Comparative environmental assessment of novel silica pei-based versus mea-based co2 capture technologies in the cement plant

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COMPARATIVE ENVIRONMENTAL ASSESSMENT OF NOVEL SILICA PEI-BASED VERSUS MEA-BASED CO_2 CAPTURE TECHNOLOGIES IN THE CEMENT PLANT

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Background

- The Global Cement and Concrete Association says current global cement production is 4.1 Billion tonnes per year and is estimated to increase by 12-23% by 2050.
- The Cement and Concrete industry accounts for 7% of the worldwide CO_2 emissions

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CO_2 Capture and Storage in Cement Industry

Existing Technologies

- MEA Process
  - Requires high regeneration energy and high solvent losses.
- Oxyfuel process
  - High capital and operating costs.
  - Can't be retrofit to existing plant.
- Membrane-assisted CO_2 liquefaction
  - High operating costs.
- Calcium looping (CaL) including direct and indirect heating
  - High operating and capital costs.
  - Design modifications are required
  - Requires a separate power plant.

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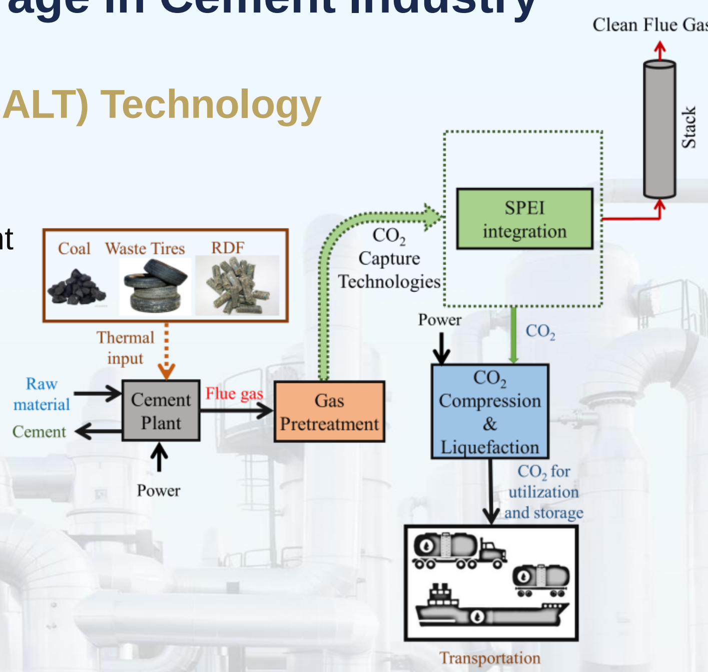
CO_2 Capture and Storage in Cement Industry (Contd.)

Novel SPEI based CCS (SALT) Technology

Advantages:

- Retrofit ability to existing cement plants
- Low regeneration energy requirement at 2.3 GJ/tonne CO_2
- Minimum sorbent losses



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Aims and Objectives

Aim: Evaluate the technical and environmental impact of integrating a SPEI based Carbon Capture and Storage (CCS) system into a cement plant and compare it with reference MEA based CCS system

Objectives

Develop simulation models based on the experimental and pilot scale date of the cement plant, incorporating SPEI-based CCS and MEA-based CCS technologies.	Perform mass and energy balance calculations to obtain life cycle inventory data.	Conduct midpoint and endpoint analyses of the CCS integration into the cement plant.

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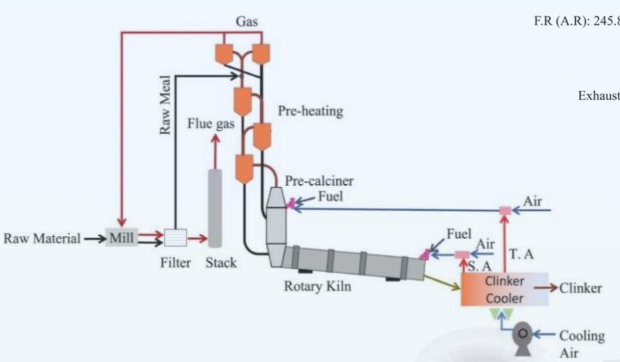
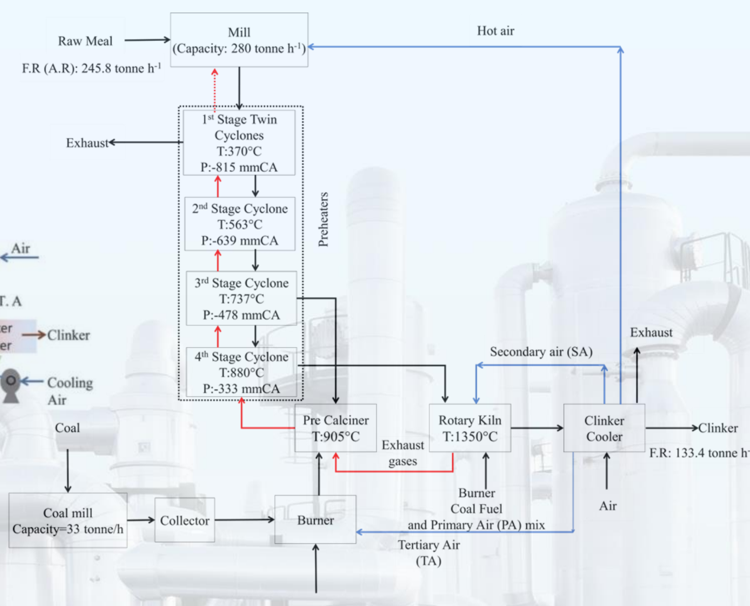
Base Case: CEMEX Cement Plant





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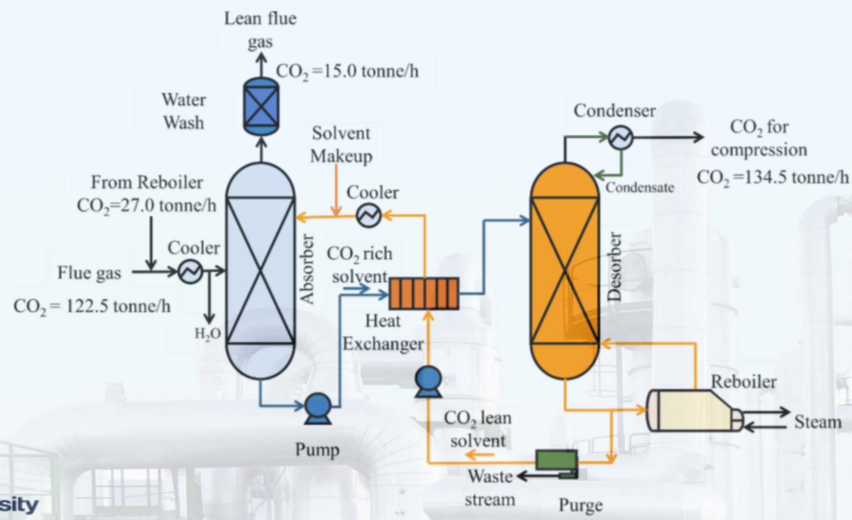
Conventional MEA Scrubbing System

Process Configuration



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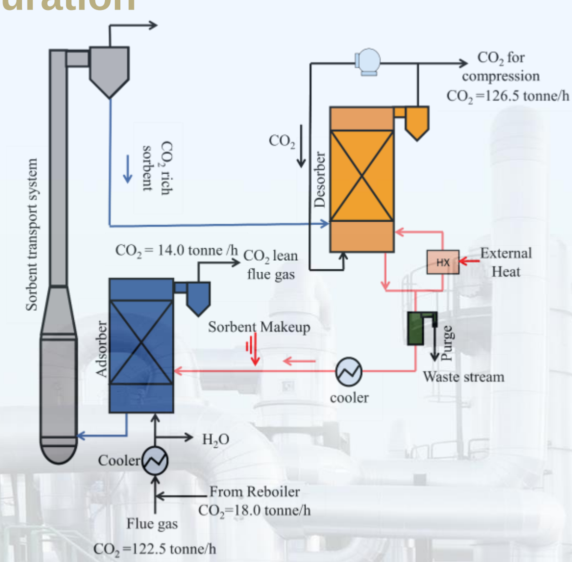
The Novel SPEI-based CCS Process (ABSALT Concept)

Process Configuration



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Technical analysis

Main process data	SPEI Integration	MEA Integration
Raw meal input (tonne/hr, dry basis)	208.9	208.9
Total thermal input for the reference plant (MWth)	133.4	133.4
Energy supply for SPEI regeneration (MWth)	101.4	162.8
Required regeneration energy (GJ/tonne CO_2)	2.36	3.53
Power consumption (MWe)	29.8	31.0
Specific power consumption (MWh/tonne Clinker)	0.22	0.23
Equivalent specific energy required (GJ/tonne Clinker)	7.66	9.34
CO_2 captured (tonne CO_2/hr)	126.5	134.5
CO_2 emitted on-site (tonne CO_2/hr)	14.1	15.0
CO_2 capture rate (%)	90	90
Specific direct CO_2 emissions (kg CO_2/tonne Clinker)	108.2	112.1
Specific indirect CO_2 emissions (kg CO_2/tonne Clinker)	61.2	63.7
Equivalent specific CO_2 emissions (kg CO_2/tonne Clinker)	163.5	175.8
Equivalent CO_2 emissions avoided (kg CO_2/tonne Clinker)	749.3	742.9
SPECCA (GJ/tonne CO_2)	4.3	6.5

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Life Cycle Analysis (LCA)

LCA Framework

Midpoint

- Life cycle inventory (LCI) results are converted to midpoint impact categories
- Depends on type of damage caused
- Conversion factors inline with **ReCiPe methodology**

Endpoint

- Midpoint indicators are further aggregated to three endpoint indicators
  - *Human Health* (DALY's - disability adjusted loss
  - of life years)
  - *Ecosystems* (species.yr – time integrated species loss)
  - *Resources* (USD2013 - surplus cost)
- **Damage assessment** results are given in terms of %, with the process with the greatest impact assigned 100%.
- Endpoint results can be normalised, weighted and summed to give a **Single Score**

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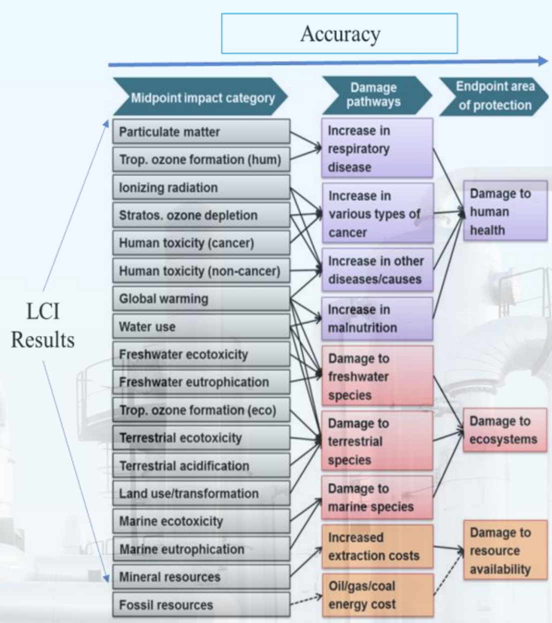

Figure 1.1. Overview of the impact categories that are covered in the ReCiPe2016 methodology and their relation to the areas of protection.

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Life Cycle Inventory

Inputs			Wastes & Emissions			Products		
Element	**Value**	**Unit**	**Element**	**Value**	**Unit**	**Element**	**Value**	**Unit**
				Reference cement plant				
Limestone	2.0691	Kg	Argon	0.0199	Kg	Clinker	1	Kg
Coal	0.0522	Kg	Water	0.4130	Kg			
RDF	0.0101	Kg	CO_2	0.9176	Kg			
Tyres	0.1048	Kg	NO_2	0.0001	Kg			
Electricity	0.44	MJ	SO_2	0.0001	Kg			
				MEA integration				
Limestone	2.0691	Kg	Argon	0.0199	Kg	Clinker	1	Kg
Coal	0.0522	Kg	Water	0.8952	Kg	CO_2	1.0085	Kg
RDF	0.0101	Kg	CO_2	0.1133	Kg			
Tyres	0.1048	Kg	NO_2	0.0001	Kg			
MEA	0.0027	Kg	SO_2	0.0001	Kg			
Electricity	0.8502	MJ	MEA	0.0037	Kg			
Natural gas	0.1066	m^3						
				SPEI integration				
Limestone	2.0691	Kg	Argon	0.0199	Kg	Clinker	1	Kg
Coal	0.0522	Kg	Water	0.4130	Kg	CO_2	0.9483	Kg
RDF	0.0101	Kg	CO_2	0.1055	Kg			
Tyres	0.1048	Kg	NO_2	0.0001	Kg			
SPEI	0.010	Kg	SO_2	0.0001	Kg			
Electricity	0.8067	MJ	SPEI	0.0011	Kg			
Natural gas	0.0711	m^3						

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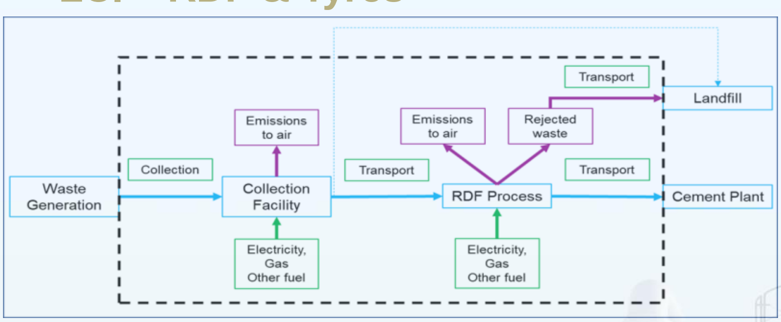
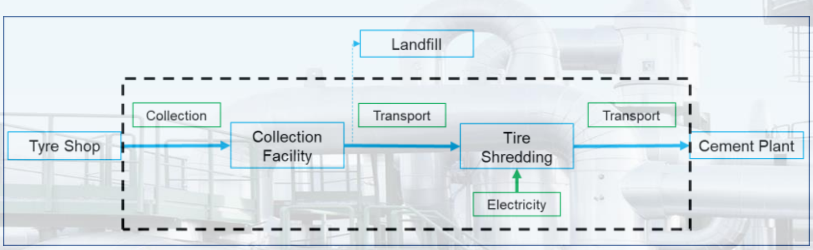
Life Cycle Inventory (Contd.)

LCI – RDF & Tyres



LCI RDF Prep and transport		
Collection	29.4	tkm
Electricity	154.4	kWh
Gas	37.1	m^3
Transport	95.6	tkm
CO_2	68.6	kg
RDF	1	t



LCI Tyres Prep and transport		
Collection	30	tkm
Transport	80	tkm
Electricity	4.5	MJ
Shredded Tyres	1	t

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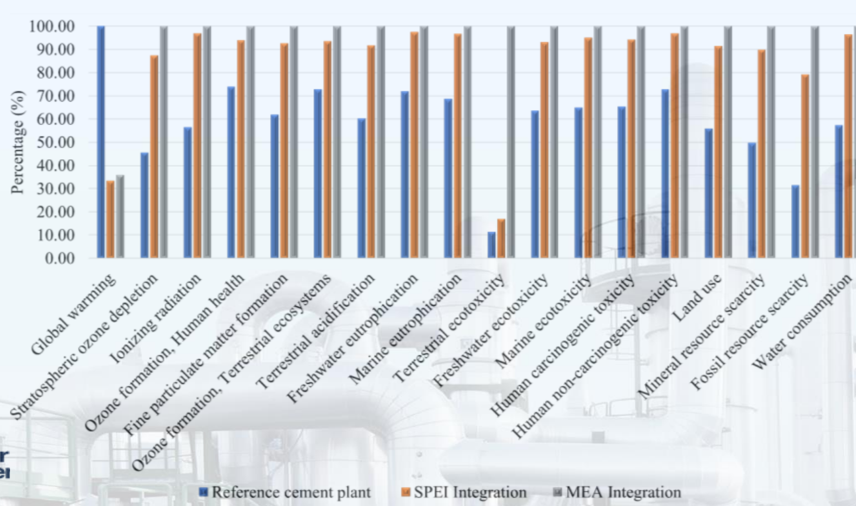
Midpoint results- Damage Assessment

Impact category	Unit	Reference cement plant	MEA integration	SPEI integration
Global warming	kg CO_2 eq	1.0100	0.3630	0.3380
Stratospheric ozone depletion	kg CFC-11 eq	0.0000	0.0000	0.0000
Ionizing radiation	kBq Co-60 eq	0.0305	0.0542	0.0524
Ozone formation, Human health	kg NOx eq	0.0005	6. 20E-04	0.0006
Fine particulate matter formation	kg PM2.5 eq	0.0002	0.0003	0.0003
Ozone formation, Terrestrial ecosystems	kg NOx eq	0.0005	0.0006	0.0006
Terrestrial acidification	kg SO_2 eq	0.0005	0.0008	0.0008
Freshwater eutrophication	kg P eq	0.0001	0.0002	0.0002
Marine eutrophication	kg N eq	0.0000	0.0000	0.0000
Terrestrial ecotoxicity	kg 1,4-DCB	0.1520	1.3400	0.2260
Freshwater ecotoxicity	kg 1,4-DCB	0.0048	0.0076	0.0071
Marine ecotoxicity	kg 1,4-DCB	0.0066	0.0101	0.0096
Human carcinogenic toxicity	kg 1,4-DCB	0.0093	0.0142	0.0134
Human non-carcinogenic toxicity	kg 1,4-DCB	0.1910	0.2630	0.2540
Land use	m^2a crop eq	0.0036	0.0064	0.0059
Mineral resource scarcity	kg Cu eq	0.0001	0.0003	0.0003
Fossil resource scarcity	kg oil eq	0.0545	0.1730	0.1370
Water consumption	m^3	0.0012	0.0021	0.0021

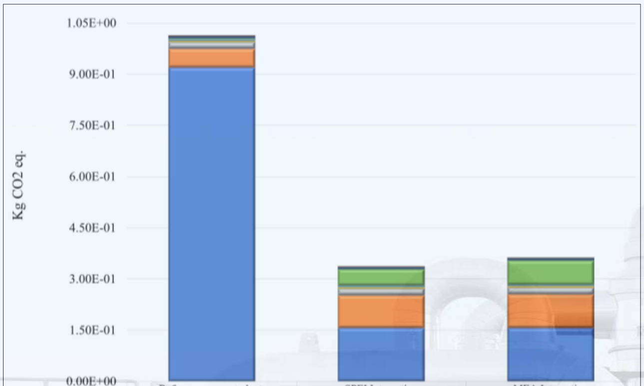
Midpoint results- Damage Assessment (Contd.)



Midpoint Results

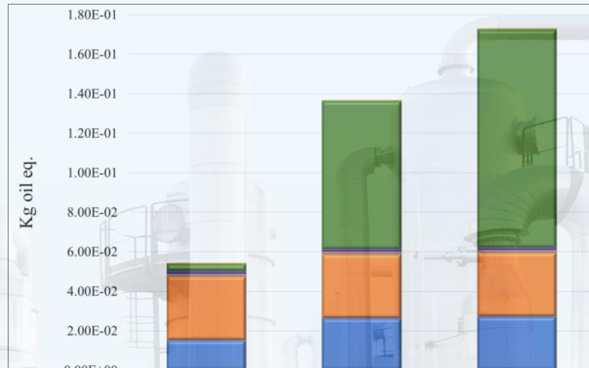
Global Warming Analysis & Fossil Fuel Scarcity

Global Warming Analysis



	Reference cement plant	SPEI Integration	MEA Integration
Freight Transport	1.78E-03	1.78E-03	1.78E-03
RDF Prep and transport	7.22E-03	7.22E-03	7.22E-03
Natural gas	2.43E-03	4.83E-02	7.10E-02
MSW collection	4.33E-03	4.33E-03	4.33E-03
Limestone	3.77E-03	3.77E-03	3.77E-03
Hard coal	2.02E-02	2.02E-02	2.02E-02
Electricity	5.52E-02	9.55E-02	9.84E-02
Clinker process	9.19E-01	1.57E-01	1.57E-01

Fossil Fuel Scarcity



	Reference cement plant	SPEI Integration	MEA Integration
Freight Transport	6.36E-04	6.36E-04	6.36E-04
Natural gas	3.77E-03	7.51E-02	1.10E-01
MSW collection	1.36E-03	1.36E-03	1.36E-03
Limestone	1.11E-03	1.11E-03	1.11E-03
Hard coal	3.25E-02	3.25E-02	3.25E-02
Electricity	1.51E-02	2.62E-02	2.70E-02

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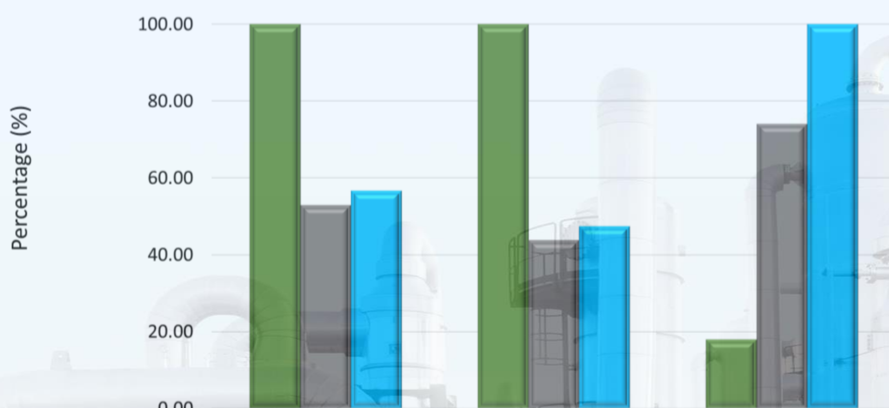
Endpoint results- Damage Assessment



	Human health	Ecosystems	Resources
1. Base Case Assembly	100.00	100.00	18.00
2. SPEI Clinker Assembly	52.94	43.79	74.00
3. MEA Clinker Assembly	56.73	47.39	100.00

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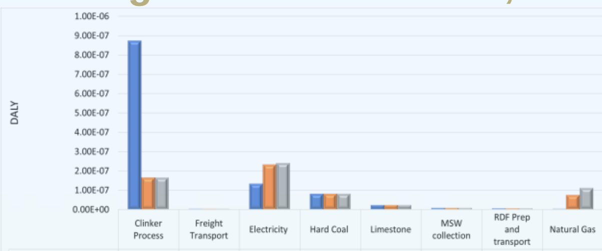
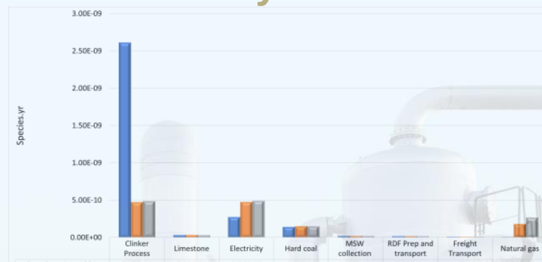
Endpoint Results

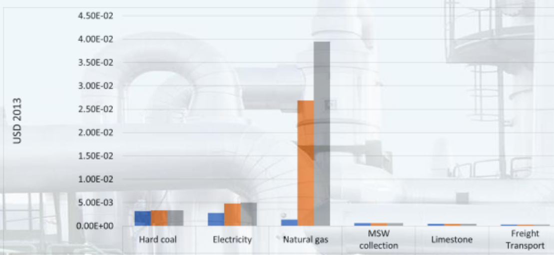
Damage to Human Health, Resources and Ecosystem



	Clinker Process	Freight Transport	Electricity	Hard Coal	Limestone	MSW collection	RDF Prep and transport	Natural Gas
Base Case Assembly	8.75E-07	4.01E-09	1.35E-07	8.25E-08	2.47E-08	8.73E-09	6.70E-09	3.87E-09
SPEI Clinker Assembly	1.66E-07	4.01E-09	2.34E-07	8.25E-08	2.47E-08	8.73E-09	6.70E-09	7.69E-08
3. MEA Clinker Assembly	1.66E-07	4.01E-09	2.41E-07	8.25E-08	2.47E-08	8.73E-09	6.70E-09	1.13E-07



	Clinker Process	Limestone	Electricity	Hard coal	MSW collection	RDF Prep and transport	Freight Transport	Natural gas
Base Case Assembly	2.61E-09	3.57E-11	2.76E-10	1.44E-10	2.06E-11	2.02E-11	1.02E-11	9.22E-12
SPEI Clinker Assembly	4.74E-10	3.57E-11	4.77E-10	1.51E-10	2.06E-11	2.02E-11	1.02E-11	1.84E-10
3. MEA Clinker Assembly	4.86E-10	3.57E-11	4.92E-10	1.51E-10	2.06E-11	2.02E-11	1.02E-11	2.70E-10



	Hard coal	Electricity	Natural gas	MSW collection	Limestone	Freight Transport
1. Base Case Assembly	3.20E-03	2.79E-03	1.35E-03	6.09E-04	4.68E-04	2.76E-04
2. SPEI Clinker Assembly	3.35E-03	4.83E-03	2.68E-02	6.09E-04	4.69E-04	2.76E-04
3. MEA Clinker Assembly	3.35E-03	4.98E-03	3.95E-02	6.09E-04	4.69E-04	2.76E-04

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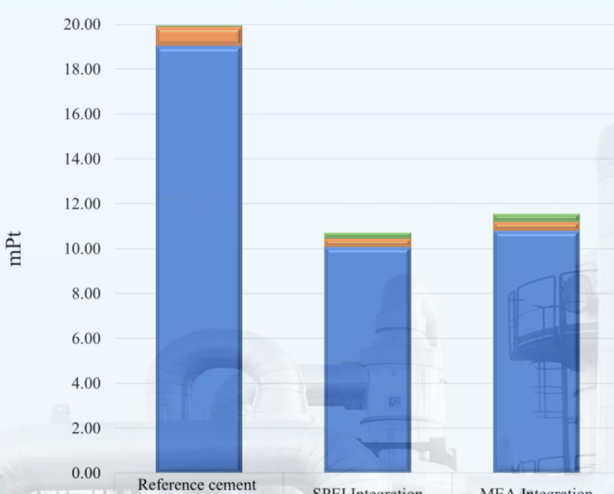
Endpoint Results

Single Score



	Reference cement plant	SPEI Integration	MEA Integration
Resources	0.06	0.26	0.35
Ecosystems	0.85	0.37	0.40
Human health	19.02	10.07	10.79

These results have been normalised with reference to the average persons annual scores, weighted, and summed.

They have the lowest accuracy but they are the easiest to understand.

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Conclusion

- The SPEI-based carbon capture process integration surpasses the MEA-based integration in all impact categories, showcasing better environmental performance.
- The MEA-based integration exhibits a 7% higher score in the global warming indicator due to increased energy requirements for sorbent regeneration, resulting in greater emissions during energy generation.
- Fossil fuel scarcity indicator shows a nearly 21% higher score for the MEA-based integration, primarily attributed to increased utilization of electricity and natural gas in the capture process operation.
- The MEA-based carbon capture process scores 7%, 8%, and 26% higher in human health, ecosystem, and resource indicators respectively.
- These results strongly support the superiority of the SPEI-based integration in terms of sustainability and efficiency for carbon capture processes.

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