Industry, clustering & transport

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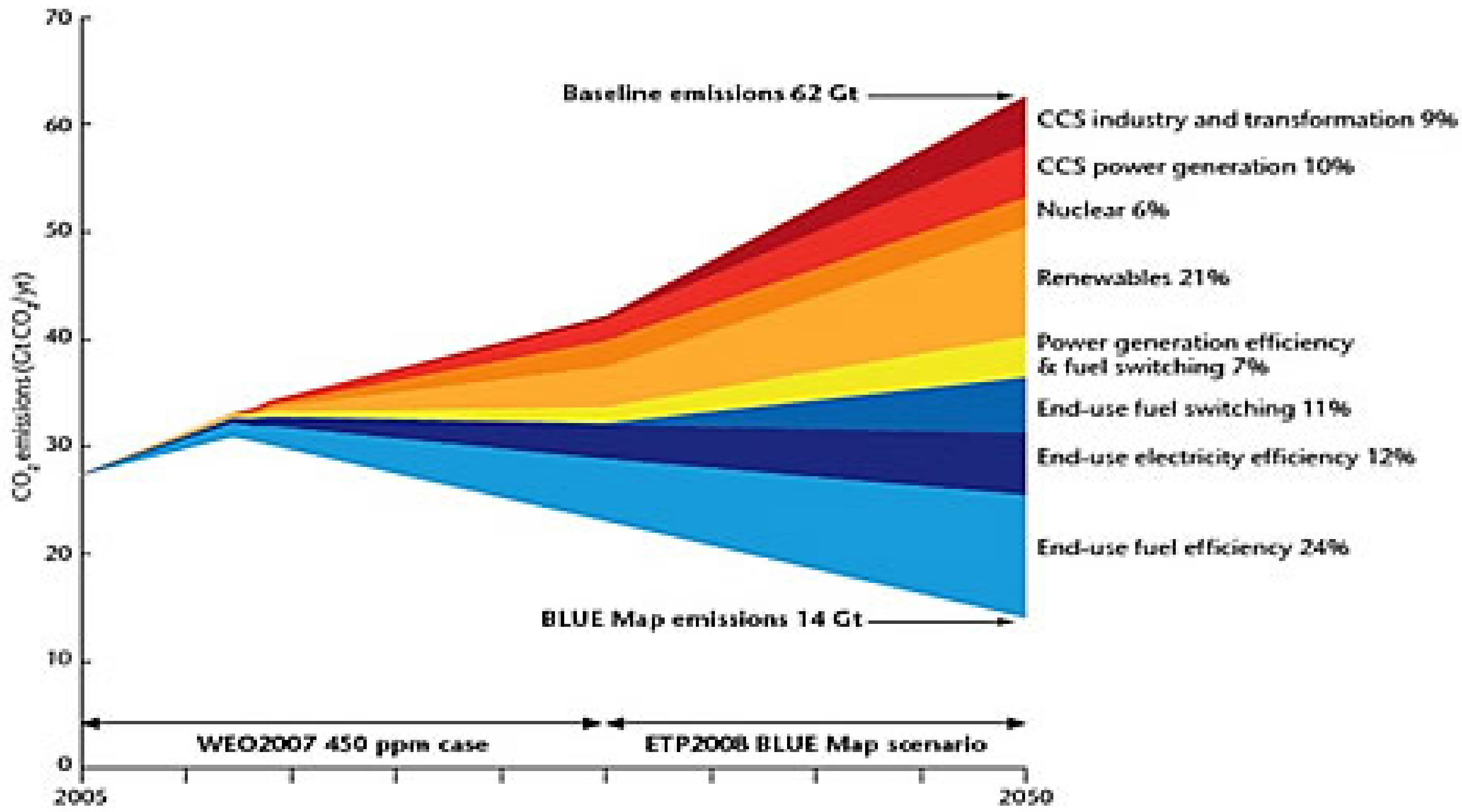
IEA "blue map" scenario



Main topics

- CO_2 capture from industrial plants
- Pipelines for transportation
- Clusters & networks
- Case study

Industrial CO_2 capture – some considerations

- Generally similar to retrofitting post-combustion capture technology on a power station
- CO_2 concentration in flue gases is generally low, requiring large absorbers and high rates of solvent regeneration
- But some processes produce a concentrated CO_2 stream eg steam methane reforming to hydrogen, ethylene oxide production, cement production, ammonia production, fermentation
- Effect of other impurities in the flue gases

Industrial CO_2 capture – some considerations (2)

- Availability of space for Carbon Capture equipment
- Availability of additional cooling water
- Access to LP steam for solvent regeneration
- Electrical power demands for CO_2 compression
- Pipeline route & wayleaves

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CO_2 pipelines – some metrics

- 3600 miles of CO_2 pipelines built over 40 years in the US
- 320 km pipeline from North Dakota to Weyburn, Canada, carrying 2.8 Mte/year
- In-Salah, Algeria: pipeline carrying 1.2 Mte/year
- 240 km pipeline under development in Alberta, Canada, with planned capacity of 14.6 Mte/year

Current *vs.* future pipelines

	Current Pipelines	The Next Generation
Location	Mostly in the USA - onshore	Worldwide, both onshore & offshore
Purpose	Enhanced Oil Recovery	Mainly climate change with possible EOR
Sources	Naturally occurring CO_2 underground	Mostly fossil fuel derived
Quality	High purity. EOR Requirements.	Impurities dependent on capture technology
Economics	High Return on Investment (ROI)	Longer time for ROI
Design	Conservative: justified by economics	Needs to be optimised with consideration of impurities present
Regulation & Standards	Regulated and designed using liquid specifications (49CFR195 & ASMEB3.4)	Design codes require modification.
Routing	Currently through mostly unpopulated areas	May need to go through densely populated areas
Safety	Conservative design	May require further work for design optimisation and impurities

Effect of Impurities

Impurities in the CO_2 stream from the capture process can:

- Change the phase diagram and the location of the critical point
- Affect the solubility of water in the fluid
- Affect the hydraulic characteristics (density, compressibility) of the fluid
- Affect the corrosion rate in a wet CO_2 environment
- Affect the susceptibility to stress corrosion cracking
- Affect the decompression characteristics following a pipeline failure

Propagating Fractures

Propagating brittle fracture

- Risk of long running brittle fracture due to cooling effects around leaks

Propagating ductile fracture

- In-service ductile fractures have propagated up to 300m in natural gas pipelines
- Need to understand the nature the decompression process & fracture velocity
- Decompression dependent on gas composition

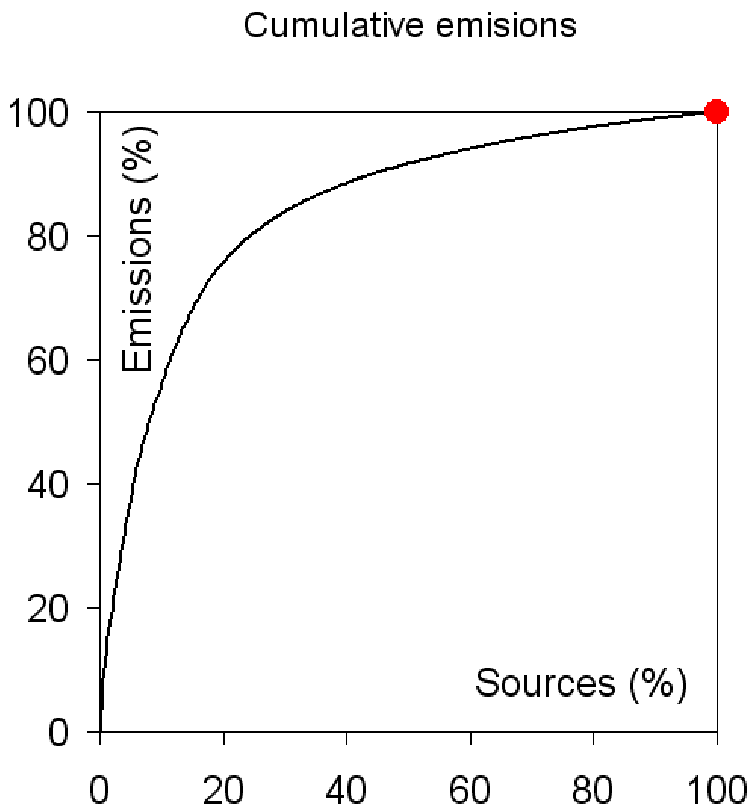
Pipeline design considerations

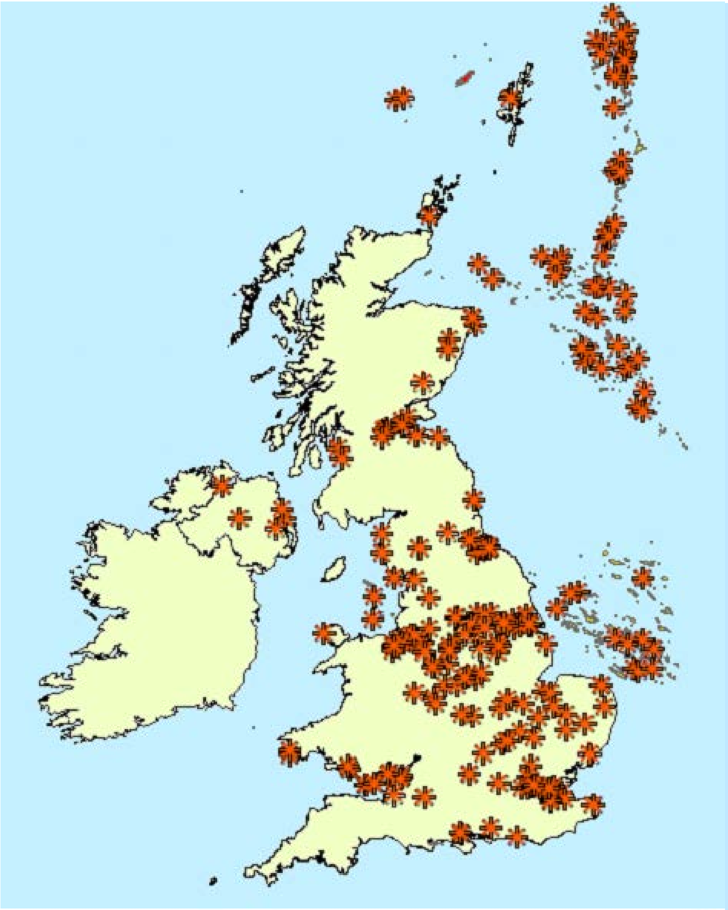
- Likely contaminants?
- Carbon steel pipelines + corrosion inhibitor injection *versus* corrosion-resistant alloys
- Materials selection for equipment & valves
- Supercritical or dense-phase? (affects pipe diameter, pumps *vs*. compressors etc)
- Avoiding 2-phase flow
- Hydrate formation (remove water?)
- Likely future safety regulations (main risk to people is asphyxiation)

Special Design Considerations

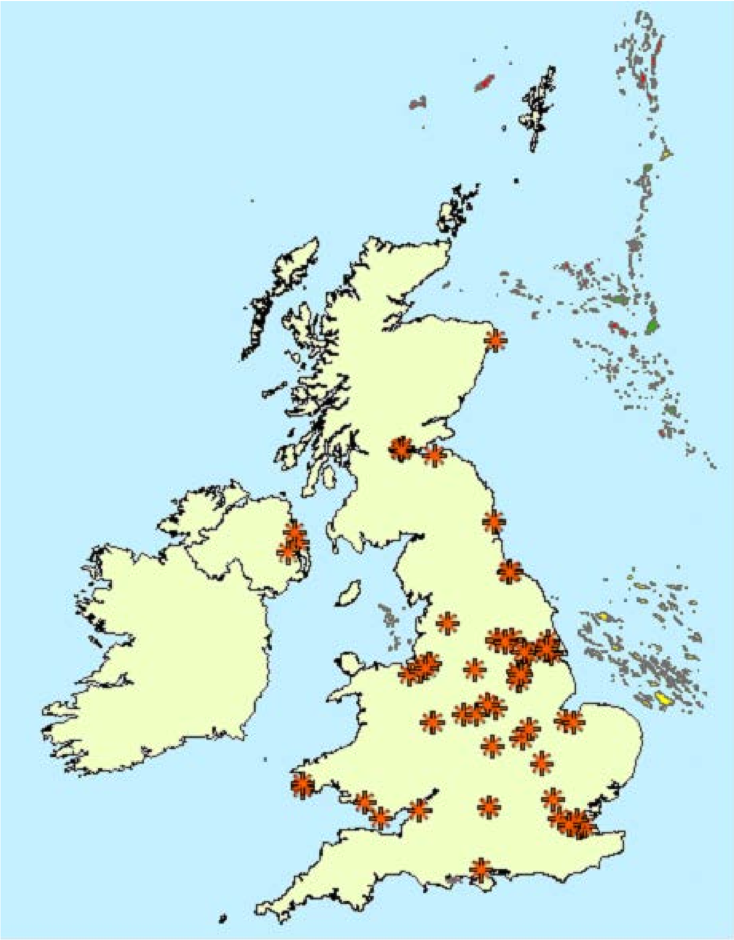
- Hydraulic modelling
  - Specifying a CO_2 composition for pipeline transport
  - Determining pipeline capacity
  - Modelling pressure and temperature drops along a pipeline
- Fracture control
  - Determining decompression properties of CO_2
  - Determining appropriate toughness requirements
- Mitigation of corrosion
  - Specifying appropriate materials or water contents to avoid corrosion and hydrate formation
- Mitigation of stress corrosion cracking
  - Specifying appropriate impurity levels to avoid stress corrosion cracking
- Safety and risk assessment criteria
  - Dispersion analysis and determining appropriate risk profiles
  - Specification of block valve distances

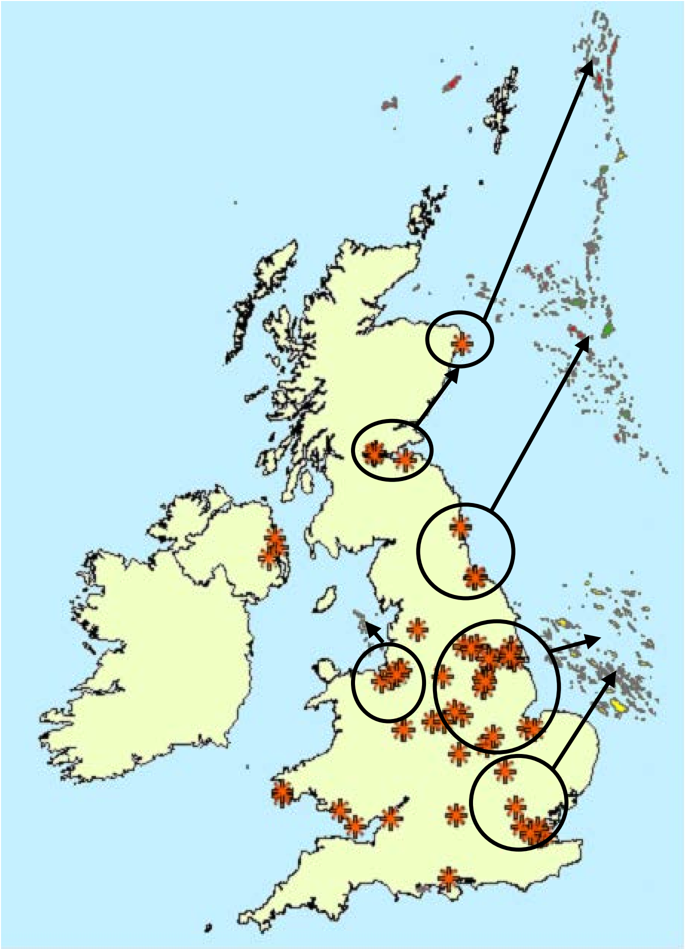
Networks & clusters





Source: BGS Database http://www.bgs.ac.uk/co2/ukco2.html





Source: BGS Database http://www.bgs.ac.uk/co2/ukco2.html

Possible plans for Yorkshire & Humber

Source: Yorkshire Forward - A carbon capture and storage network for Yorkshire and Humber.

- Annual CO_2 emissions: 90 Mte/year
- 90% is from 12 point sources

www.yorkshire-forward.com/media-centre/documents/10760

Some industrial CCS cluster studies

	Dimensions
Yorkshire/Humber	90 Mte/year of CO_2
Scotland	20 Mte/year of CO_2
NE England	27 Mte/year of CO_2
Portugal	27 point sources
Italy	8 Mte/year; 3 storage sites
California	50 Mte/year of CO_2; 37 point sources; 14 potential storage sites

Network design considerations

- Entry specifications for CO_2 on multi-user systems
- Route selection – who to include?
- Need for compulsory purchase orders (power of eminent domain)
- Rights of access to pipeline and a "fair" charging mechanism

Approaches to optimising network growth

- Time-based: often based on MARKAL models, future targets on a timeline, future policy drivers and comparative data for other ways of reducing CO_2 emissions

- Spatially-based: modelling geographic differences in construction cost, locations of point sources and storage sites

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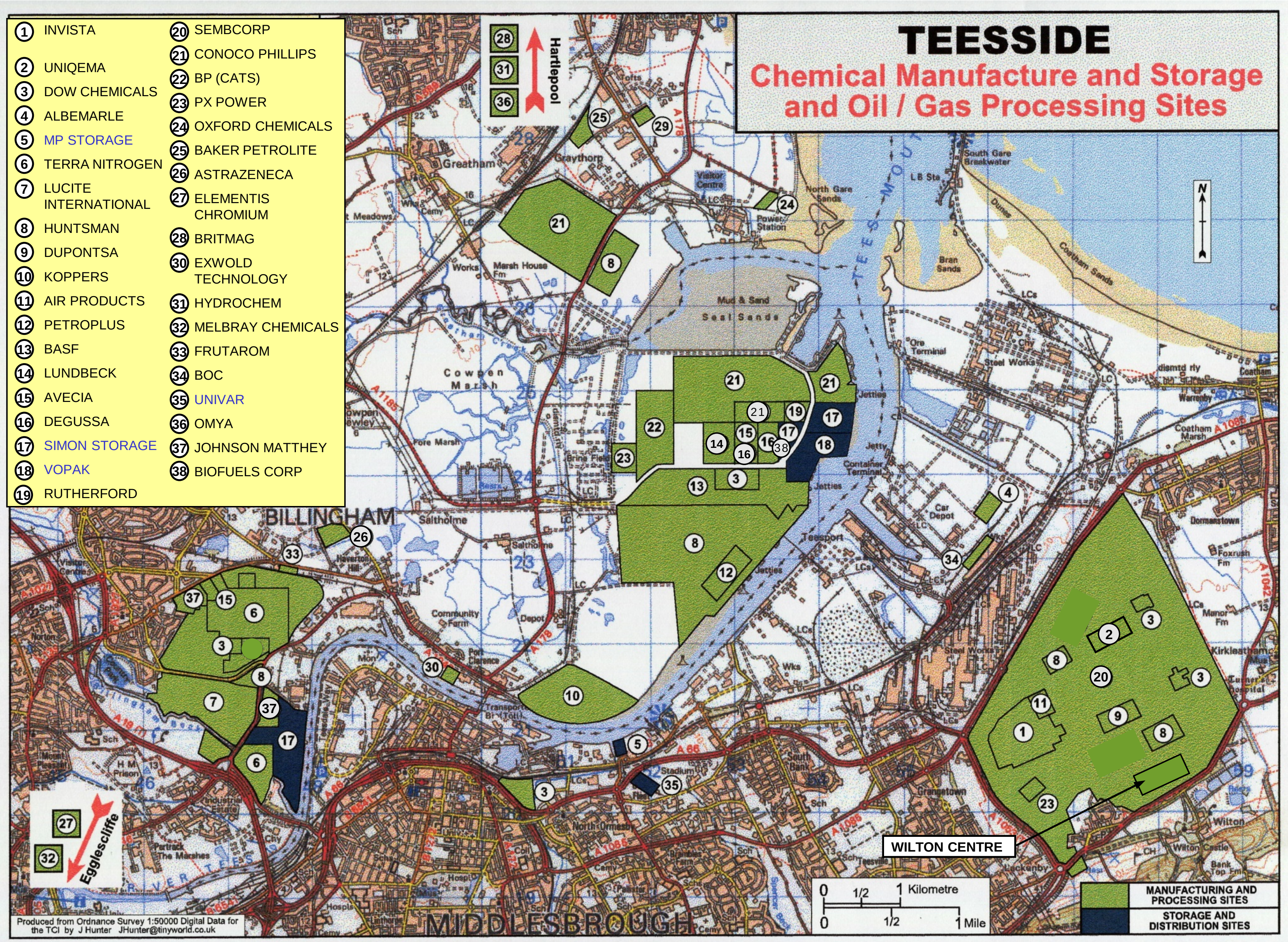
Case study: Northeast England


TEESSIDE
Chemical Manufacture and Storage and Oil / Gas Processing Sites
1 INVISTA
2 UNIQEMA
3 DOW CHEMICALS
4 ALBEMARLE
5 MP STORAGE
6 TERRA NITROGEN
7 LUCITE INTERNATIONAL
8 HUNTSMAN
9 DUPONTSA
10 KOPPERS
11 AIR PRODUCTS
12 PETROPLUS
13 BASF
14 LUNDBECK
15 AVECIA
16 DEGUSSA
17 SIMON STORAGE
18 VOPAK
19 RUTHERFORD
20 SEMBCORP
21 CONOCO PHILLIPS
22 BP (CATS)
23 PX POWER
24 OXFORD CHEMICALS
25 BAKER PETROLITE
26 ASTRAZENECA
27 ELEMENTIS CHROMIUM
28 BRITMAG
30 EXWOLD TECHNOLOGY
31 HYDROCHEM
32 MELBRAY CHEMICALS
33 FRUTAROM
34 BOC
35 UNIVAR
36 OMYA
37 JOHNSON MATTHEY
38 BIOFUELS CORP
Hartlepool
Egglescliffe
BILLINGHAM
MIDDLESBROUGH
WILTON CENTRE
N
0 1/2 1 Kilometre
0 1/2 1 Mile
MANUFACTURING AND PROCESSING SITES
STORAGE AND DISTRIBUTION SITES
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Biomass-based plants

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northeast biofuels

Pipeline networks

- Built over last 50 years
- Up to 45 cm diameter
- Carrying: hydrogen, ammonia, LPG, naphtha, petrol, methane, nitrogen, ethylene, propylene, fuel oil, fuel gas, cyclohexane

CO_2 emissions

Installation	CO_2 emissions (Mte/year)	IEA tier
Steelworks	6.95	0
Proposed IGCC plant (850MW)	5.00	0
Existing gas-fired power station (1.9GW)	3.15	0
New gas-fired power station (1GW)	2.89	0
Proposed 300MW biomass power plant	1.20	0
Petrochemicals site utilities supplier	1.43	0
Petrochemicals operator	1.36	0
All 7 tier 0 emitters	21.98	0
19 tier 1 emitters	3.99	1
13 tier 2 emitters	0.23	2
Sum of tier 0, 1 & 2 emissions	26.2	

CO_2 emitters

Layout drawings and cost estimates produced for carbon capture on 6 plants.

Economics of CO_2 capture

	Anchor only	Small	Medium	Large
No. of point sources	1	5	8	35
Annual CO2 captured (Mte CO2/year)	5	14	22	26
Lifetime CO2 avoided (20 years)	83 Mte	262 Mte	377 Mte	434 Mte
Incremental capital cost of capture and compression	£151 m	£1.1 bn	£2.0 bn	£3.1 bn
Incremental operating and energy costs for capture and compression of CO2	£55 m/yr	£187 m/yr	£298 m/yr	£371 m/yr
Mean average £/te CO2 captured	£15	£21	£24	£30
Mean average £/te CO2 abated	£18	£25	£29	£36

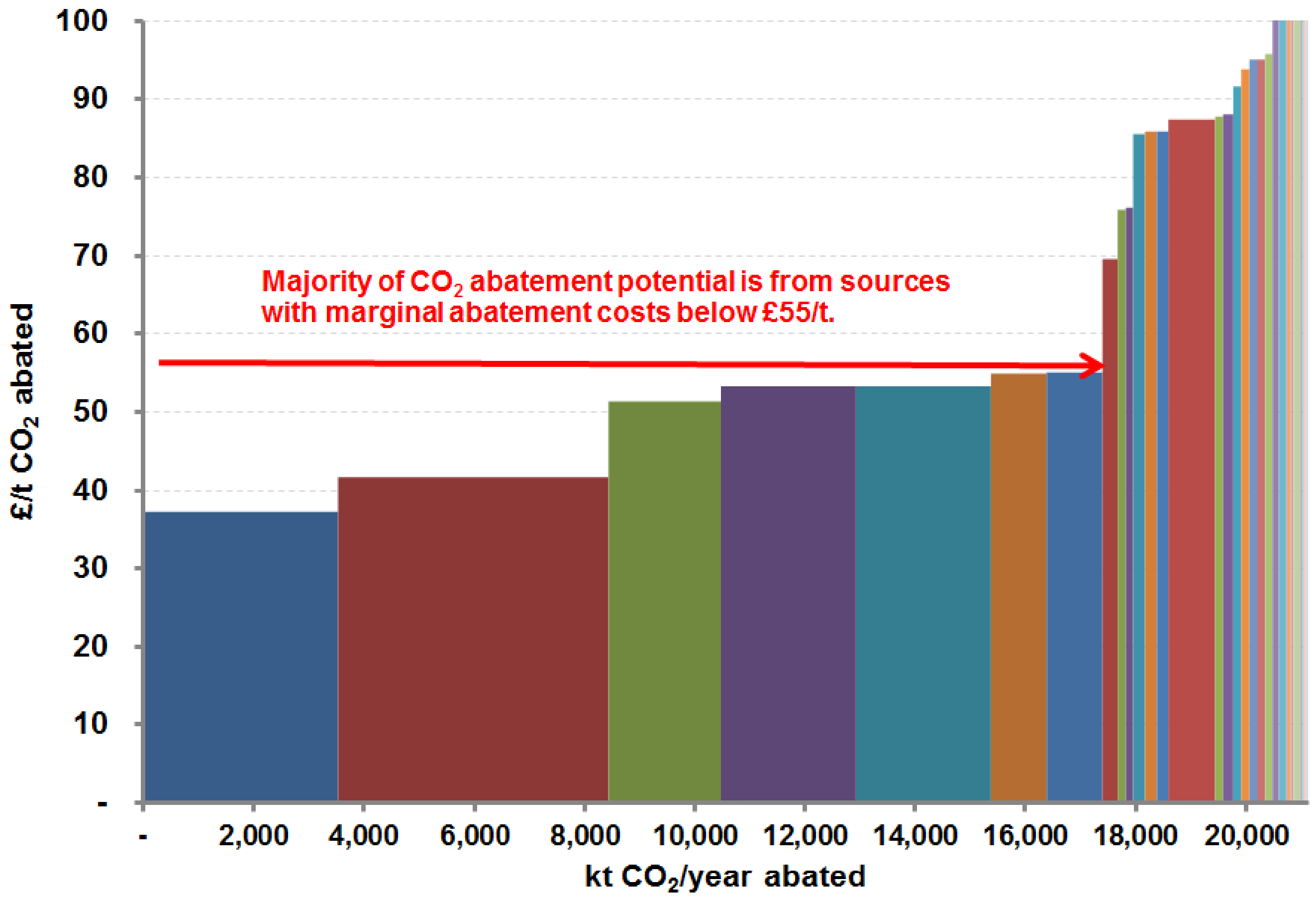
Onshore transport networks

	Anchor-only	Small	Medium	Large
Number of sources	1	5	8	37
Peak capacity (Mt/yr)	5	14	22	26
Onshore pipeline distance	5 km	19 km	22 km	37 km

Cost of pipelines & compression

Network description	**Anchor-only**	**Small**	**Medium**	**Large**
Network physical capacity	5 Mte CO_2/yr	14 Mte CO_2/yr	22 Mte CO_2/yr	26 Mte CO_2/yr
Modelled diameter offshore (for 200 km length)	500 mm (20”)	600 mm (24”)	900 mm (36”)	900 mm (36”)
Capital cost for offshore pipelines	£333 m	£365 m	£485 m	£485 m
Combined capital cost for network (onshore and offshore pipelines and shoreline compression)	£346 m	£425 m	£546 m	£562 m
Additional capital cost for network compared to anchor/demonstration only	£0	£79 m	£201 m	£216 m
Cost of service (assuming users pay equally for access)	£12/te	£7.3/te	£7.4/te	£7.4/te

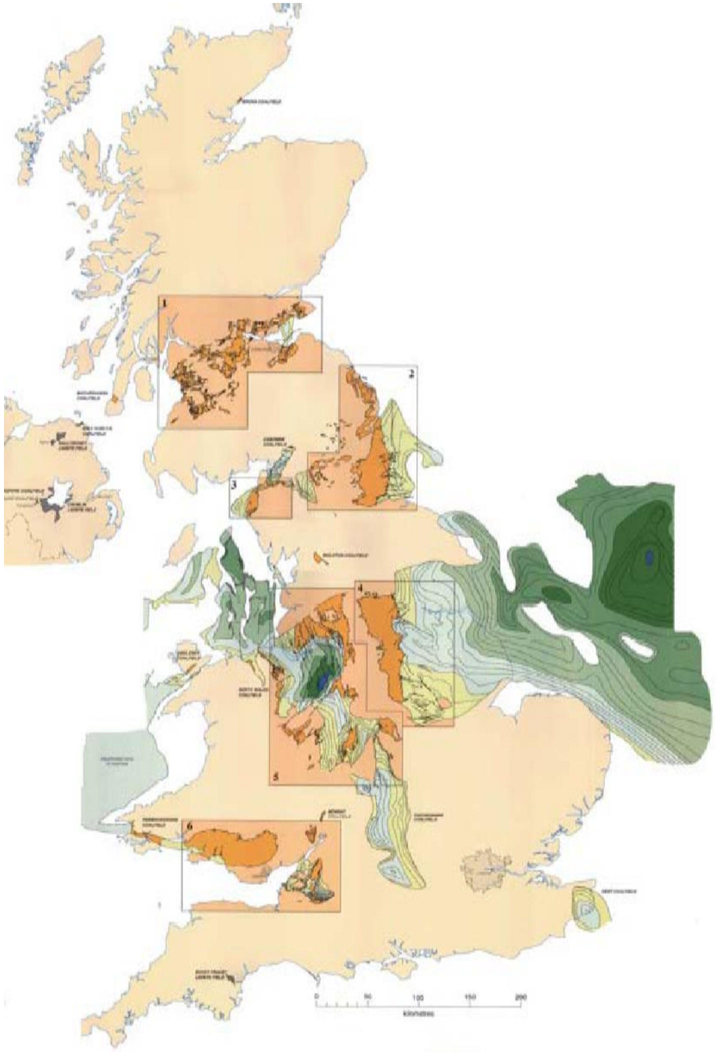
Marginal abatement cost curve

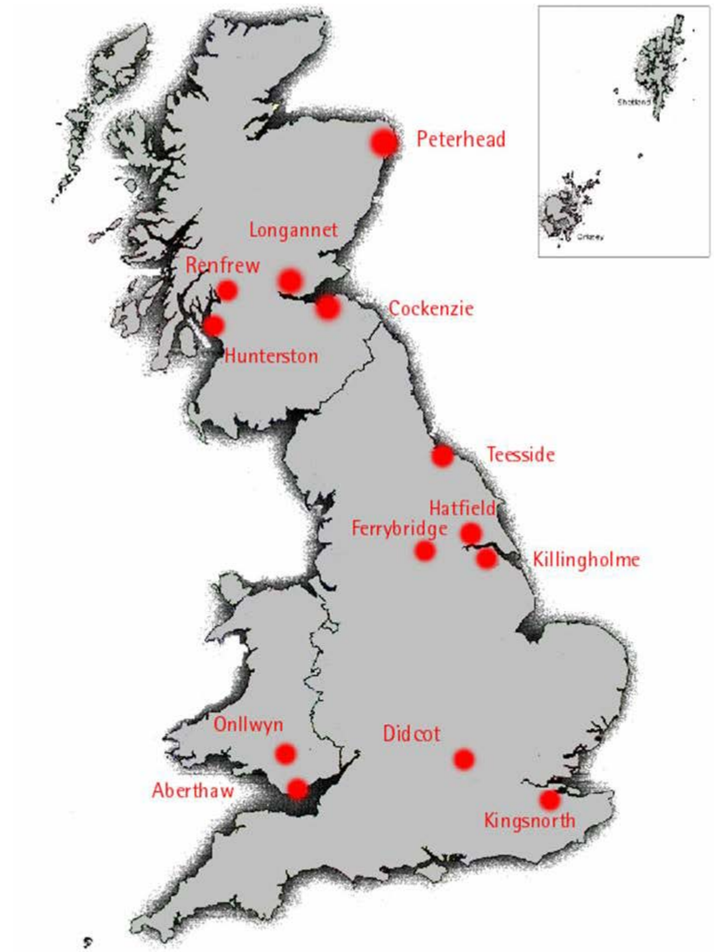


Conclusions from NE England study

- For any estimated future CO_2 emissions cost we can see where CCS is economic
- The first 8 plants fall within the range usually quoted for 2020-2030
- A larger system could be built in anticipation of even higher prices in future – but there is a risk of smaller emitters not connecting
- There is a strong case for a network aimed primarily at the largest 8 emitters.

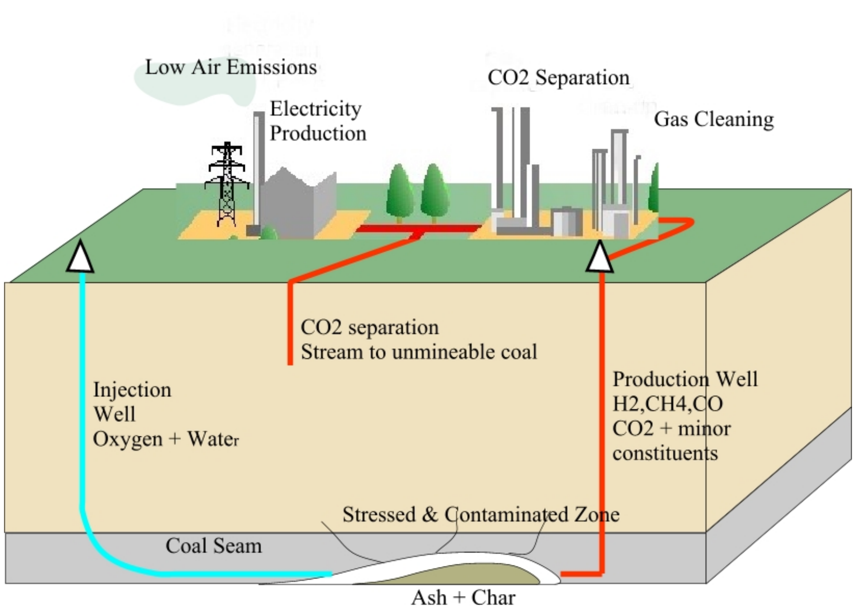
What about UK coal resources?

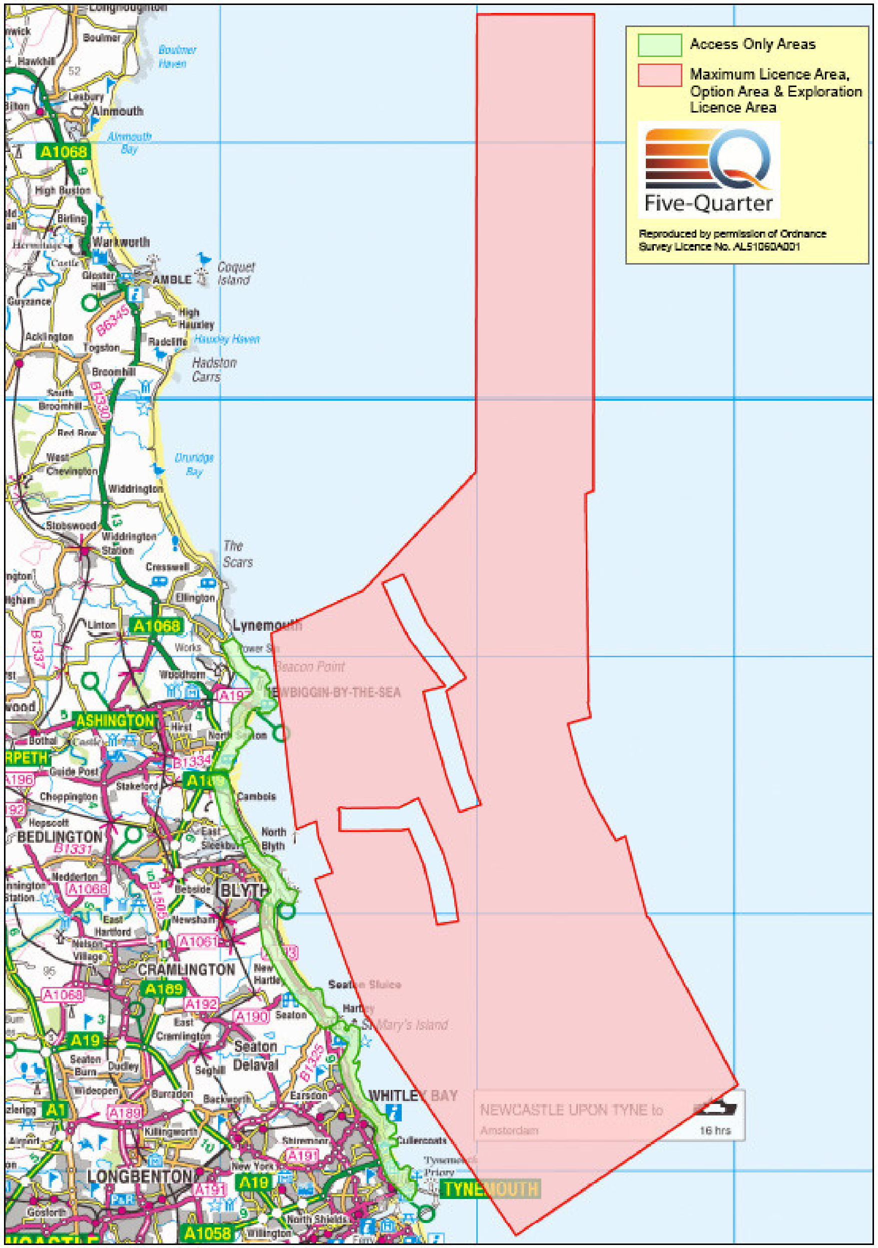




Source; http://www.ccsassociation.org.uk/ccs_projects/uk_projects.html

Expanding the scope





www.ucgassociation.com

www.five-quarter.com

Some international examples (studies)

Location	Features
Germany (NRW)	177 Mte/year from power stations + 50 Mte/year from industry; propose a 1200 km network based on 2 clusters
Italy	Split country in to 5 regions and optimise within each region
Po Valley (northern Italy)	Propose an 8 Mte/year network with 34km (20") + 88 km (12") of pipelines
Portugal	27 Mte/year spread across 27 point sources; propose 3 clusters
US	2 policy scenarios: one requires 11,000 miles of new pipelines and the other 23,000 miles (to include high-purity sources eg refineries)

Pricing considerations

- Who pays for over-sizing of the initial network?
- Fair mechanism for relating charges to throughput?
- Fair mechanism for recovering costs from those who use the system more/less/earlier/later than planned?
- Differentiate between those who operate in international national markets *vs*. national?

Acknowledgments

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To find out more.....

Roddy, DJ, Development of a CO_2 network for industrial emissions, Applied Energy 91 (2012), 459-465, doi:10.1016/j.apenergy.2011.10.016

- dermot.roddy@ncl.ac.uk

- EPSRC MATTRAN project http://research.ncl.ac.uk/mattran/

- On pipeline technology: julia.race@ncl.ac.uk