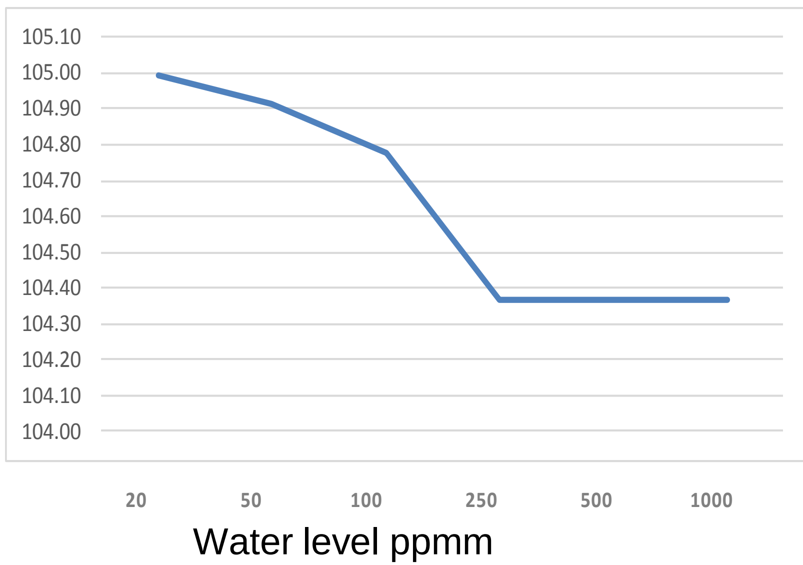
The effect of Nitrogen in the CO_2 CCS stream

- as an inert impurity displacing marginal CO_2: cost quite low at depth
- at lower depth the Nitrogen forms two-phases and hence reduced capacity

IMPACTS Sensitivities

Effect of Nitrogen & Water reduction on Pre-combustion Capture costs





Allowing a higher level of nitrogen allows for a cheaper ASU

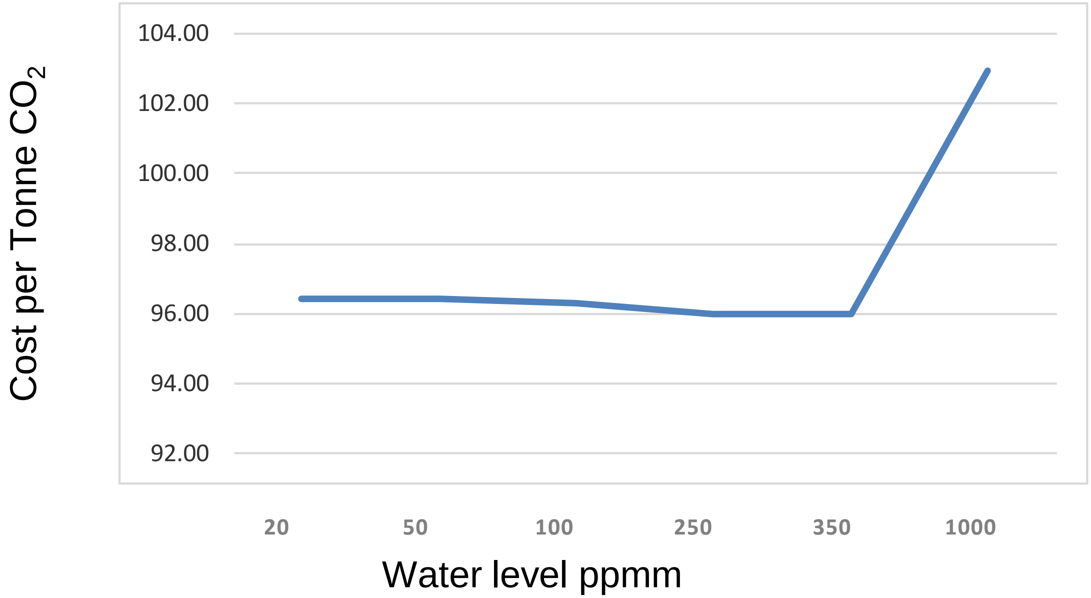
Further tightening of the specification requires use of CO_2 in lock-hoppers

Step change at 250ppmm with introduction of methanol drying

Increasing opex costs to get moisture level down further

IMPACTS Trade-offs

Add the Pre-combustion plant to a long pipeline (Case C)



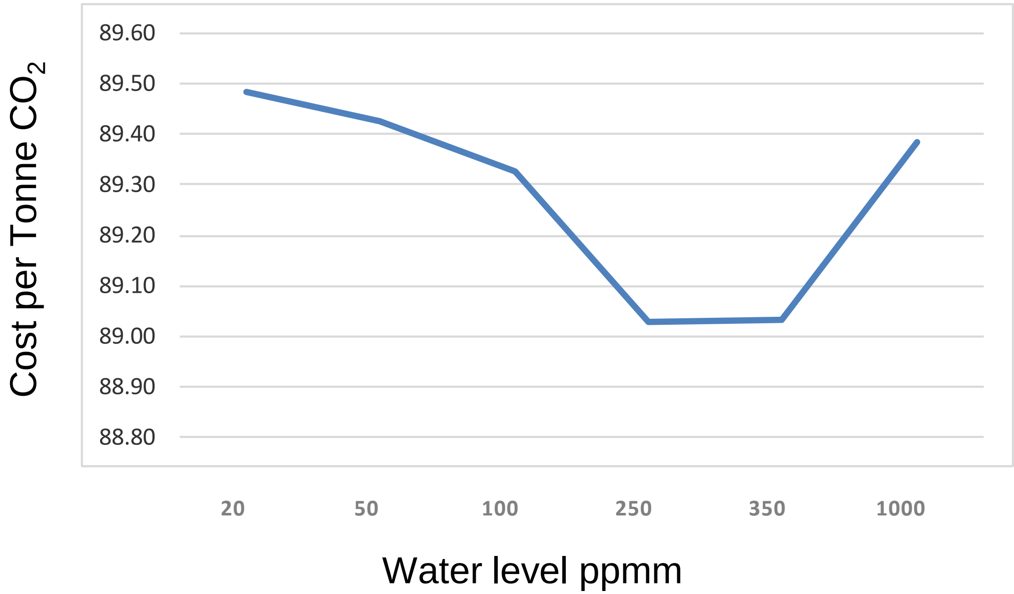
Step change at 350ppmm H_2O with switch to stainless steel pipe

Increase below 250ppmm from introduction of methanol drying

Hence optimal range of 250 – 350 ppmm

IMPACTS Trade-offs

"Bathtub" is more balanced with a short onshore pipeline (Case B)



Lower overall costs makes ppm reduction relatively more costly

Additional pipeline costs much smaller

Risk Limits

Risk Limitations from Impurities

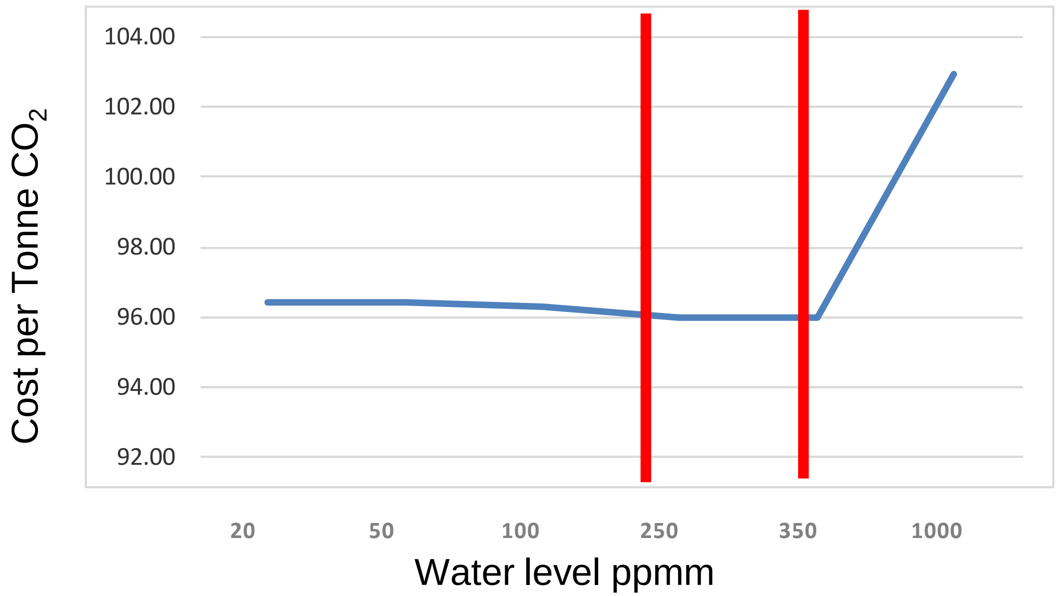
Commercial TE analysis also needs to be tempered by any Fatal Flaws or Red Lines arising from impurities.

May be in the form of :

- Increased risk to structural integrity
- Heightened risks to human health
- Increased possibilities of environmental damage

Any such limits need to be overlaid on the economic analysis

"Red Lines"



Limit of 350ppmm H_2O is not a red line as there is the expensive option of a stainless steel pipeline

Limit of 250ppmm for hydrate formation can be an operational red line as pipeline could become blocked under some conditions

CO_2 Toxicity and Impurities

For the IMPACTS project, it has been assumed that an accident will give rise to a concentration of 10% CO_2 in air, and that breathing increases up to six times normal (84 breaths/minute).

Even when the multiplier of x6 is applied equivalent figures for impurities, the effect of inhaling the CO_2 will far outweigh the proposed range of impurity levels e.g. for H_2S at 30 mins:

SLOT in Air	Max Impacts	at 10%	x6
500 ppm	200	20	120

Safe Limit of Toxicity (UK HSE)

(CO_2 30min SLOT 62,000 ppm)

Hence the conclusion is that the CO_2 will be more toxic than any of the impurities (including combinations) at the levels considered by IMPACTS

The IMPACTS Project

Thank you for your attention

To be reinstated it not elsewhere

Effect of Impurities on Storage Capacity

Example: Overall capacity of Aquifer storage by depth

Effect of adding additional N_2, O_2 to mixture

Depth (m) reservoir	Coal-fired power station Post-combustion ammonia — Aquifer Storage capacity (Mt)			Coal-fired power station Oxyfuel Combustion — Aquifer Storage capacity (Mt)		
	Pure	Mixture	Diff (%)	Pure	Mixture	Diff (%)
800	14.1	13.9	-1.4	14.1	7.8	--44.7
900	15.9	15.7	-1.3	15.9	11.0	-30.8
2000	34.4	34.2	-0.6	34.4	30.7	-10.8
3400	57.0	56.8	-0.3	57.0	52.5	-7.9

Effect on critical point

Effect on density

1% N_2

2.5% N_2
2.2% O_2

Impurities used in model

Data from TNO using REFPROP