Study of the CO_2 Pipeline Network Planned in the Humber Region of the UK:

Simulation-based Techno-economic Evaluation for Optimal Design

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OUTLINE

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Pipeline scheme in the Humber region

(National Grid, 2013)

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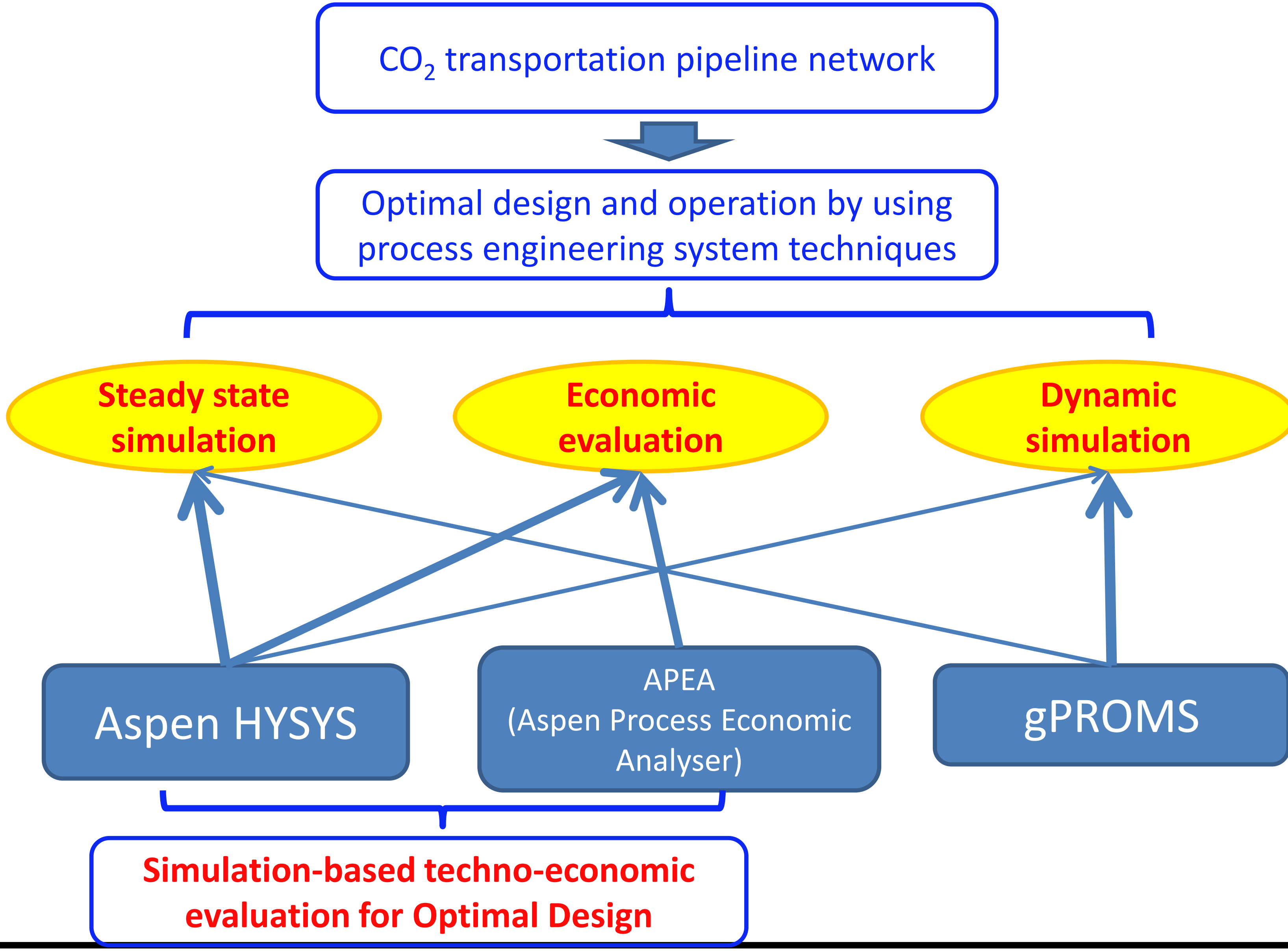
Work Package Overview



Methodology-model development

Equation of state (EOS) selection

❑ An entry specification was agreed to be 96 mole% CO_2 and a mixture of nitrogen, oxygen, hydrogen, argon and methane with hydrogen limited to 2.0 mole% and oxygen limited to 10 ppmv.

❑ EOS selection in the literature

- Span and Wanger (for pure CO_2)
- GERG (for CO_2 and impurities)
- Peng-Robinson (for CO_2 and impurities)
- SAFT (for CO_2 and impurities)

Table 1. EOS used in published studies

Papers/studies	EOS used
Hein et al. 1985	Soave-Redlich-Kwong (SRK) equation
Hein et al. 1986	Peng-Robinson (PR) equation for CO_2 mixture
Zhang et al. 2006	Peng-Robinson (PR) equation with Boston -Mathias modification for CO_2 mixture
Seevam et al. 2008	Peng-Robinson (PR) equation
Mahgerefteh et al. 2008	Peng-Robinson (PR) equation
E.ON's report , 2010	Span and Wagner EOS for pure CO_2
Nimtz et al. 2010	Span and Wagner EOS for pure CO_2
Munkejord et al. 2010	Soave-Redlich-Kwong EOS
Liljemark et al.2011	Span and Wagner EOS for pure CO_2 and GERG-2004 for the CO_2 mixtures
Klinkby et al. 2011	Span and Wagner EOS for pure CO_2
Chaczykowski et al. 2012	GERG-2004 for CO_2 mixture

Methodology-model development

Peng-Robinson with calibrated binary interaction parameters

AAD% between experimental data and PR EOS for corresponding kij values

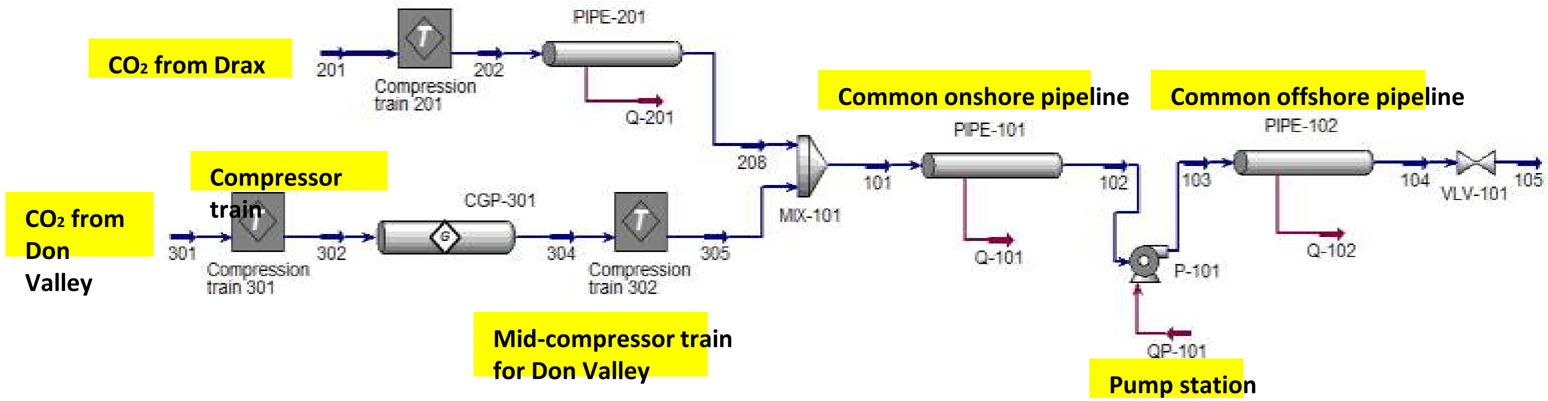
	k_{ij}	Bubble pressure Temperature (K)	Pressure (Mpa)	AAD%	Liquid volume Temperature (K)	Pressure (Mpa)	AAD%	Reference
CO_2 - N_2	-0.007	220-301	1.4-16.7	3.73	209-320	1.4-16.7	1.54	Diamantonis et al. (2013) Li & Yan (2009)
CO_2 - Ar	0.141	288	7.5-9.8	2.32	288	2.4-14.5	1.83	Diamantonis et al. (2013)
CO_2 – H_2	0.1470	290.2	5.0-20.0	5.6%	-	-	-	Foster et al.

E.ON's report (2010) show PR EOS is not very accurate in the near-critical region. In this T/P range(4°C - 20°C/ 101 bar - 150 bar) in this study, the deviation of pure CO_2 density is from -4.8% to 0.1% in E.ON's report.

Temperature (°C)	Pressure (bara) 1.01	30	40	50	60	70	74	80	100	150
-20	2.13	1033.23	1039.74	1045.94	1051.86	1057.52	1059.72	1062.95	1073.18	1095.80
	0.0%	-0.3%	-0.1%	0.1%	0.3%	0.5%	0.5%	0.6%	0.9%	1.5%
0	1.97	77.88	900.04	913.17	925.04	935.90	940.01	945.93		
	0.0%	0.7%	-3.4%	-2.9%	-2.4%	-2.0%	-1.9%	-1.7%		
10	1.90	71.85	109.66	817.39	837.78	855.16	861.48	870.40		
	0.0%	1.2%	1.2%	-5.9%	-5.0%	-4.2%	-4.0%	-3.6%		
20	1.83	67.04	99.14	143.12	706.08	744.71	756.86	772.92		
	0.0%	1.3%	1.7%	1.8%	-9.8%	-7.9%	-7.3%	-6.6%		
30	1.77	63.06	91.37	126.69	175.43	269.79	551.08	617.82	709.99	814.08
	0.0%	1.4%	1.8%	2.2%	2.3%	1.2%	-14.9%	-12.0%	-8.0%	-3.9%
31	1.77	62.70	90.69	125.39	172.54	256.52	470.36	593.02	697.49	806.61
	0.0%	1.4%	1.8%	2.2%	2.4%	1.7%	-16.9%	-12.8%	-8.3%	-4.1%
32	1.76	62.34	90.03	124.14	169.84	246.44	316.46	563.51	684.50	799.04
	0.0%	1.4%	1.8%	2.2%	2.4%	2.0%	0.5%	-13.6%	-8.7%	-4.3%
33	1.76	61.99	89.38	122.93	167.31	238.23	291.96	526.03	670.96	791.37
	0.0%	1.4%	1.8%	2.2%	2.4%	2.1%	1.3%	-14.3%	-9.1%	-4.4%
35	1.74	61.30	88.13	120.63	162.65	225.23	264.77	400.25	642.07	775.75
	0.0%	1.4%	1.8%	2.2%	2.4%	2.3%	1.9%	-4.5%	-9.9%	-4.8%
40	1.72	59.67	85.22	115.45	152.87	202.94	229.32	282.27	556.57	734.96
	0.0%	1.3%	1.7%	2.1%	2.4%	2.5%	2.3%	1.6%	-11.5%	-5.8%

Methodology-model development

✓Model flow sheet in Aspen HYSYS



✓Model validation by comparing the results of PIPEFLO®

- ❖ no available operating and experimental data
- ❖ PIPEFLO® is used for the concept design of the project
- ❖ GERG-2008 EOSwas used in PIPEFLO® for the project

	Entry pressure at White Rose	Entry pressure at Don Valley	DP of mid-booster for Don Valley	DP of pump station	Arrival pressure
	barg	barg	bar	bar	barg
Aspen HYSYS®	119.50	34.0	86.92	43.0	125.0
PIPEFLO®	119.20	34.0	86.70	42.4	125.0
Relative difference	0.25%	-	0.25%	1.40%	-

Methodology-economic evaluation

Economic evaluation using APEA

❑Aspen Process Economic Analyzer (APEA)

❑CAPEX

- total capital investment cost

(capital return factor is 0.15 for annualized capital cost)

- ❖ Equipments purchase
- ❖ Engineering
- ❖ Construction
- ❖ others during project implement

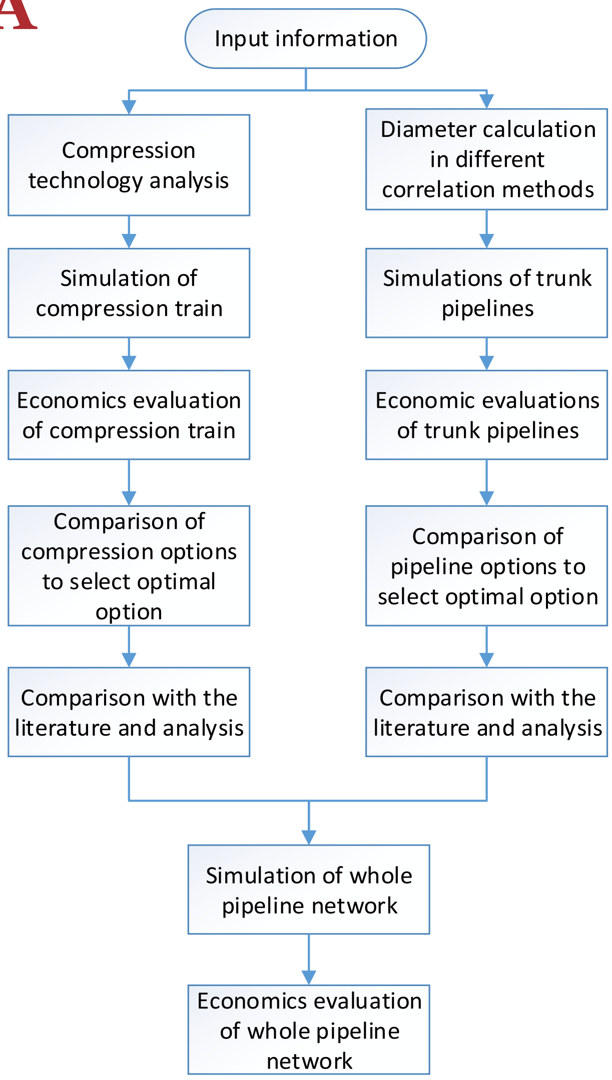
❑OPEX

•Fixed OPEX

❖O&M cost (per year)

•Available OPEX

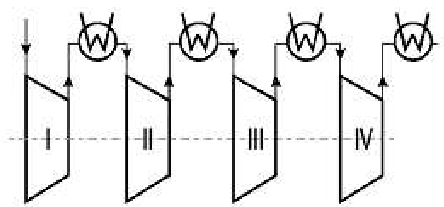
❖Energy and utilities cost (per year)



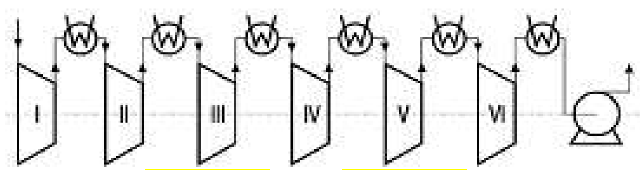
Evaluation of CO_2 compression

Compression technology options and their process definition

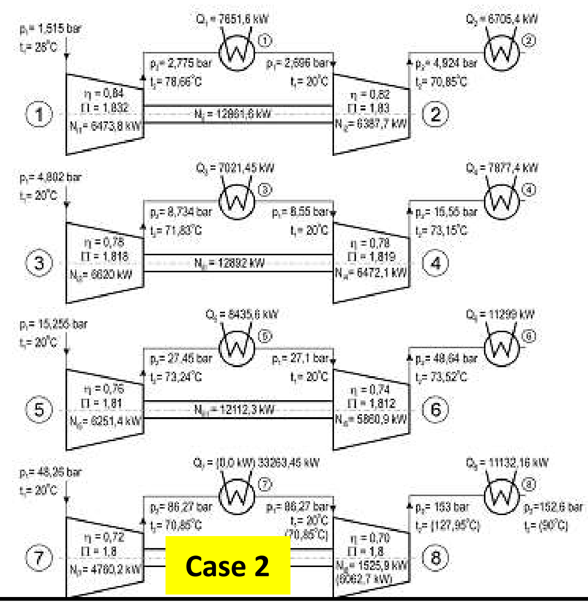
Option	Unit	Base Case	C1	C2	C3	C4
Description		Centrifugal 5 stage with 4 intercoolers	Centrifugal 16 stage 4 intercoolers	8 stage centrifugal geared with 7 intercoolers	6 stage integrally geared with 5 intercoolers to 20 °C +pumping	6 stage integrally geared with 5 intercoolers to 38 °C +pumping
Capacity	t/h	245	245	245	245	245
Suction pressure	MPa	0.101325	0.101325	0.101325	0.101325	0.101325
Suction temp.	°C	20	20	20	20	20
Pumping suck pressure	MPa	-	-	-	8.0	8.0
Pumping suck temp.	°C	-	-	-	20	20
Exit pressure	MPa	13.5	13.5	13.5	13.5	13.5
Stage	-	5	16	8	6	6
Isentropic efficiency	%	75	75	75	75	75
Interstage cooler exit temperature	°C	20	38	38	20	38
Last stage exit temp.	°C	20	20	20	20	20



Base case Case 1



Case 3 Case 4



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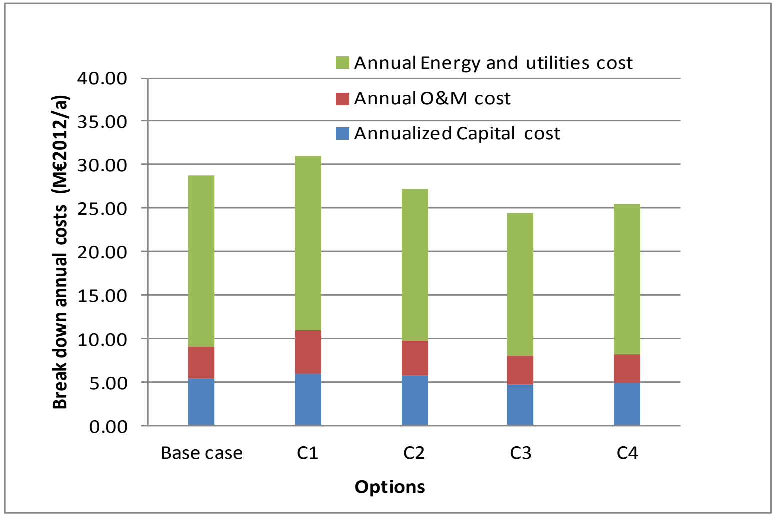
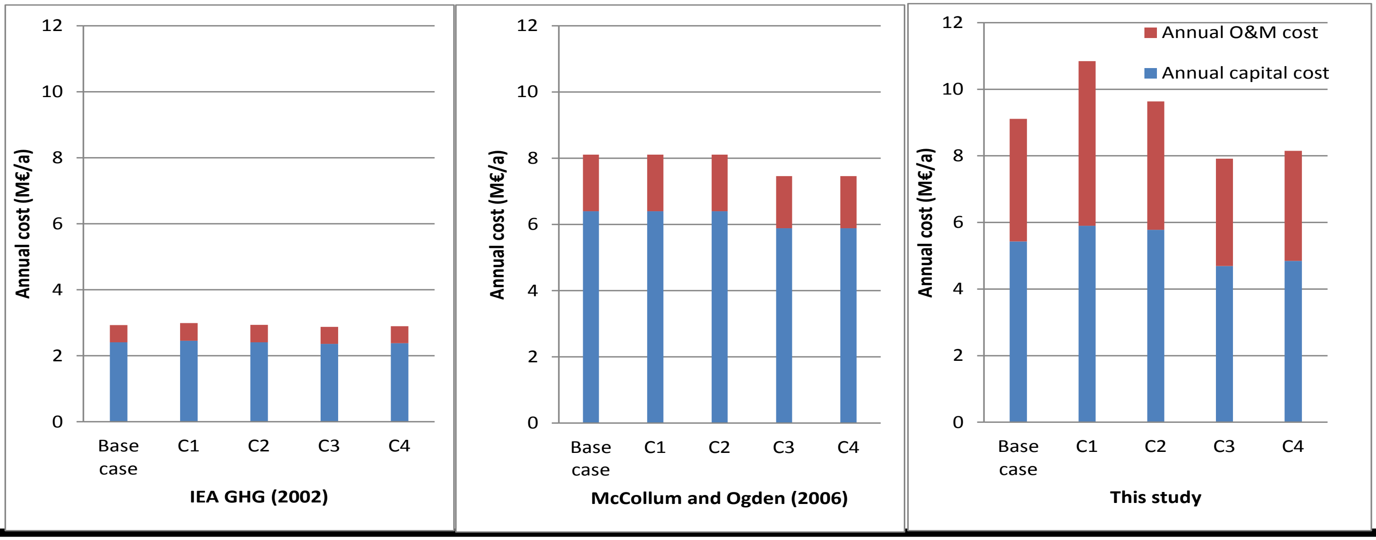
Evaluation of CO_2 compression

Comparison of annual costs of different compression options

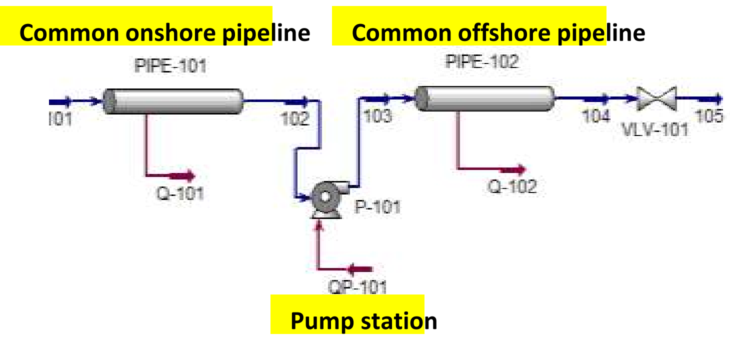


The comparison of levelized cost of different cost model in the literature



Evaluation of trunk pipelines

✓The calculation results of different diameter calculation methods in literature



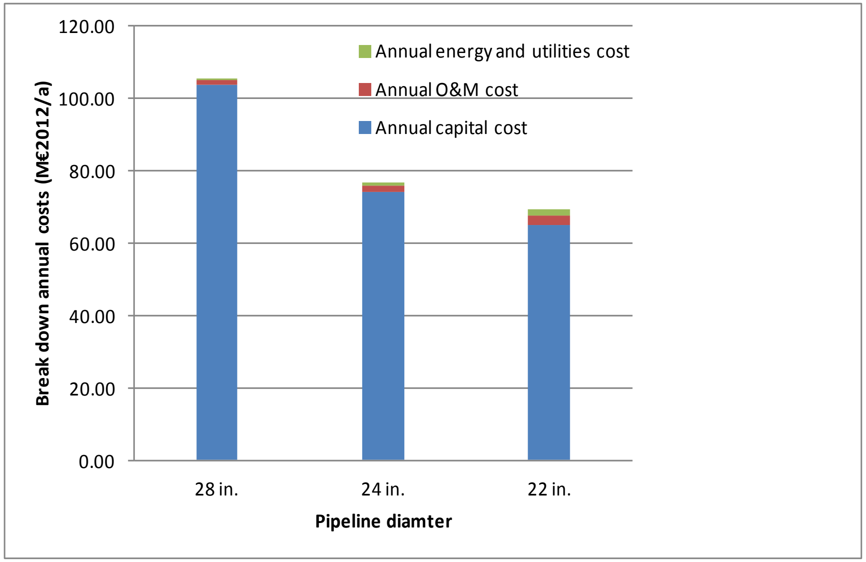
Diameter calculation method Unit	Calculated diameter (m)	Velocity (m/s)	Selected diameter in APEA DN (inch)
Velocity based equation	0.699	1.0	28
	0.5713	1.5	24
	0.4948	2	20
Hydraulic equation	0.5262	1.77	22
Extensive hydraulic equation	0.6173	1.29	24
McCoy and Rubin model	0.5672	1.52	22

✓Hydraulic performance and energy requirement of trunk pipelines in different diameters

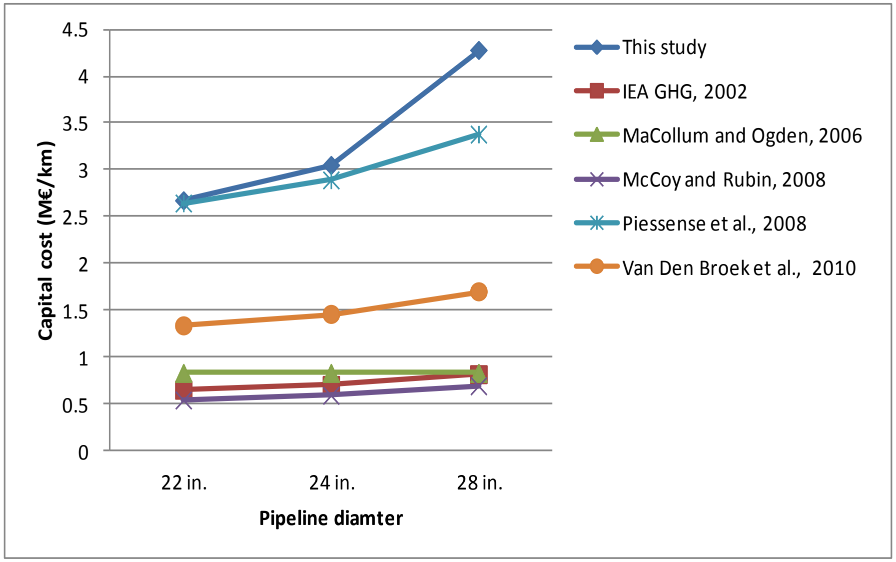
Pipeline diameter (inch)	Actual initial velocity (m/s)	Pressure drop of onshore pipeline (bar)	Pressure drop of offshore pipeline (bar)	Boosting pressure of pump station (bar)	Energy required of pump station (kWh)
28	1.08	5.9	10.0	5.9	301.5
24	1.49	13.5	20.6	24.1	1243
22	1.81	22.1	32.2	44.3	2305

Evaluation of trunk pipelines

Annual cost comparison for different diameters of the pipelines

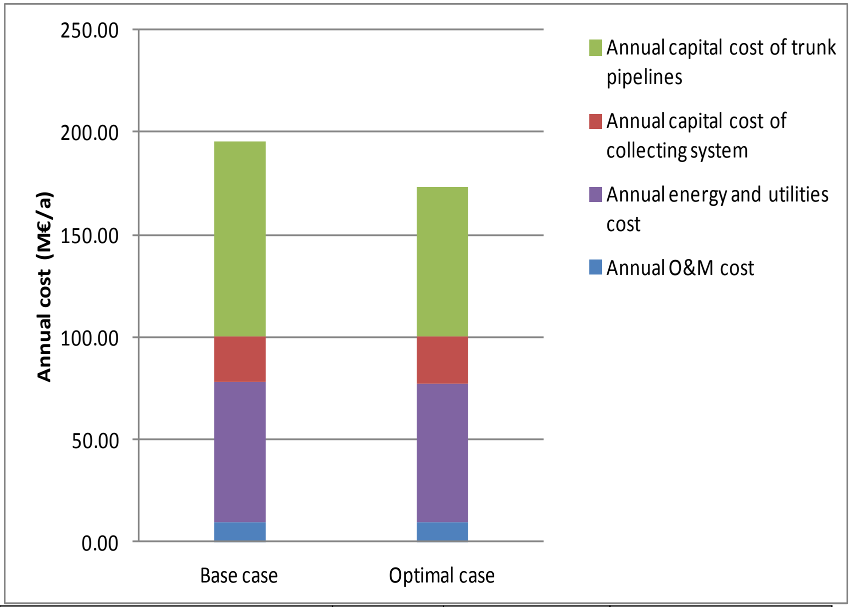


Comparison of capital cost of different cost models in the literature



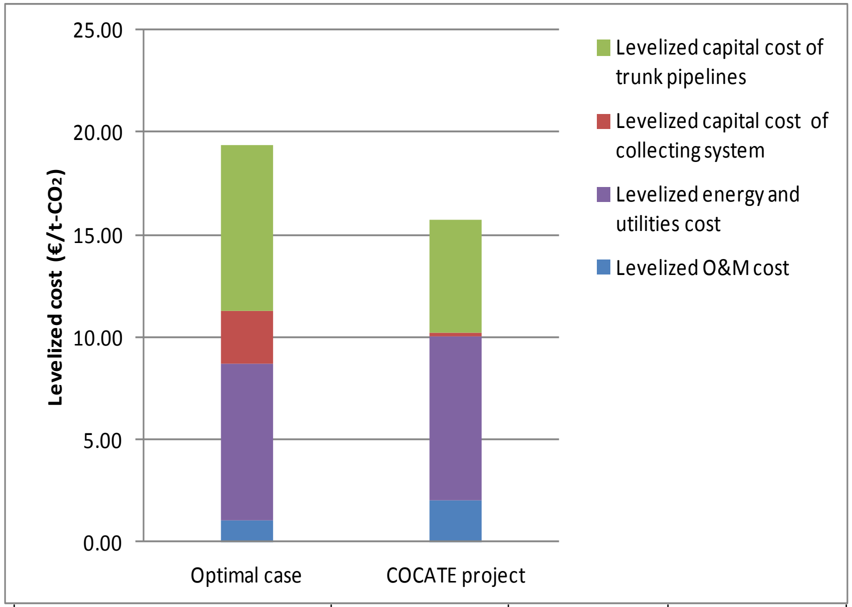
Overall cost of whole pipeline network

Comparison of annual costs of base case and optimal case



		Base case	Optimal case
Annual energy and utilities cost	M€/a	68.7	68.0
Annual CAPEX of the trunk pipeline	M€/a	69.4	53.6
Annual CAPEX of collecting system	M€/a	45.2	39.5
Annual O&M cost	M€/a	9.2	9.2
Annual total cost	M€/a	192.5	170.3

Comparison of levelized cost of the optimal case and COCATE project (Roussanaly et al., 2013)



		Optimal case	COCATE project
Levelized energy and utilities cost	€/t-CO2	7.6	8
Levelized CAPEX of the trunk pipeline	€/t-CO2	6.0	5.5
Levelized CAPEX of collecting system	€/t-CO2	4.4	0.2
Levelized O&M cost	€/t-CO2	1.0	2
Levelized total cost	€/t-CO2	19.1	15.7

✓key findings

- ✓ For CO_2 compression, lower intercooler exit temperature (20 °C vs 38°C in this study) contributes lower both energy cost and capital cost.
- ✓ The O&M cost of CO_2 compression is found to be low in other published models.
- ✓ The pipeline diameter models in literature are generally reliable. With optimal diameter of pipelines, the initial velocity of CO_2 mixture in dense phase is about 1.7m/s in this study.
- ✓ The cost range of the pipelines are large for different models. The weight based model (Piessense et al. 2008) has the prediction close to this study.
- ✓ Simulation-based techno-economics evaluation method offers a powerful tool for optimal designs for the projects, especially for the decision making support about the detailed technical options selection.

✓Reference Lists

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NATURAL ENVIRONMENT RESEARCH COUNCIL

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Related publications:

Luo, X., Mistry, K., Okezue, C., Wang, M., Cooper, R., Oko, E., Field, J. (2014), Process simulation and analysis for CO2 transport pipeline design and operation – case study for the Humber Region in the UK, European symposium on computer-aided process engineering (ESCAPE24), Budapest, Hungary.   Published in Computer Aided Chemical Engineering, Vol. 33, p1633-1639

Luo X, Wang M, Oko E, Okezue C. Simulation-based techno-economic evaluation for optimal design of CO_2 transport pipeline network. Applied Energy 2014;132(0):610-620

Thanks

Thank you for you attention!

Questions are welcome.

Contact us if you are interested in our works.

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