Squaring the Circle on Coal - Carbon Capture and Storage (CCS)

Claverton Group conference, Bath 24-26 October 2008

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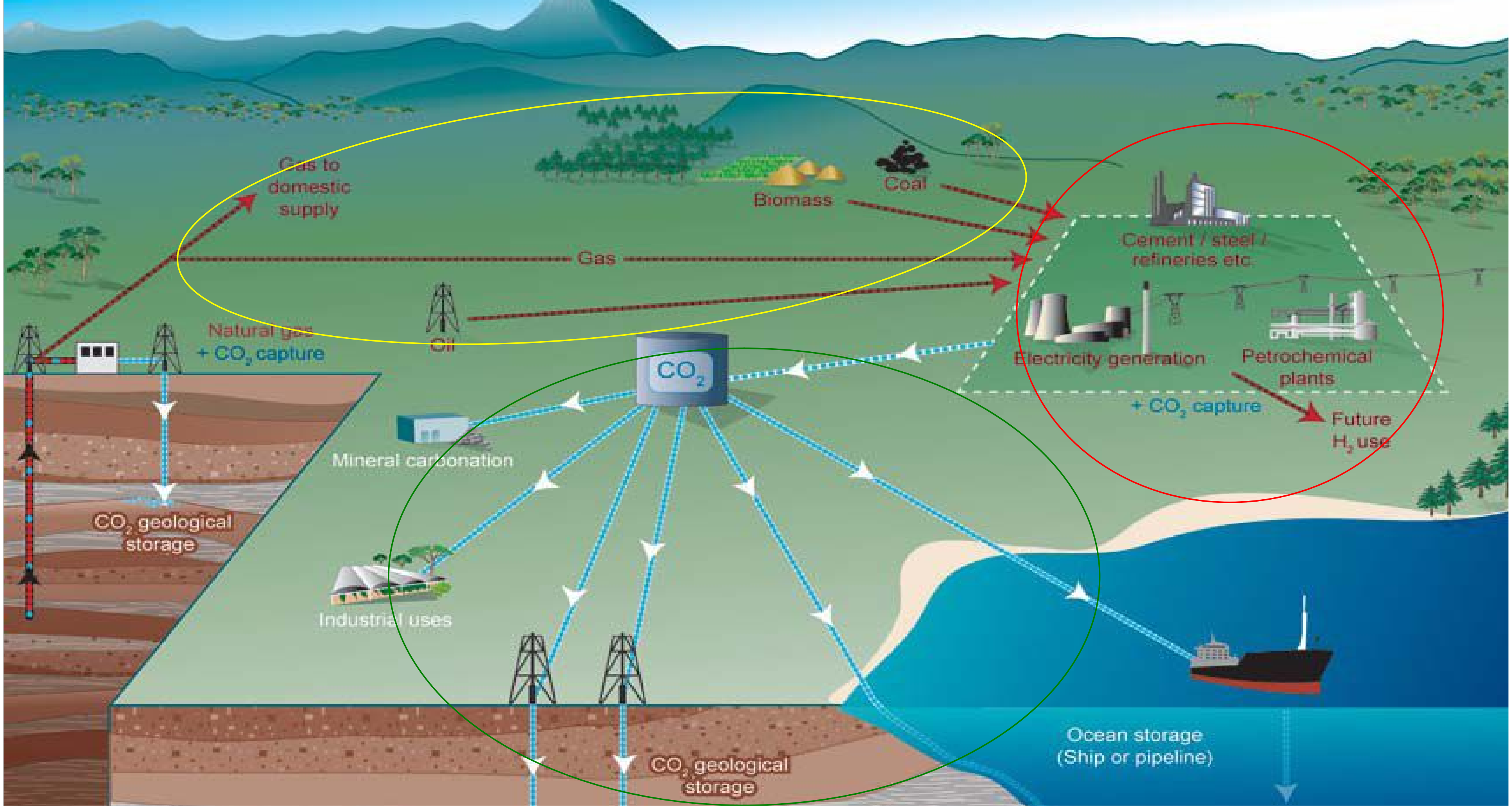
Carbon Capture & Storage Association

How CCS works

Picture courtesy CO2CRC



“The field of carbon capture and storage is a long-term priority for the European Commission and the sector as a whole”

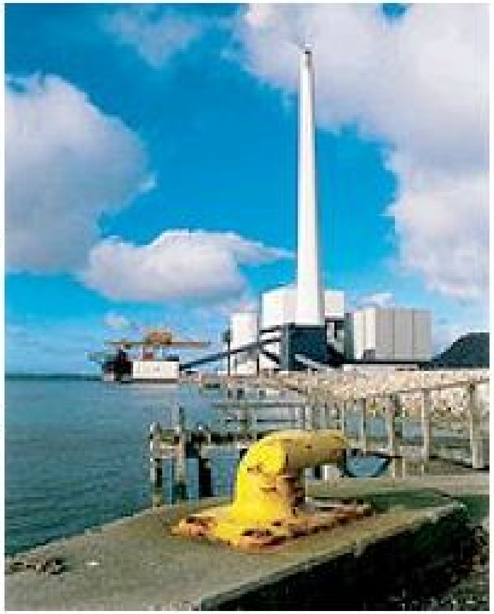
IEA, Stern review, EU, IPCC all state that “CCS is a key measure to meet 2030,2050 CO2 targets – expect to provide ~30% of all CO2 reductions from power industry” 2030 = 500-550 plants (EU 80-120) saving 3.6 GT/y of CO2

EU 'CASTOR' post-capture small pilot plant startup, Mar 2006

Europe Tests Carbon Capture at Coal-Fired Power Plant

ESBJERG, Denmark, March 15, 2006 (ENS) - The world's largest pilot plant for the capture of carbon dioxide (CO2) from a conventional power station was opened in Denmark today. It is the first installation in the world to capture the CO2 in the flue gases of a coal-fired power station.

The pilot project at the Elsam power station near Esbjerg, will demonstrate new technology for capturing carbon dioxide emissions as they are produced by power stations and then storing the CO2 emissions underground, so they cannot enter the atmosphere and produce the greenhouse effect responsible for global warming.



Elsam coal-fired power plant at Esbjerg, Denmark is the site of the CASTOR pilot project. (Photo courtesy Elsam)

CASTOR, which stands for CO2 from Capture to Storage, is an European initiative grouping 30 partner industries, research institutes and universities from 11 European countries.

"The European Commission is committed to a low-carbon future, said European Science and Research Commissioner Janez Potocnik, commenting on the inauguration of the new pilot plant at the 420 megawatt Elsam power station.

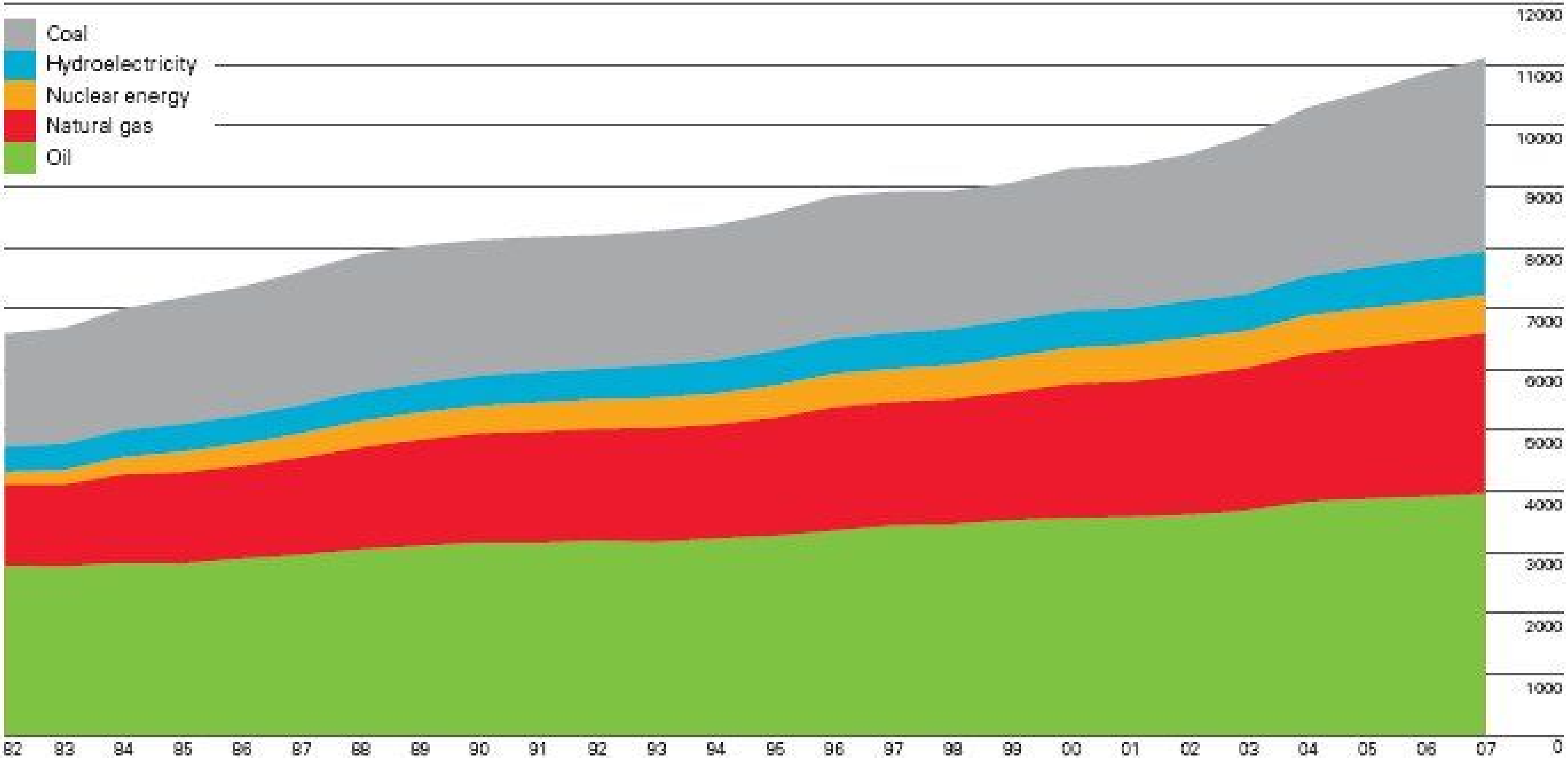
Kårstø CCGT CCS Project, Norway

The Norwegian Government will construct a full scale CCS (retrofit) solution for a gas-fired power plant in connection to the existing gas fired power plant at Kårstø on the Western coast of Norway. The capture plant is planned to be operational as soon as possible. The plan is to make the investment decision in 2009.

The facility is planned to capture 1 million tonnes/year of CO_2 from the exhaust gas at the power plant and subsequently transport the CO_2 by pipeline to safe storage in geological formations under the sea bed. The State owned entity Gassnova is responsible for this important and comprehensive work. the investment cost would

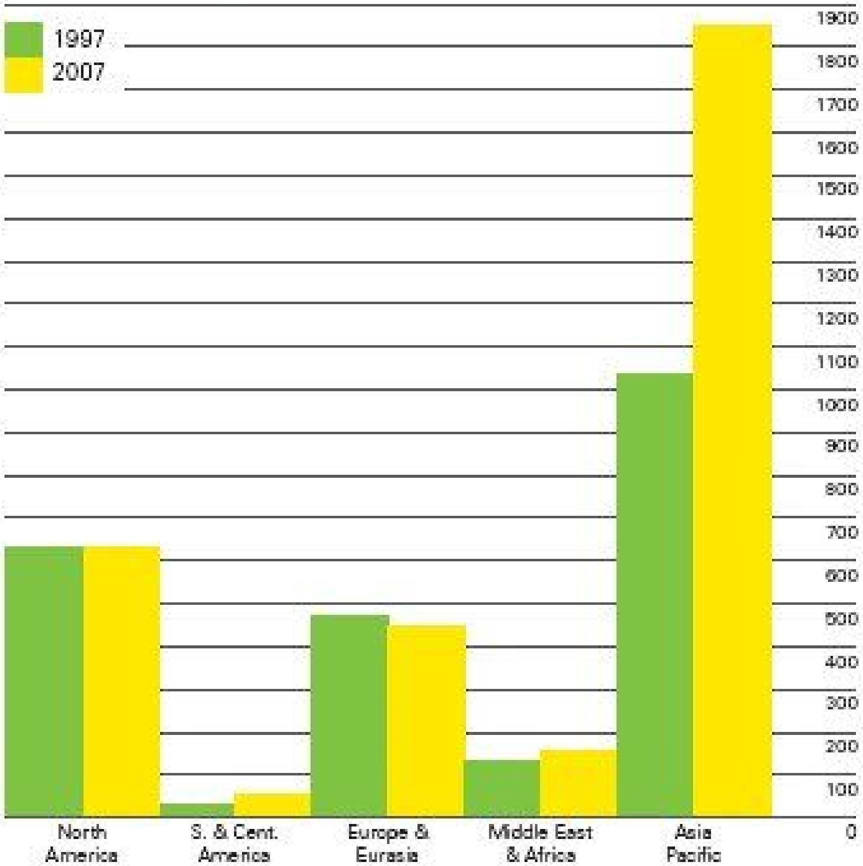
amount to approximately 5 billions NOK, including transport and storage of CO_2. Abatement cost (NPV)of NOK 700 per ton CO_2.

World consumption
Million tonnes oil equivalent

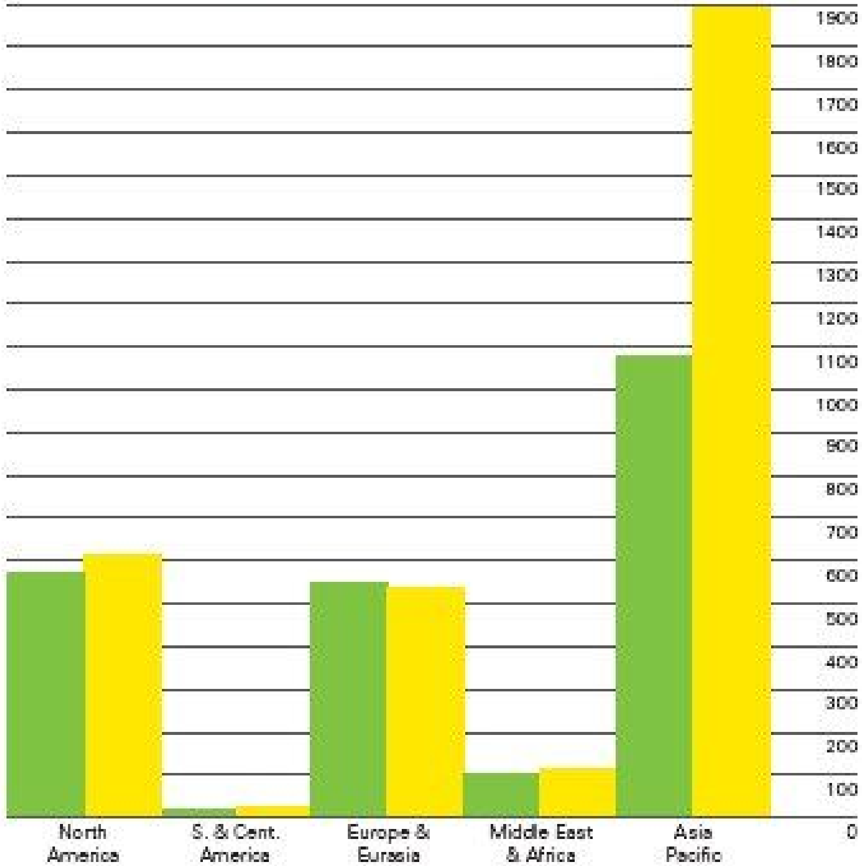


World primary energy consumption slowed in 2007, but growth of 2.4% was still above the 10-year average. Coal remained the fastest-growing fuel, but oil consumption grew slowly. Oil is still the world's leading fuel, but has lost global market share for six consecutive years, while coal has gained market share for six years.

Production
Million tonnes oil equivalent



Consumption
Million tonnes oil equivalent

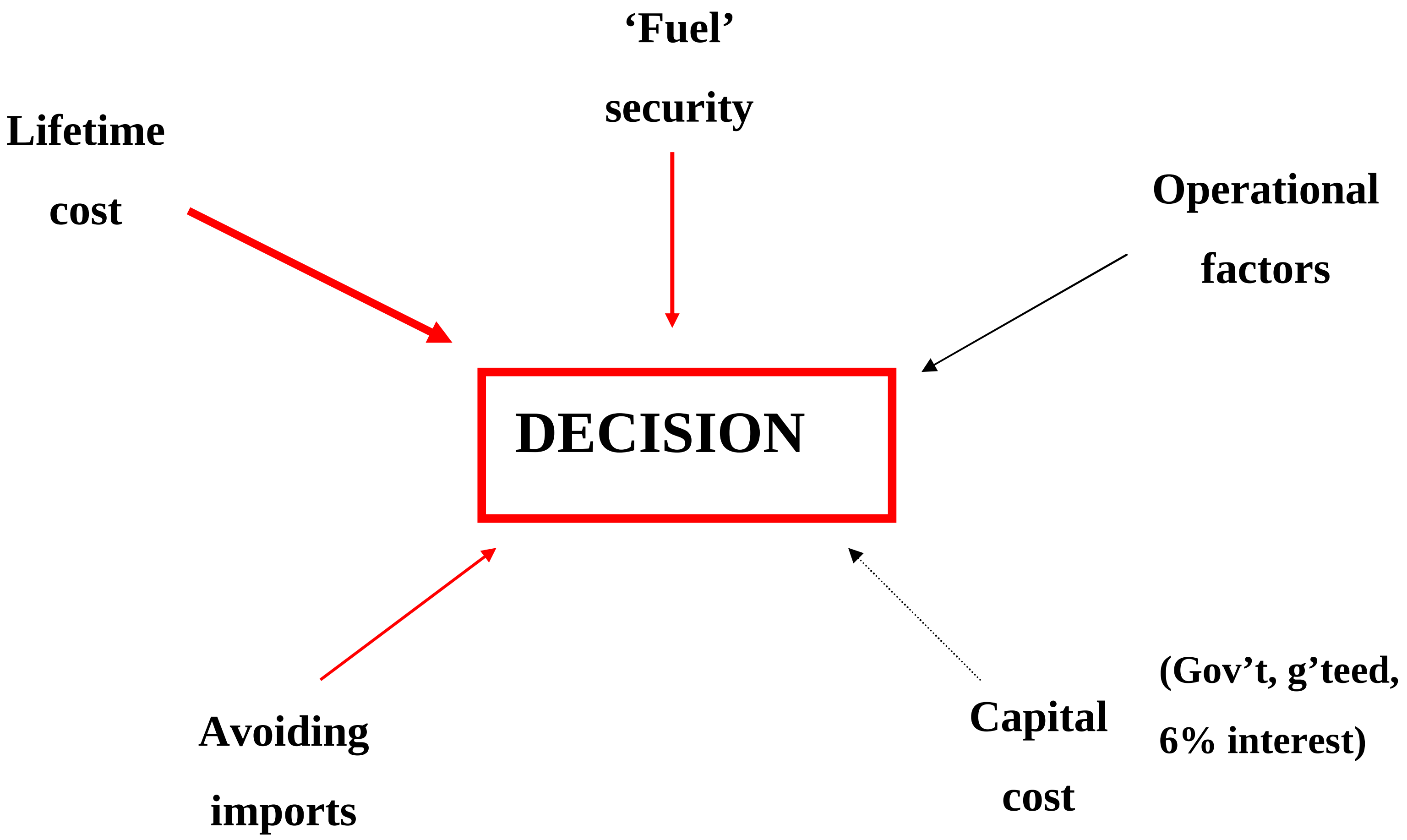


World coal consumption grew by 4.5%, well above the 10-year average. Coal was the world's fastest-growing fuel for the fifth consecutive year. Growth was above average in all regions except the Middle East. Chinese consumption growth accounted for more than two-thirds of global growth.

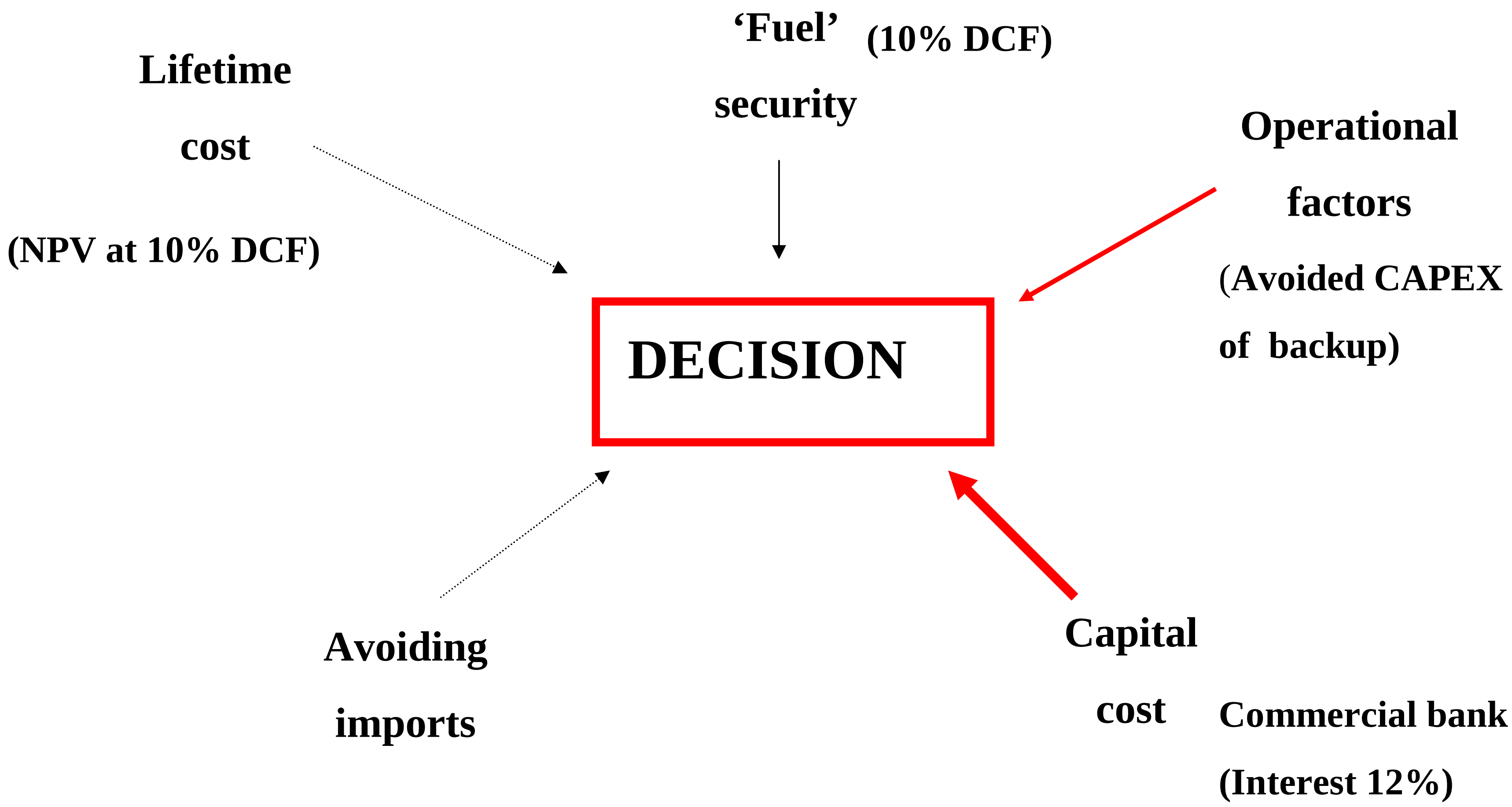
Table 1: coal vs wind turbine attributes

	Coal	Wind
Reliability/continuity	Very high	Very low
Predictability	Very high	Very low
Outages	Plannable	Unplanned
Ability to back-up other plant on-demand	Yes	No
Spinning-reserve ability	Yes (good)	No
Land area per MW	v. small	v. large
Retrofit to existing sites/grid	Yes (near-100%)	Tiny
Planning consent	Accepted	Controversial (onshore)
Need for new grid lines	Minimal	Significant
Fuel storage	Yes	No
Fuel storage cost	Low	N/A
Expected energy-source price rise	Moderate	Zero
Capital cost/MW	Moderate	v. high
Power cost/MWh	Below grid average	High
Need for subsidy	Zero (no CCS) Moderate (CCS)	High
Competitiveness vs. gas CCGT	Improving	Improving

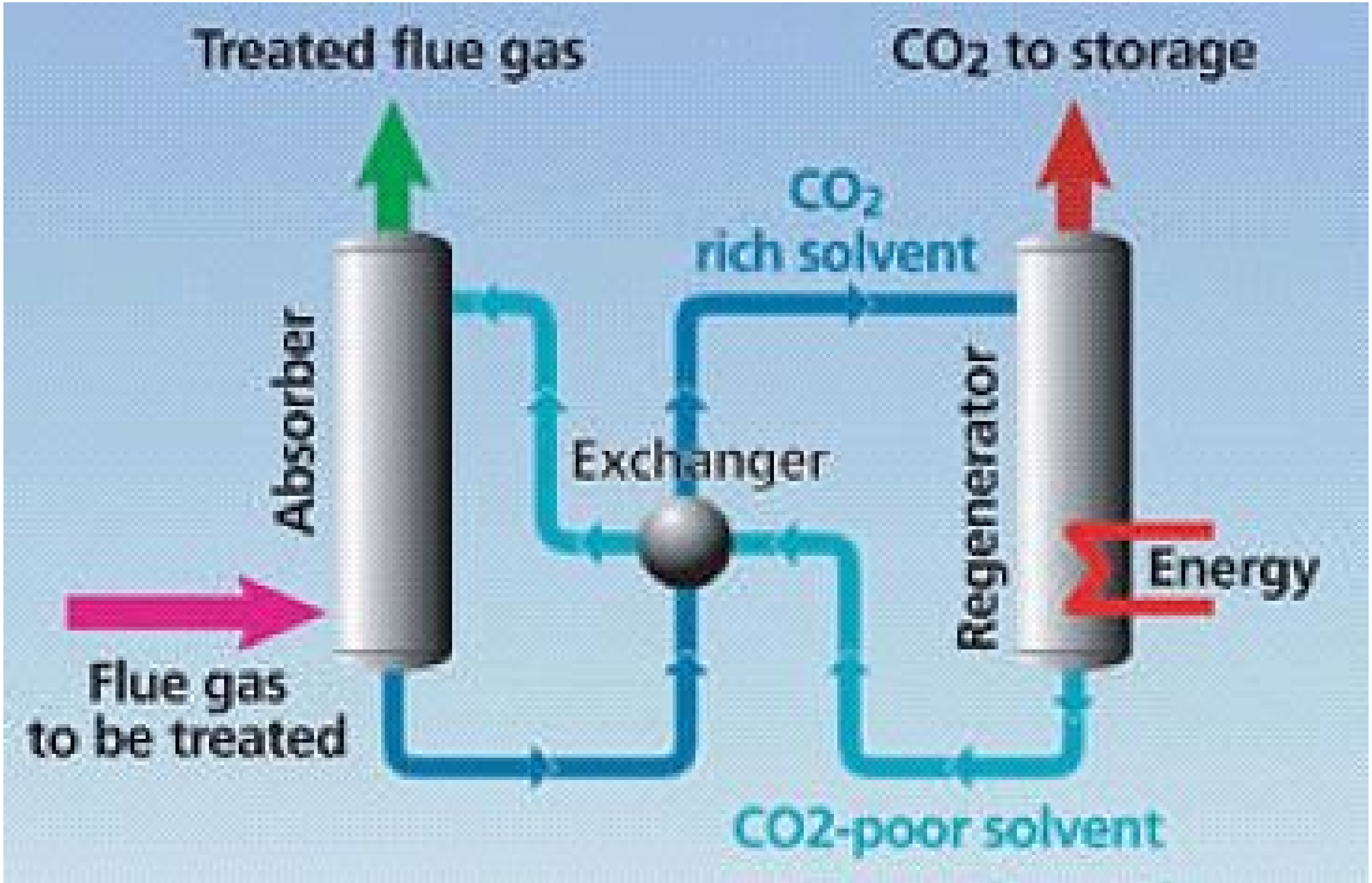
Plant decision process:
- 1) CEGB/Gov't (1985)



Plant decision process:
- 2) Privatised (today)



CO2 capture unit

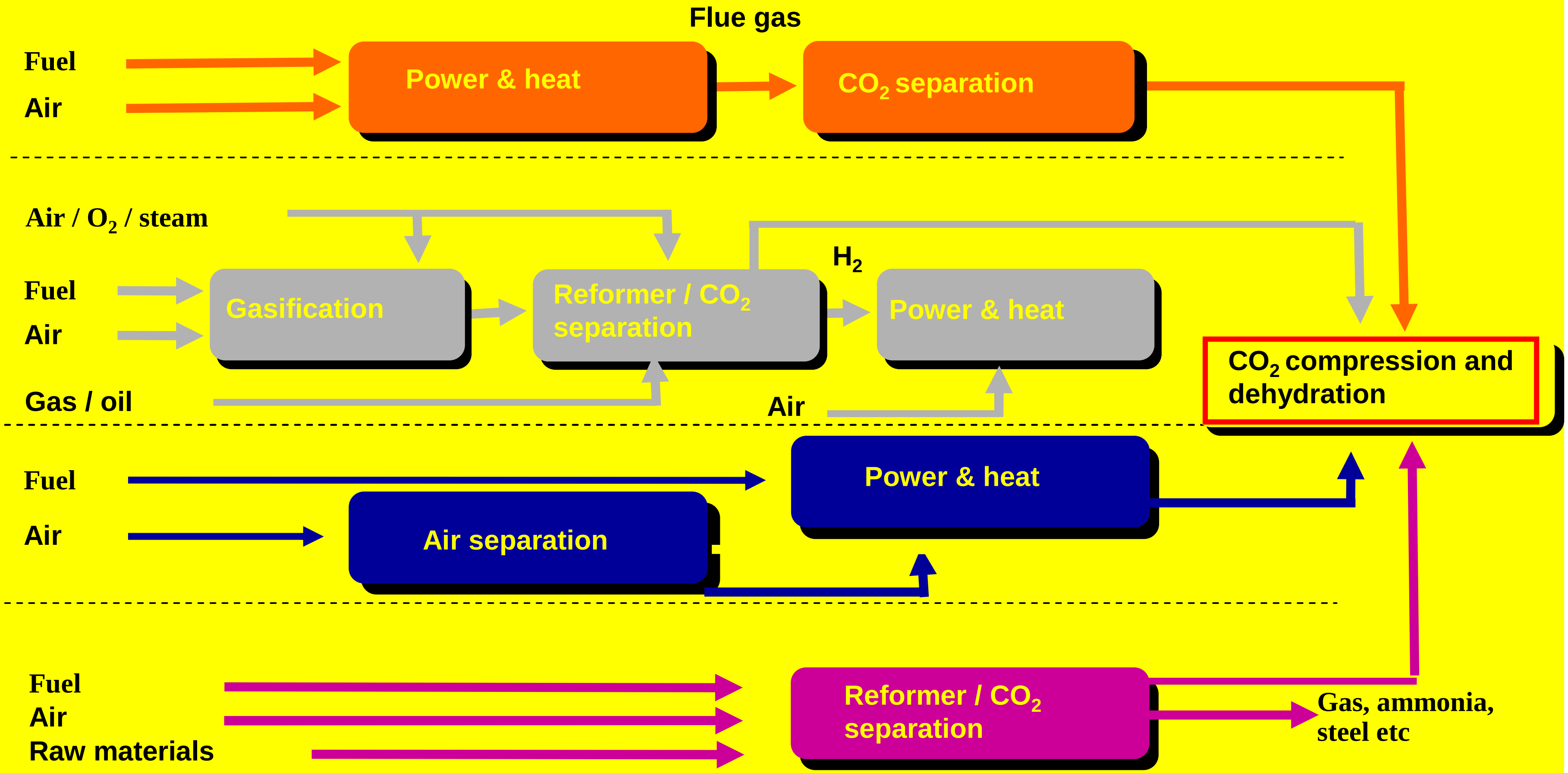


CO2 capture process options

(all the processes down to Benfield HiPure are fully proven with guarantees)

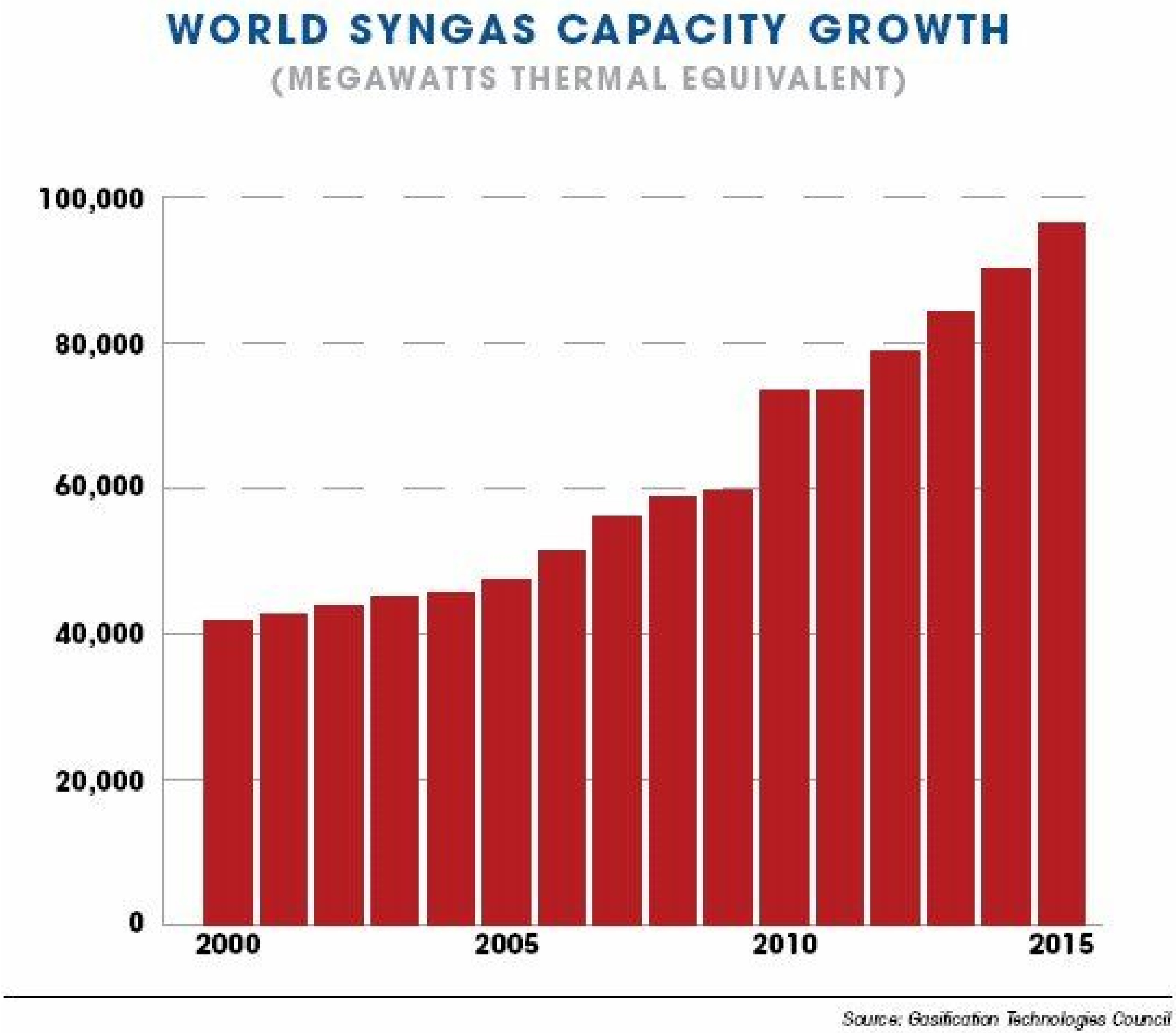
Physical solvents	Chemical solvents
Water	Amines:
Selexol	MEA
Rectisol (methanol)	DEA
Purisol	MDEA
Fluor Solvent	DGA
	Fluor Econamine
Hybrid	**Carbonates:**
Sulfinol	Benfield
ADIP	Vetrocoke
Flexsorb	Hybrid:
	Benfield HiPure
	Novel:
	Alstom ammonia
	Cansolv

How CCS works - technologies

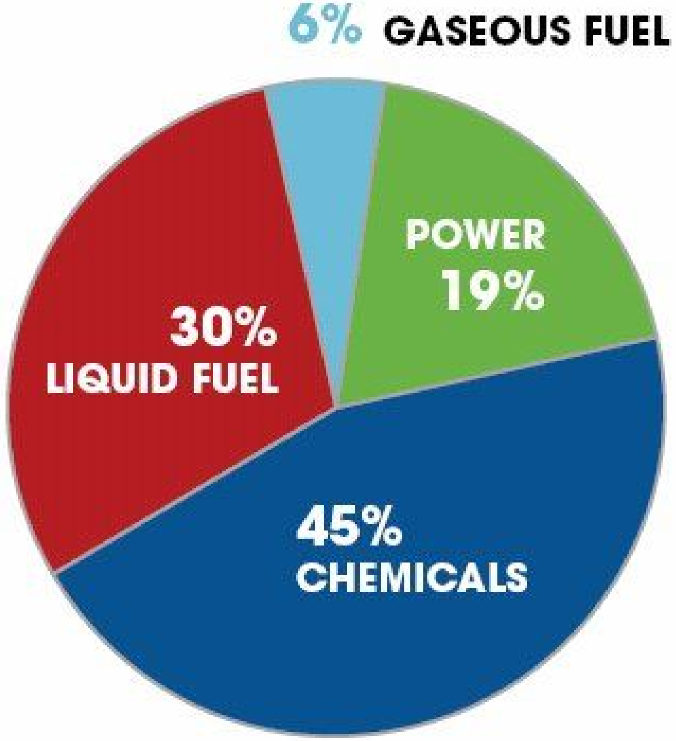


Gasifier Market

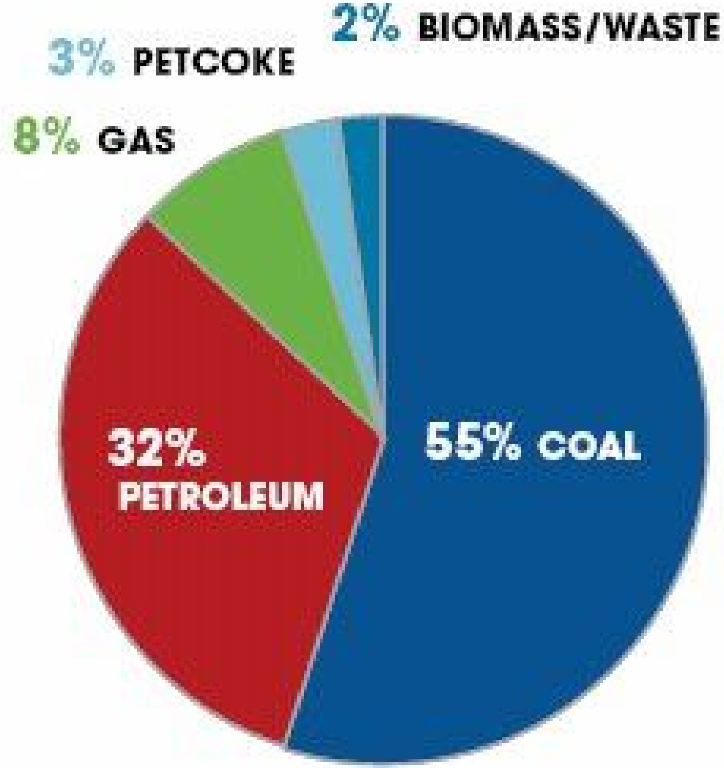
- Total (inc. construction/planned):
- 163 sites with 450 gasifiers
- SASOL's 3 sites in S. Africa alone have 97 Lurgi fixed-bed coal gasifiers + US Great Plains SNG demo plant has another 14
- 140 sites already in operation
- Coal – 37 sites Oil Residues, biomass etc –126
- 115 sites – chemical syngas + a few pipeline gas
- 48 IGCC sites – 16 operating, 32 planned
- Operating IGCC:
- Coal-6, Oil residues-7, small biomass -3


WORLD SYNGAS CAPACITY GROWTH
(MEGAWATTS THERMAL EQUIVALENT)
100,000
80,000
60,000
40,000
20,000
0
2000
2005
2010
2015
Source: Gasification Technologies Council

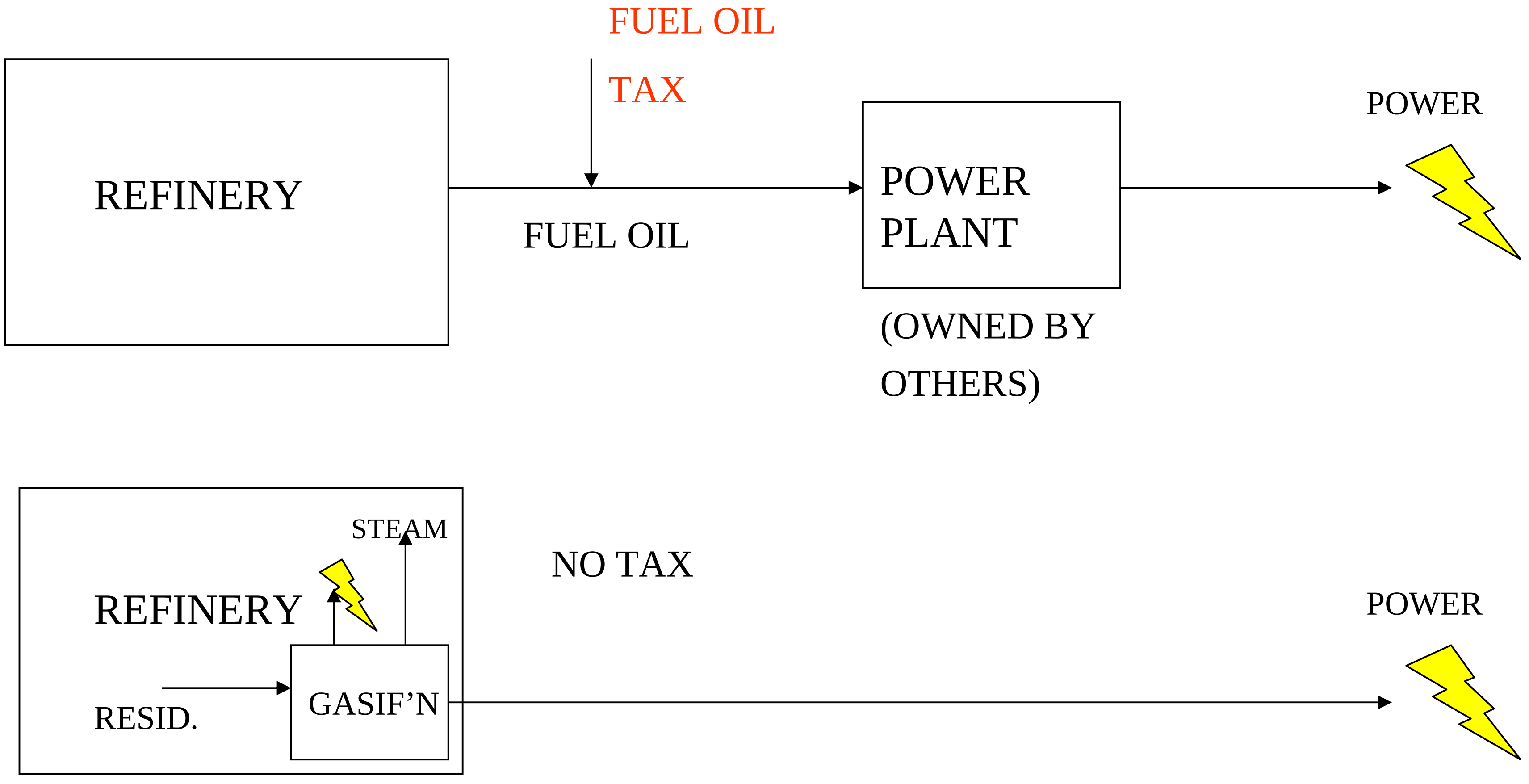
PRODUCT DISTRIBUTION OF 2007 WORLD GASIFICATION CAPACITY



GLOBAL SYNGAS OUTPUT BY FEEDSTOCK



Refinery gasification market opportunity



Refinery Gasification

- Operation within the refinery:
- Saves refining the residues to fuel oil specification
- Flexibility in feedstock – any waste oils/gases – helps refinery balance
- Supplies the refinery power, steam and heat “at-cost”
- Avoids fuel oil tax
- Can use refinery support services (water, effluent treat, etc)

Biomass+waste IGCC Plants (non-CCS)

Schwarze Pumpe	Germany	BGL	(chemicals)	1995
Americentrale	Holland	Lurgi CFB	46MW	2000
Kymijarvi	Finland	FW CFB	26MW	1998
Varnamo	Sweden	FW CFB	6MW	1993
Renovavel	Brazil	TPS	37MW	2005

Biomass and waste gasify **easier** than coal (more reactive)

Waste “gate fees” -> lower power cost

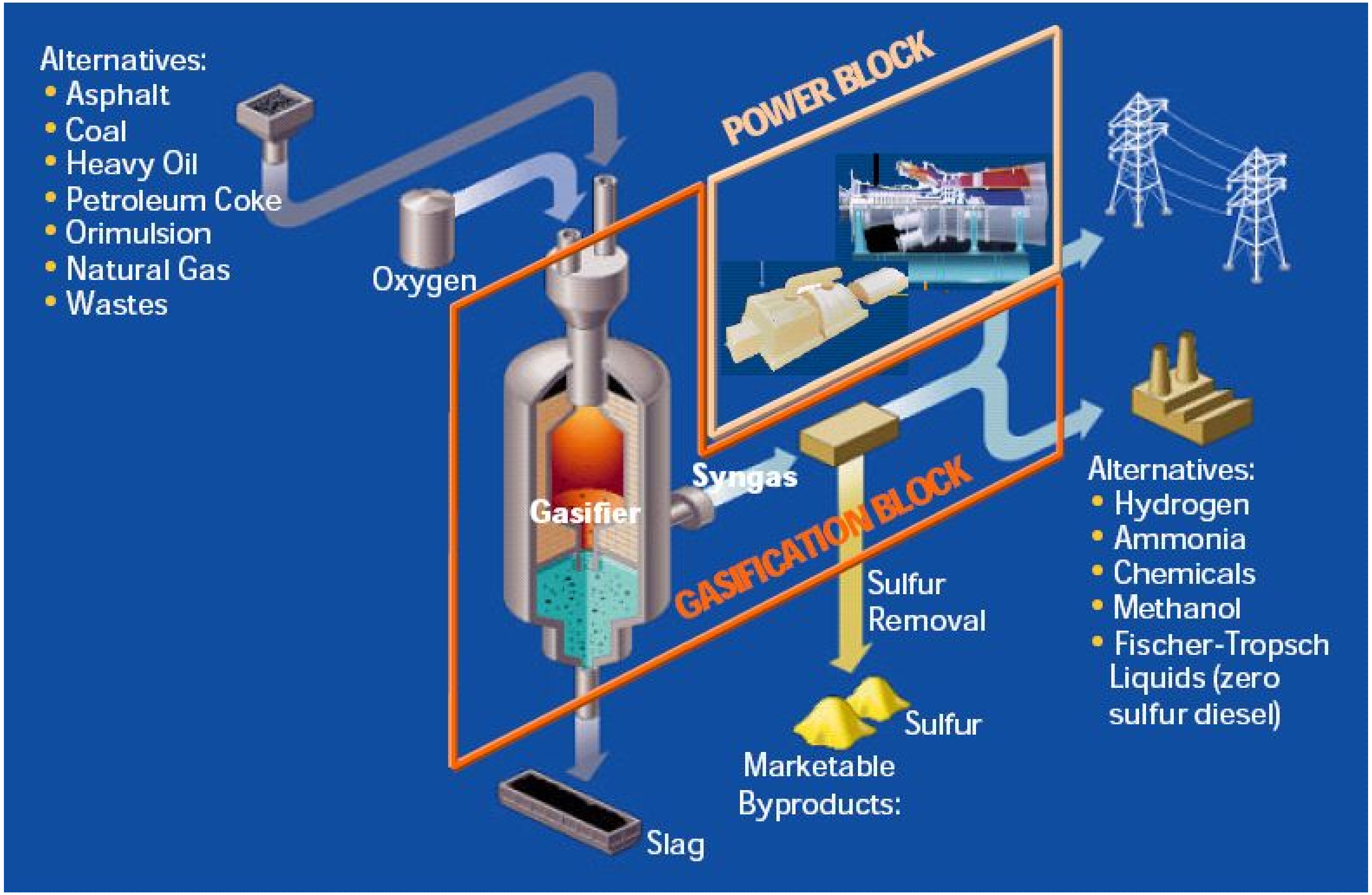
Biomass/waste IGCC +CCS = **NEGATIVE** CO_2 emission!!

Some IGCC Prototype Plants

Cool Water*	USA	CVX(Texaco)	100MW	1984
Wabash River	USA	E-Gas (Destec)	262MW	1995
Polk (Tampa)	USA	CVX(Texaco)	250MW	1996
Pinon Pine*	USA	KRW (air)	107MW	1996
Buggenum	Holland	Shell SCGP	253MW	1995
Puertollano	Portugal	Prenflo	300MW	1997
Delaware	USA	CVX(Texaco)	284MW	2001
Sulcis	Sardinia	Shell SCGP	522MW	2005

* - shut down

IGCC Process

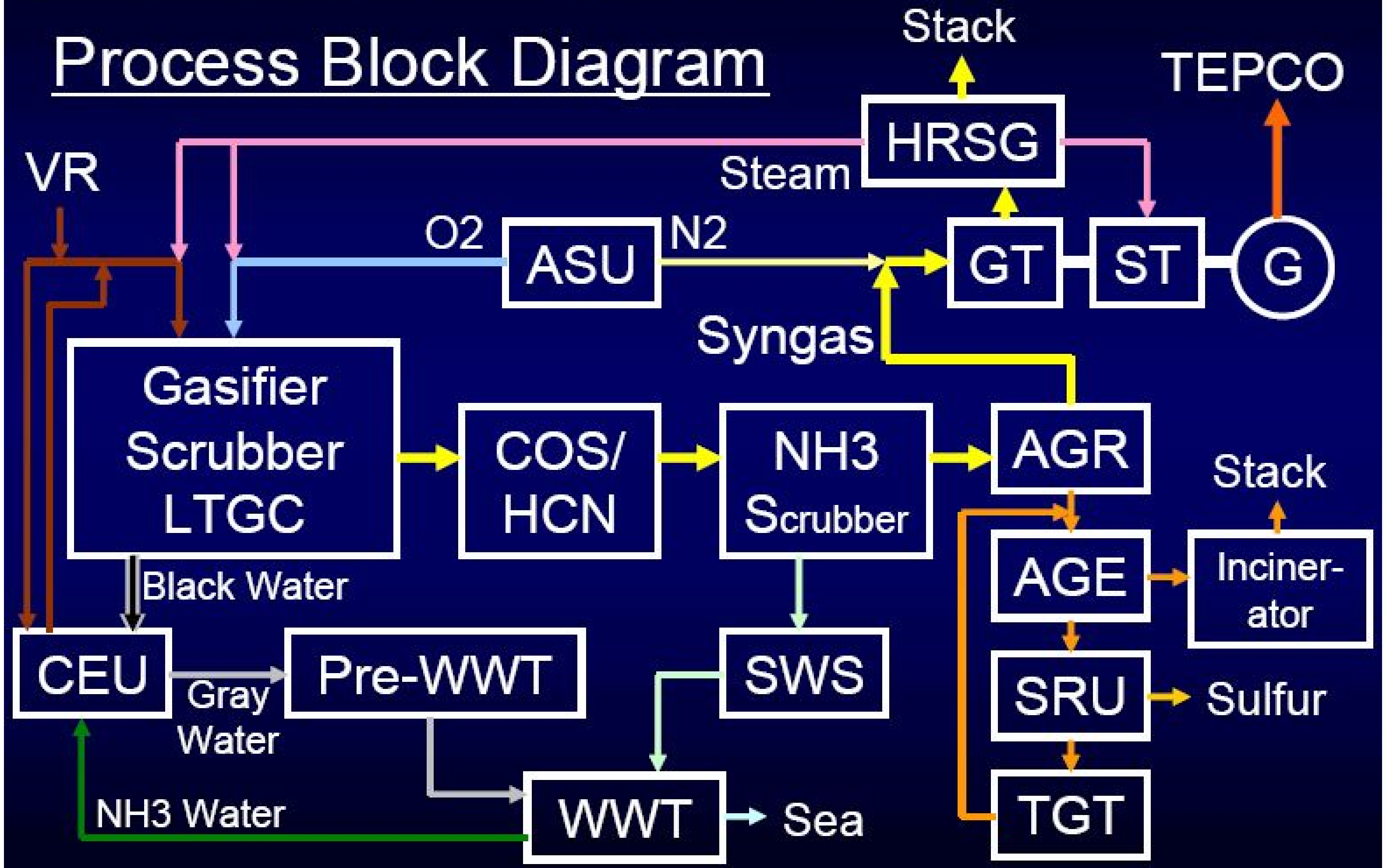


Source: GE Basis: Texaco (CVX) gasifier

2.Outline of Negishi IGCC

NIPPON OIL CORPORATION
Your Choice of Energy

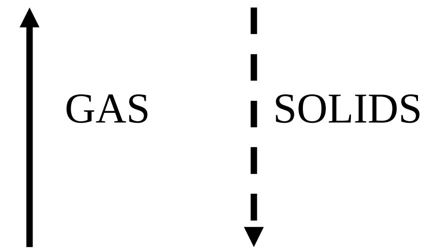
Process Block Diagram

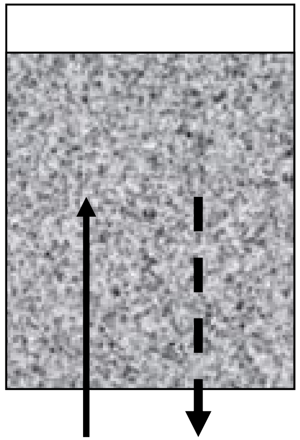


Gasification as a Solid Fuels Purifier

- Removal of:
  - Ash (solids)
  - Sulphur
  - Nitrogen (ammonia)
  - Chlorine/fluorine
  - Trace heavy metals (Ni,V,Pb….)
  - Trace alkali metals (Na,K,…)
  - Organic compounds
  - Carbon as CO2

Flow Directions

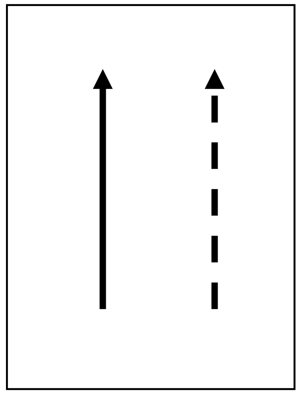




FIXED BED

COUNTER-CURRENT

(4 types)

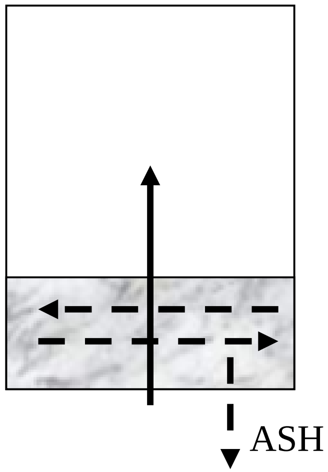


ENTRAINED

UP-FLOW

CO-CURRENT

(3 types)

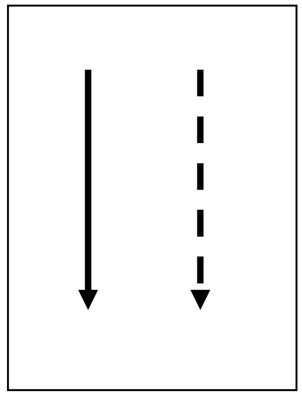


FLUIDISED BED

CROSS-FLOW

(WELL-STIRRED)

(3 types)



ENTRAINED

DOWN-FLOW

CO-CURRENT

(3 types)

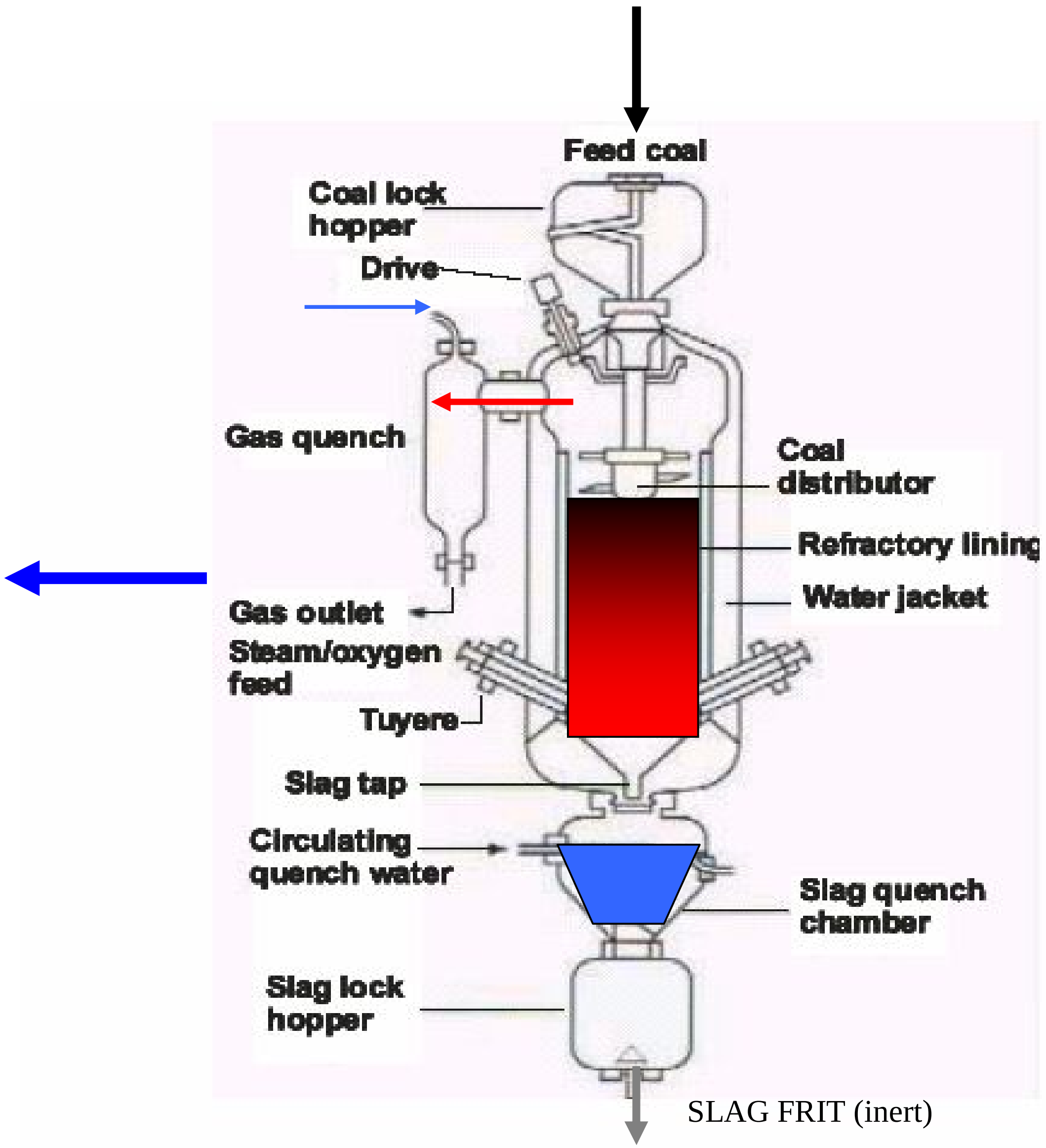


Figure 5.2 The British Gas Lurgi Gasifier (White 2000)

Prenflo IGCC plant

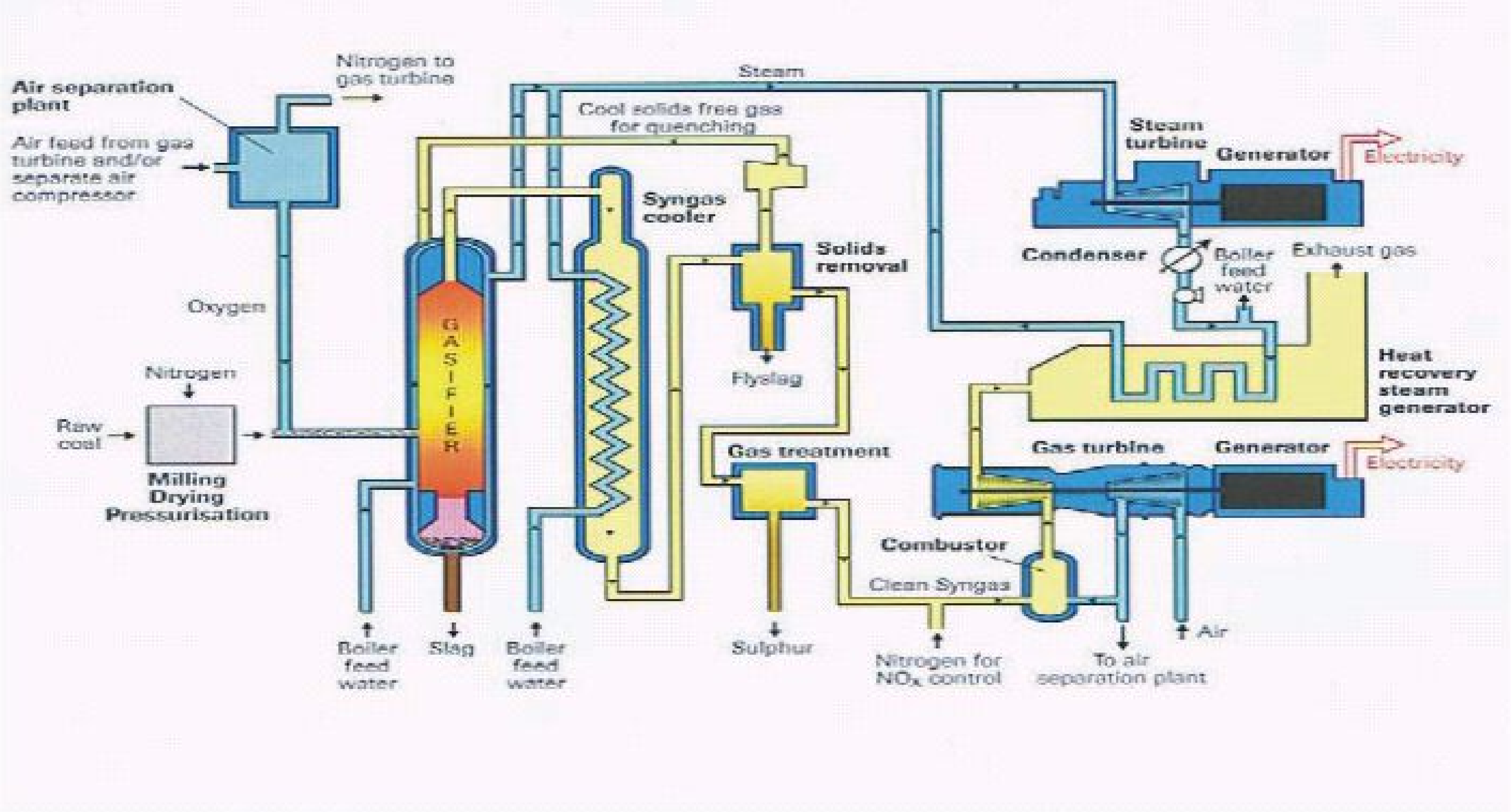
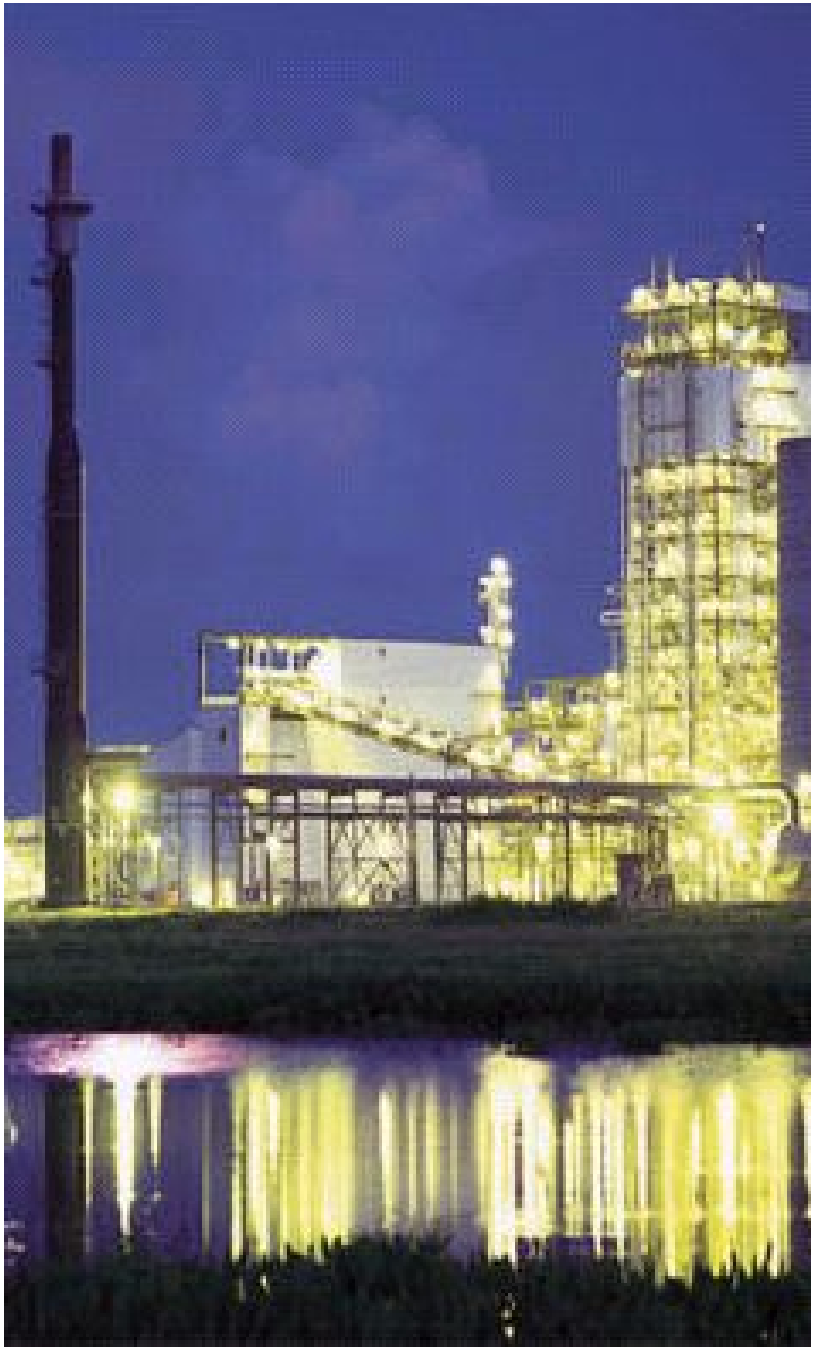


Figure 5.3 Schematic of IGCC showing key system components

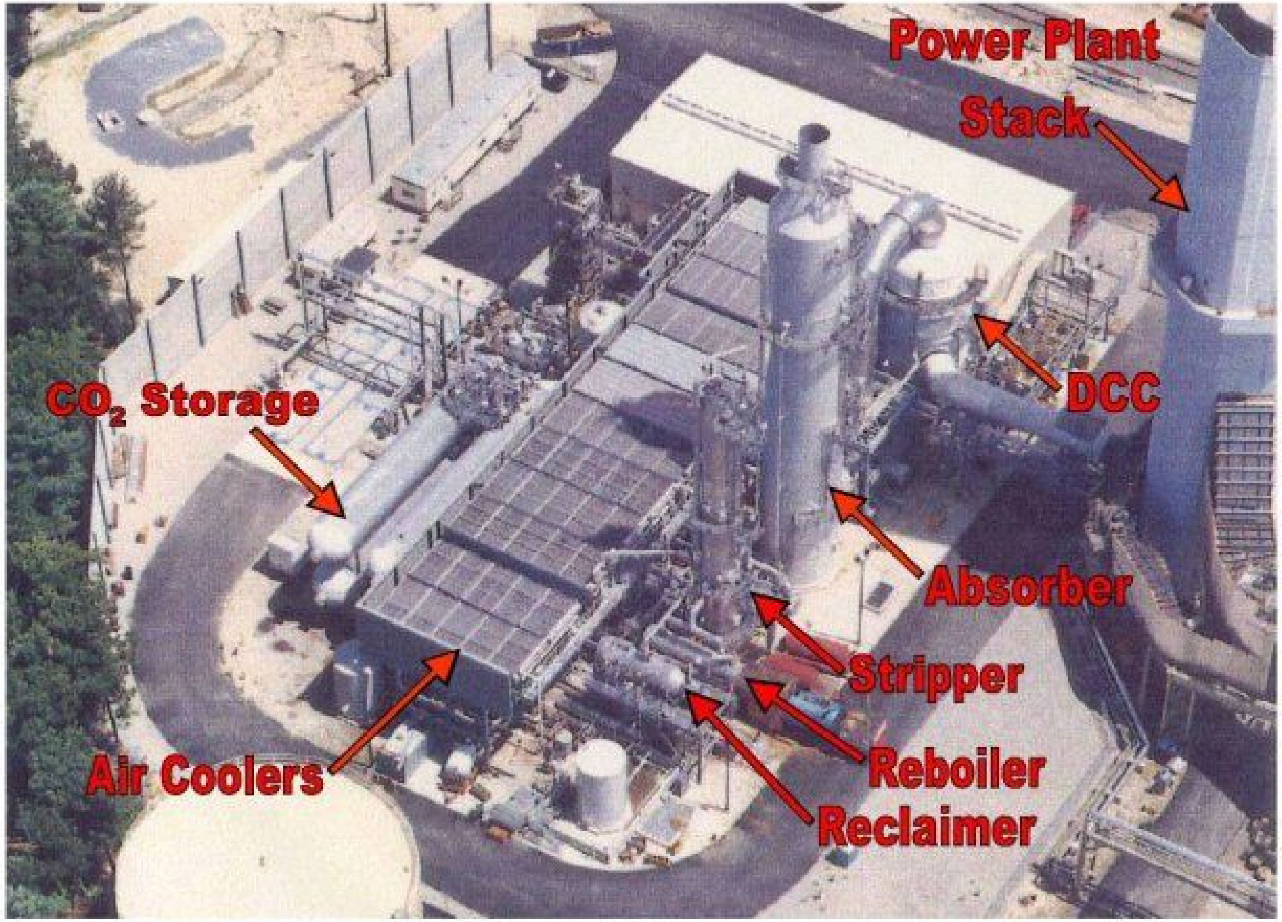
Negishi 431MW Residue Oil IGCC plant

Oxygen plant | Combined Cycle | Gas purif'n | Gasifier plant

CVX (Texaco) gasifier tower, Polk 250MW IGCC plant, Tampa, Florida



Bellingham, USA – GT powerplant - CO2 absorber unit



Fluor absorber in USA for 360 tonne/day CO_2

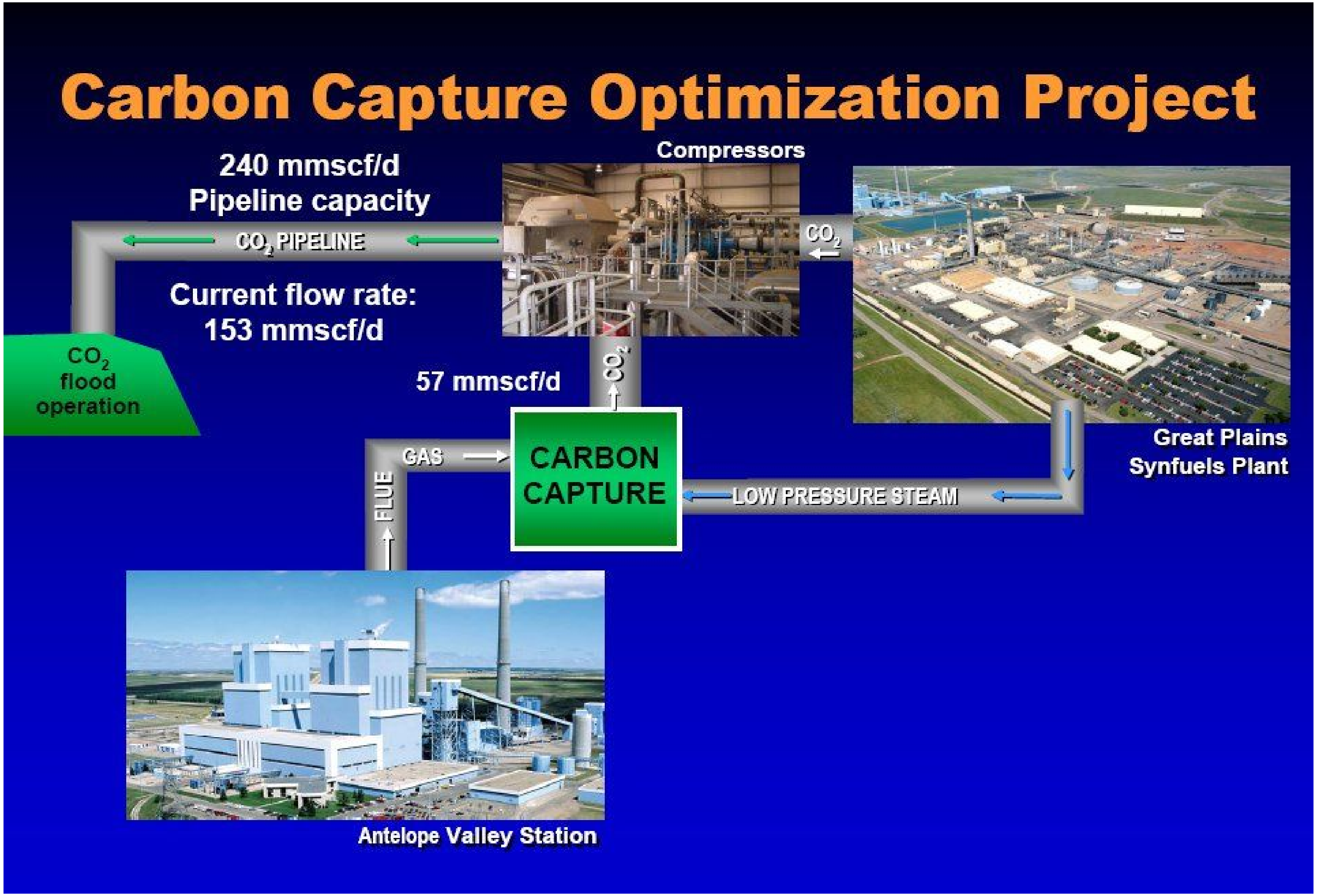
Bellingham, USA – GT powerplant - CO2 absorber unit

Bellingham Econamine FG^{SM} Plant Ground View

Large amine absorber, Saudi Arabia refinery

Fluor's Econamine (DGA) Plant in Uthamaniyah, Saudi Arabia has an absorber (center-right) with a large diameter.

Great Plains (aka Dakota Gasification) SNG Plant CCS project, Beulah, North Dakota, USA **–"is this proven enough for you"?** (153 million ft3/day CO2 pipelined and sequestered, 160 million ft3/day SNG produced to pipeline) - 13 MT sequestered so far



Anwendungen - Referenzbeispiele

Enhanced Oil Recovery in North Dakota / USA

CO2-Compressor of an Integrally Geared Design

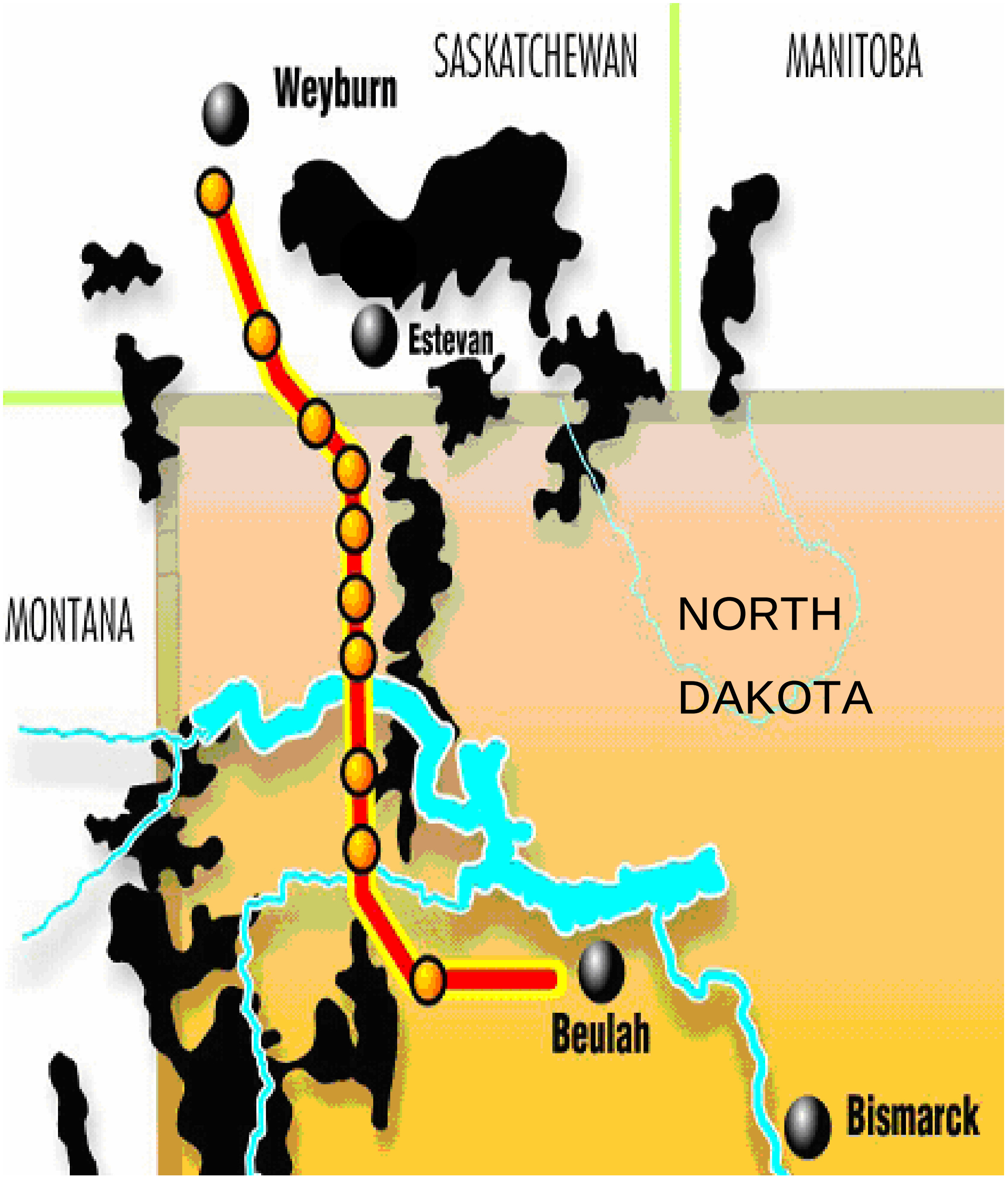
Project description

In 1997 MAN TURBO received an order for a compressor high pressure application. The compressor station consists of two units to feed CO2 in the front end station of a pipeline starting in a coal gasification plant in North Dakota, USA. The pipeline routes from North Dakota over the canadian boarder to Saskatchewan oil fields, where the CO2 is injected into oil wells for enhanced oil recovery. The total length of this 14 inch pipeline is 205 miles. There are no booster stations foreseen in between. The CO2 gas is injected into the oil well directly out of the pipeline, which requires a high pressure at start.

Source: MAN Turbo website

MAN CO2 Compressor – 10 stages, 125 tonnes/h, 190 bar pressure

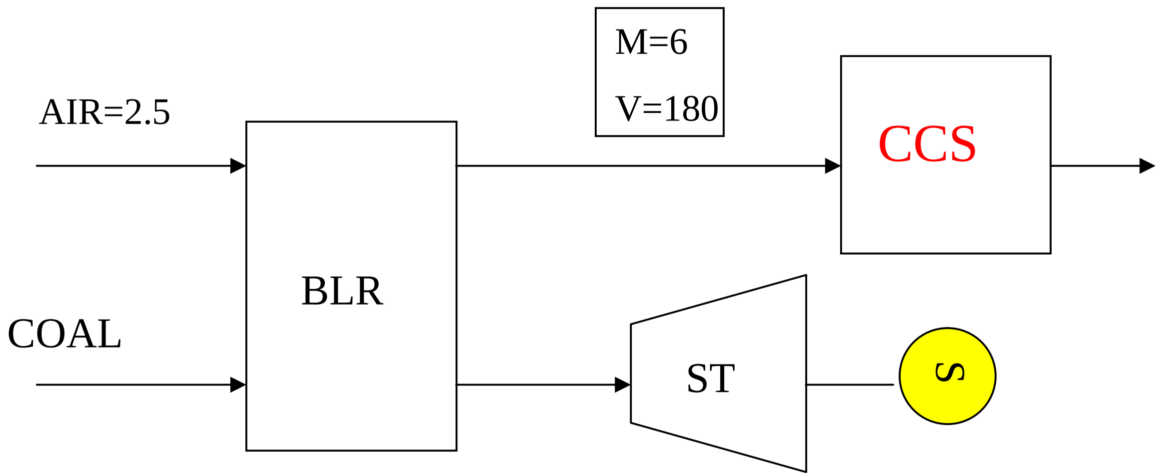
Great Plains SNG plant - EOR CO2 international pipeline map (205 miles)



Why is Purification Easier for IGCC? – pre-combustion purification

PC + post-capture

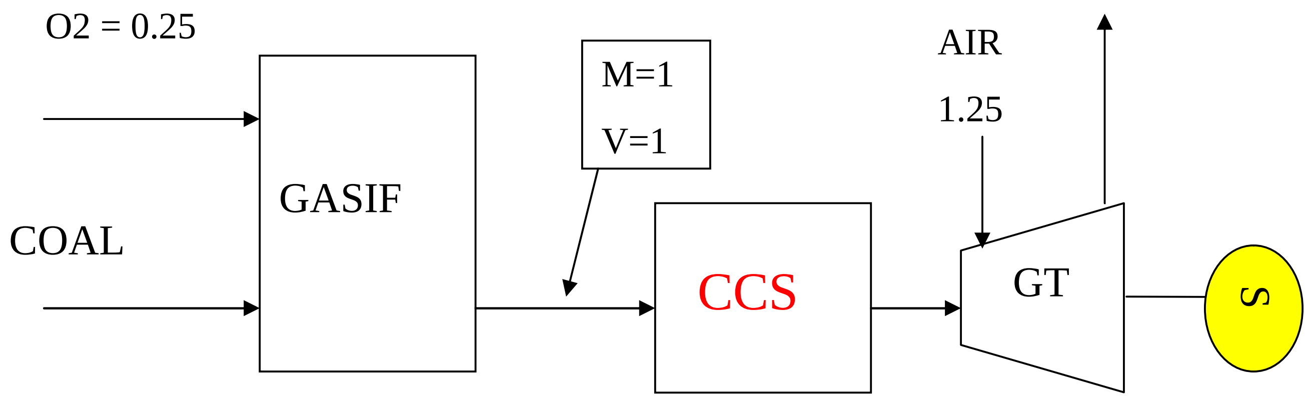
P = 1atm



IGCC

+pre-capture

30 atm



M = Molar flow (relative) V= actual volume flow

Why is Purification Easier? –2

- Conv. Powerplant:
  - 180x Volume flow – huge equipment
  - Contaminants in **oxidised** form (SO_2, NO_x,CL_2) –less soluble + attacks Amines (also resid. O_2)
  - Pressure = 1 atm -> tiny driving forces for absorption

    -> v. large absorbers
- IGCC:
  - Vastly lower volume flow
  - Contaminants in **reduced** form (H_2S, NH_3,HCL) – more soluble, no problems
  - Pressure = 20-50 atm -> large partial-pressure driving forces for absorption
    - Can use physical solvents (<< lower energy use)
  - Conventional absorption process equipment

Why is Purification Easier? –3

- Conv. Powerplant:
  - Treated gas required dry and at >85 C for chimney plume rise
    - High temp. ->low absorption driving force
    - >60% of ash in flue gas as fine dust
    - Dry dust removal difficult - Electrostatic Precipitators (ESP)
    - High inherent NOX formation from direct coal combustion
- IGCC:
  - Gas turbine accepts fuel gas wet and at 15-40C
  - Gas cooling energy loss low because small flow
  - Ash dust in gas can be <10% for some gasifiers
  - Wet dust removal easy/ “natural”
  - lower inherent NOX formation + low-Nox burners for fuel gas
  - Easier NOx removal options (dust-free gas)

Purification - results

- Conv. Powerplant:
  - All Sulphur (SO2) removal expensive
  - Sulphur (SO2) removal >90% difficult
  - Dust removal >98% difficult
  - NOx reduction/removal to <500 ppmv difficult/costly
  - Post-combustion CCS very costly
- IGCC:
  - >99% removal of all non-CO2 impurities affordable
  - CO2: 90% removal affordable, 99.999% practicable)
  - Typically down to **few-ppmv*** level
  - Sulphur +nitrogen +ash all recovered as **saleable** products
  - NOx reduction to 25 ppmv "routine"
  - NOX removal to 3 ppmv achievable at moderate cost (burners)
  - - BUT: 'difficult' liquid chemical effluents

Purification - Conclusion

- IGCC will steadily become a **more** desirable option as environmental regulations tighten, putting up the cost of conventional solid fuel powerplant (PC) as clean-up systems are added

Current Options

		IGCC	SCPC	
Capital Cost	\$/kW	\$1,450	\$1,225	**+18%**
Emissions				
- NO_x	lb/MMBtu	0.02	0.03	
- SO_2	lb/MMBtu	0.01	0.04	
- PM	lb/MMBtu	0.005	0.01	
Efficiency	% HHV	40%	40%	
Fuel Flexibility	Feedstocks	All coals plus liq. & solid opportunity fuels	Low sulfur coals favored	
COE (1st year)	¢/kWHr	4.22	3.94	**+7%**

Source: GE   Basis: Texaco (CVX) gasifier

IGCC Is a Pollution Prevention Solution Capable of Meeting Future Environmental Challenges

		IGCC	SCPC	Concerns
Mercury	Removal %	95%	40%-70%	Contamination of PC solid waste
	$/lb	$3,412	$37,800	
Water	gal/MW-hr	304	521	Water restrictions & air cooling
CO_2	kW penalty	-5%	-28%	Cap, credit or Tax ($6- $50/ton)
	Capital Cost	+30%	+73%	
	COE Increase	+25%	+66%	
Solid Waste	**COE, c/kWhr**	**5.25**	**6.54**	**IGCC = - 20%**
Sludge	lb/MW-hr	0	156	Land-bans
Ash	lb/MW-hr	0	71	Land-bans
Aggregate (vitrified)	lb/MW-hr	71	0	None Useful Byproduct

Source: GE   Basis: Texaco (CVX) gasifier

IGCC -The problems

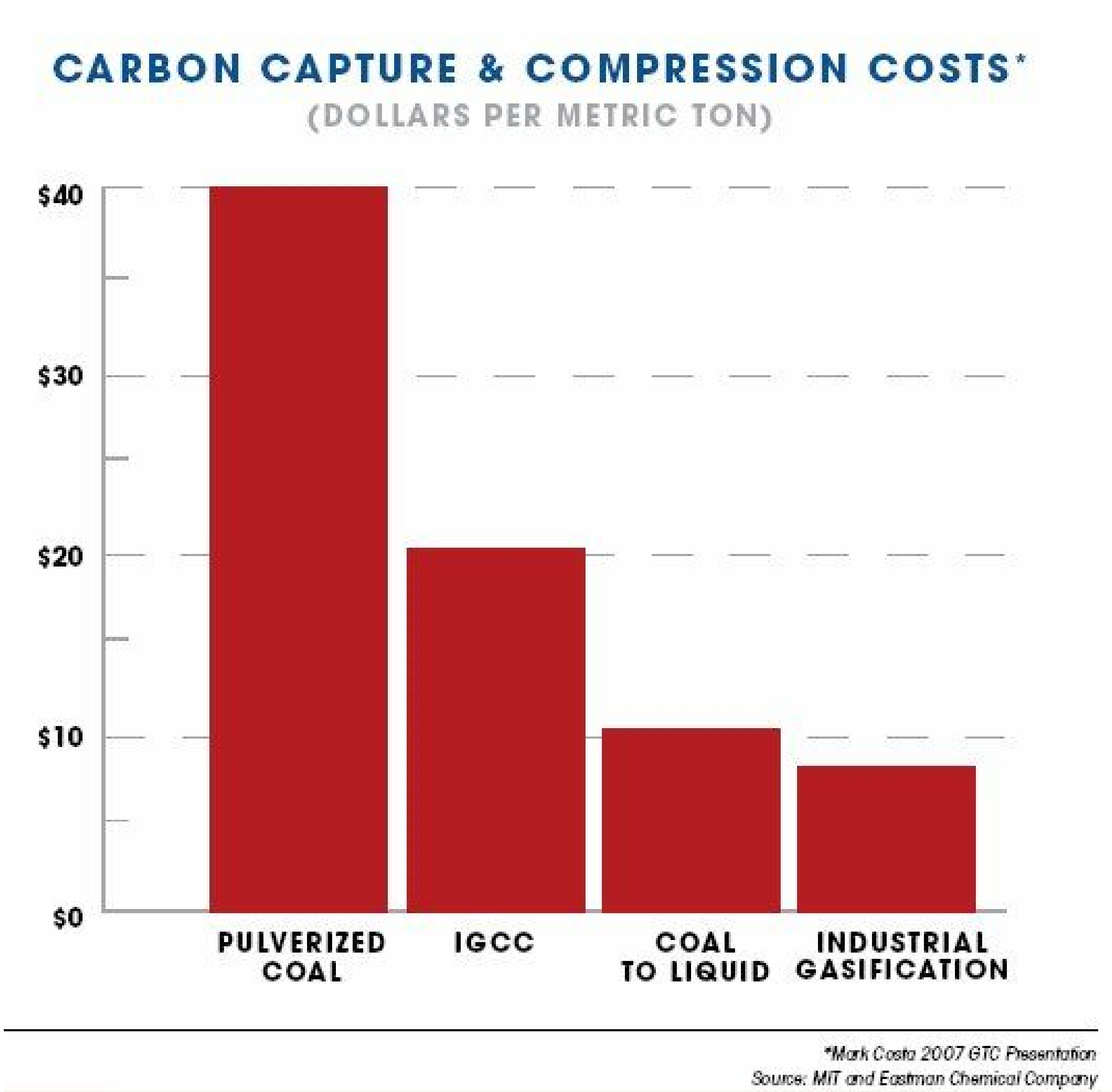
- IGCC has:
  - ~20% higher capital cost than PC at present (<u>non</u>-CCS)
  - Higher plant complexity
  - Requires skilled process engineers
  - 20-30% energy loss in gasification/ purification stage; combined cycle has to be very efficient to balance this
  - Needs oxygen separation plant –high cost, high power use, O2 hazardous
  - “difficult” liquid effluents (-but much lower flow)
  - High temperature corrosion issues
  - Less proven technology (improving)
  - Fewer manufacturers

IGCC- The Opportunities

- Benefits “for free” from GT efficiency + size developments for normal NG CCGT
- Benefits from improved novel CCGT cycle designs
- more compact, road/rail-portable process equipment, of standard types for process industry contractors
- Opportunities for better energy integration with GT, oxygen plant
- Potential improved gas purification methods, e.g “hot/dry” treatment
- Cost reduction “learning curve”
- Economies of scale for larger units

IGCC- The advantage for CCS

- **a decisively lower** CCS penalty compared with post-capture on **both** power de-rating (5 vs 28%) and power cost increase (25% vs 66%)
- - this makes IGCC + pre–capture **the definitive economic choice** in a **full**-CCS **new**-build scenario


CARBON CAPTURE & COMPRESSION COSTS*
(DOLLARS PER METRIC TON)
$40
$30
$20
$10
$0
PULVERIZED COAL
IGCC
COAL TO LIQUID
INDUSTRIAL GASIFICATION
*Mark Costa 2007 GTC Presentation
Source: MIT and Eastman Chemical Company

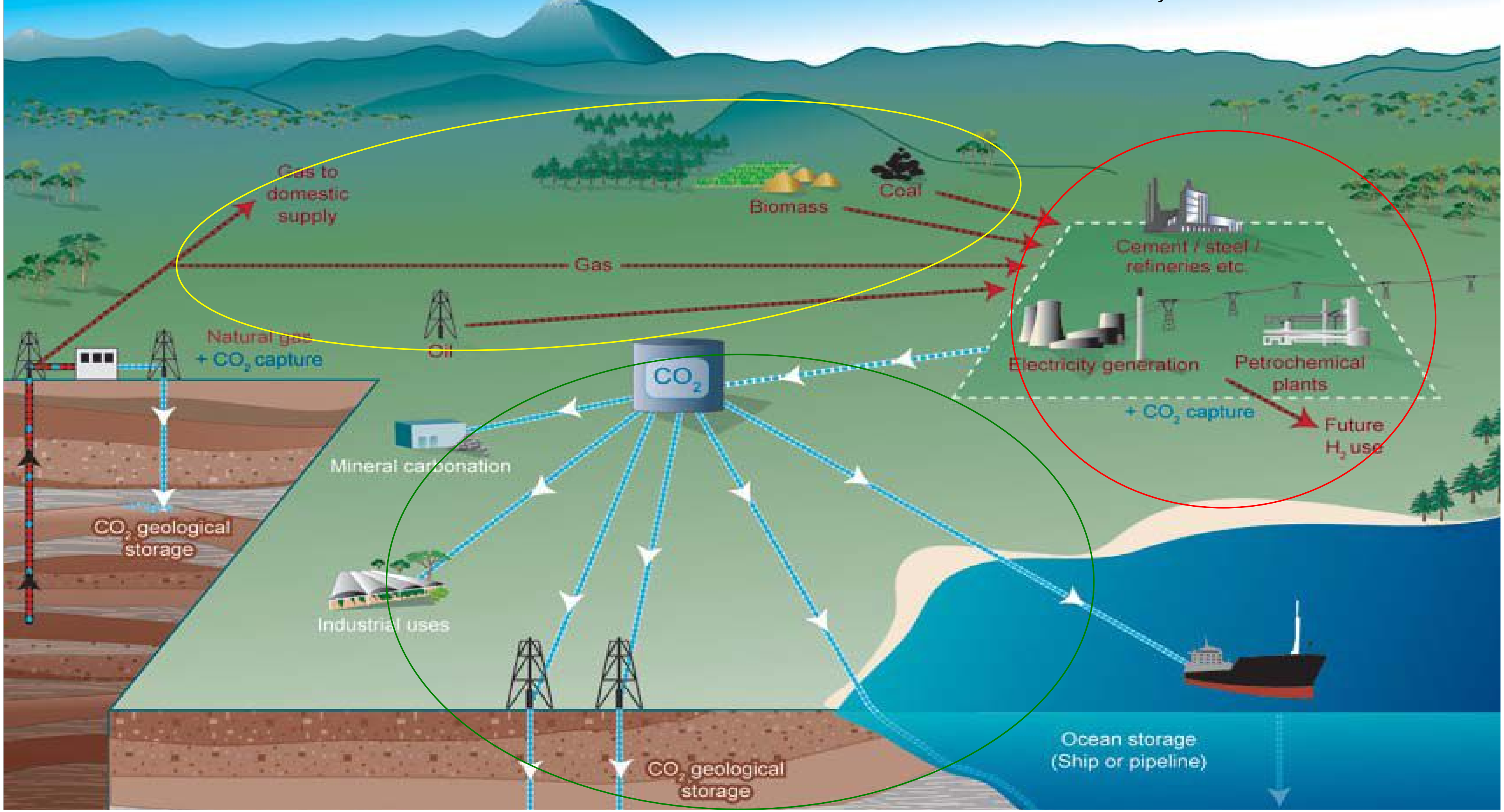
CCS cost – McKinsey report Sept 08

- IEA Forecast:
  - Total global power use +100% (x 2) in 2030
  - Fossils share **INCREASES** to 70%
- 2030 cost: **€35-50 /t** CO_2 saved

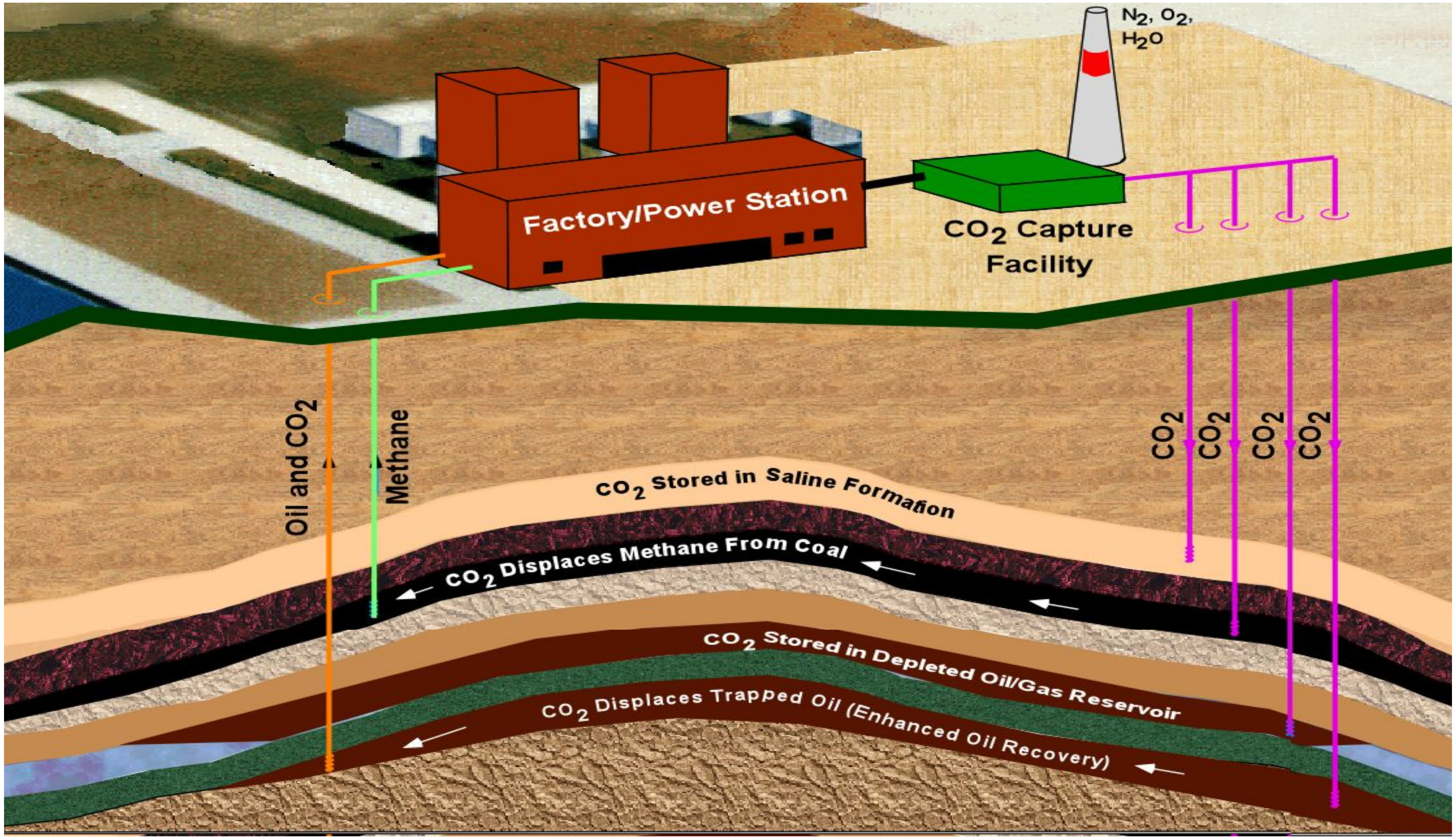
  = **PARITY** with expected ETS price
- 1st demo's cost: **€60-90 /t** CO_2 saved
- Cost 90% capture, 5% transport, 5% storage
- BASIS: 900MW plant, supercritical 50% effy "pre-CCS",86% availability/CF (**NO** CCS penalty), CCS eff'y penalty 7-12 "% points" (14-24% extra fuel), **ZERO*** EOR credit, 40 year life, hard coal €65/T, transp'+store 100km/onshore <-> 200km/ offshore
- **Extra** 200km transp' adds only €**10**/T

How CCS works

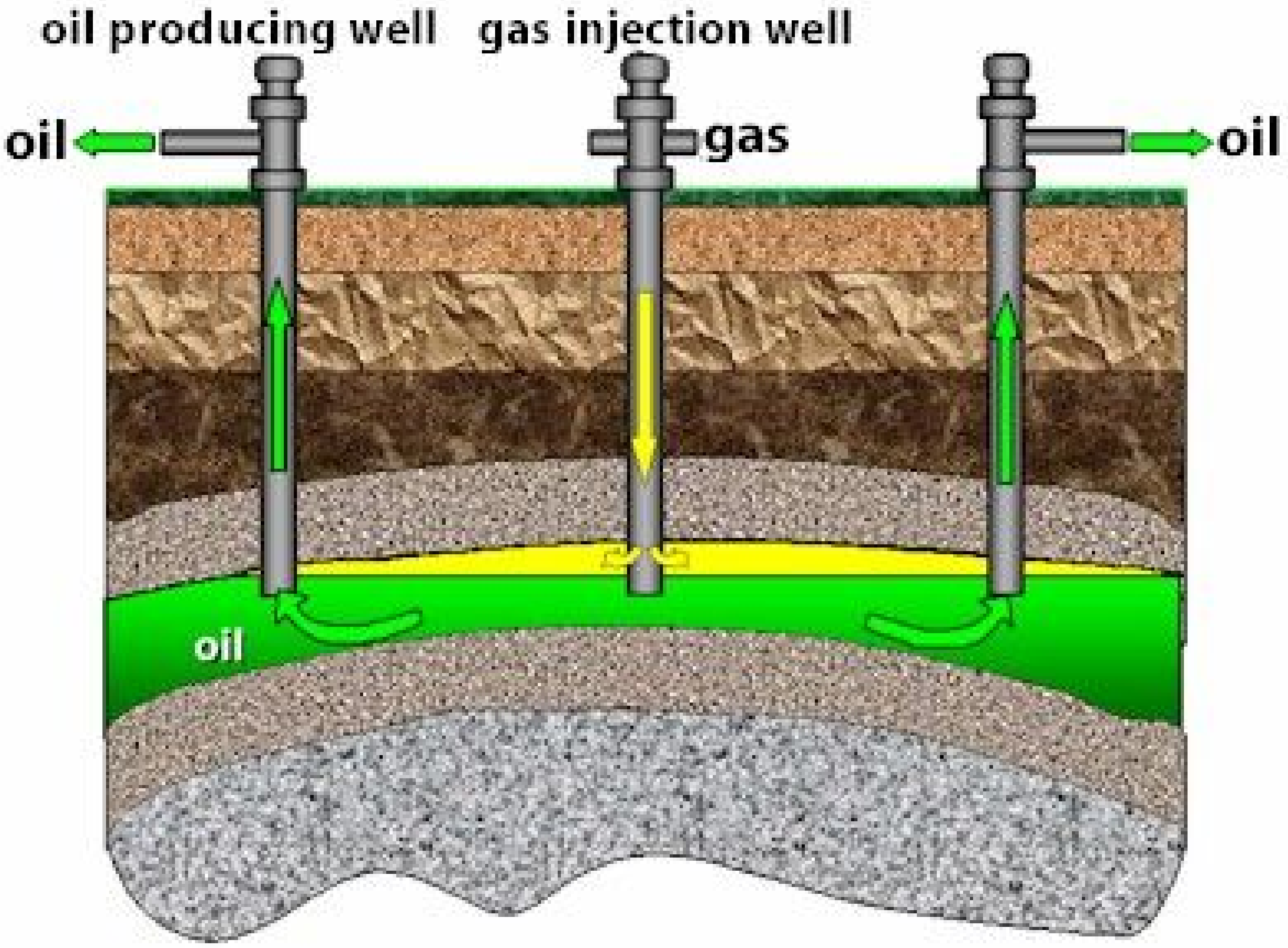
Picture courtesy CO2CRC



How CCS works - storage options



Enhanced Oil Recovery (EOR) process



Storage sites

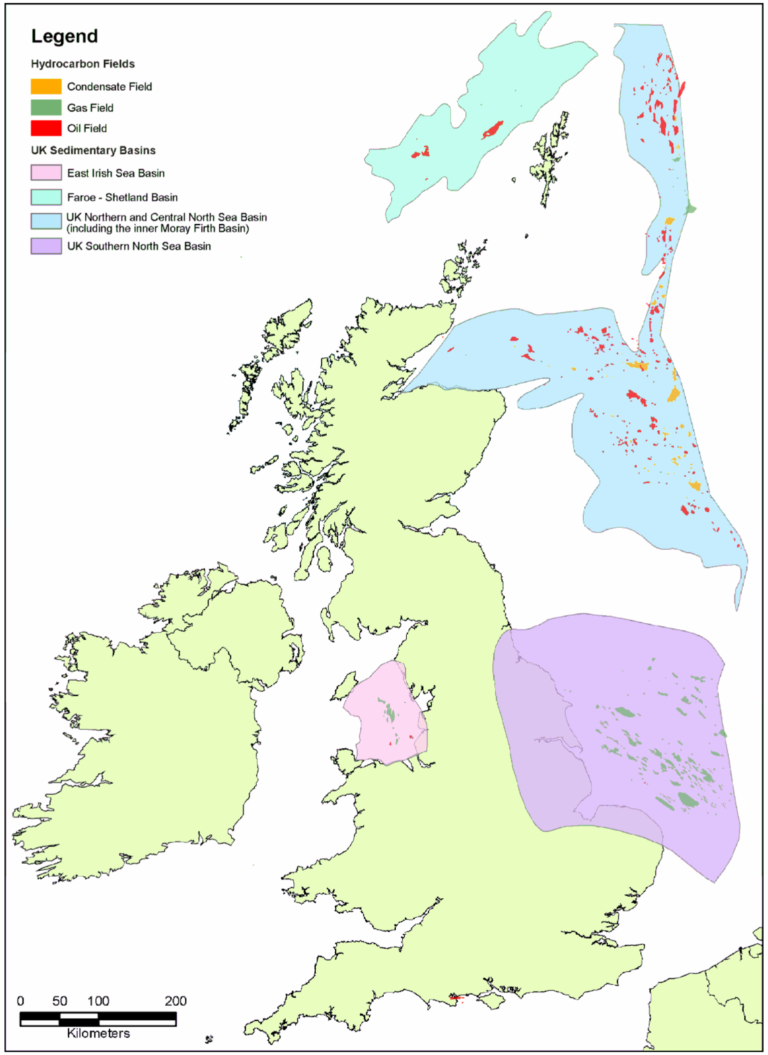
Oil fields

Gas fields

Gas/condensate fields

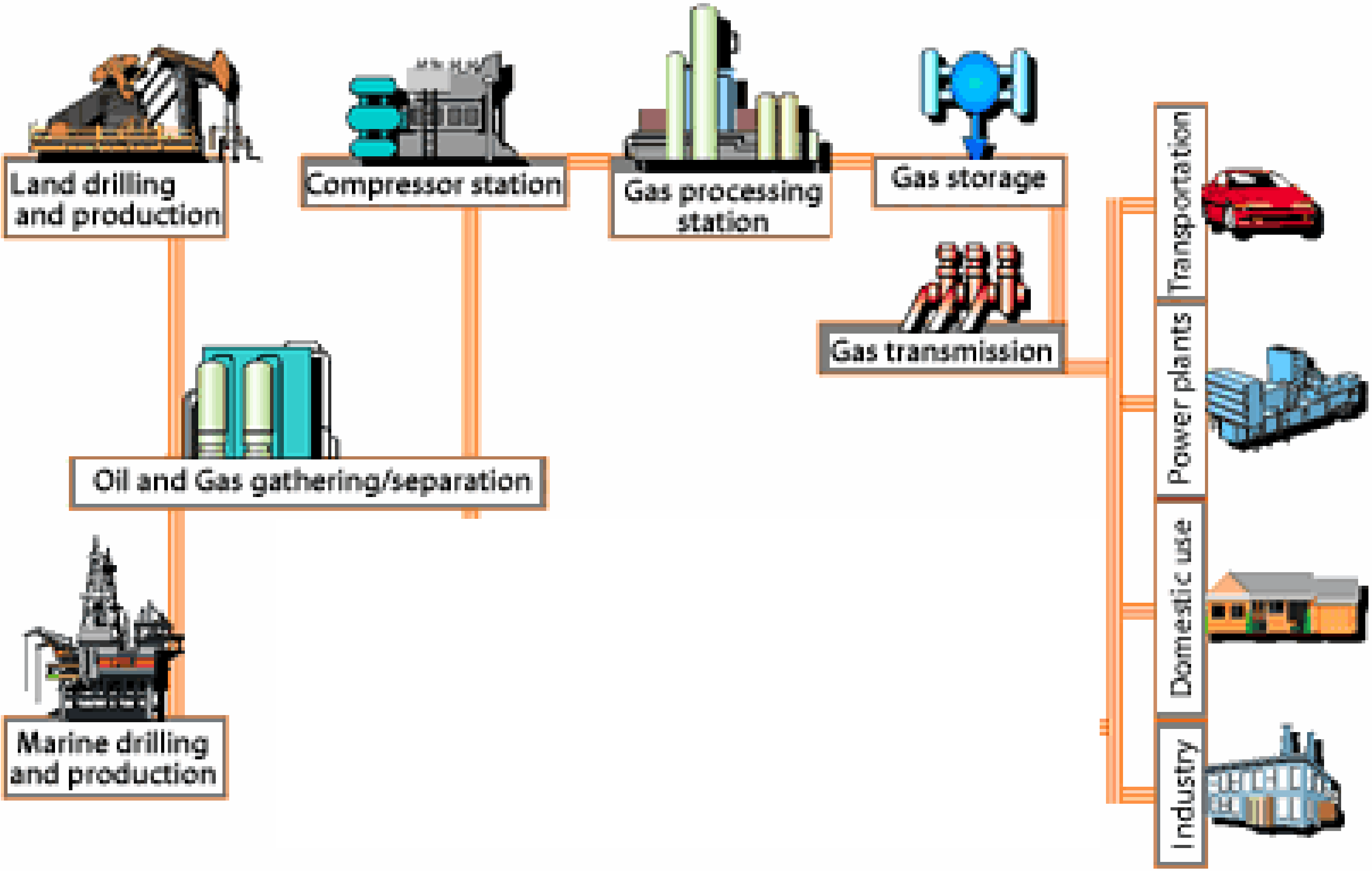
Saline-water-bearing reservoir rocks (saline aquifers)

Coal seams



(Courtesy BGS)

CO2 disposal pipeline network



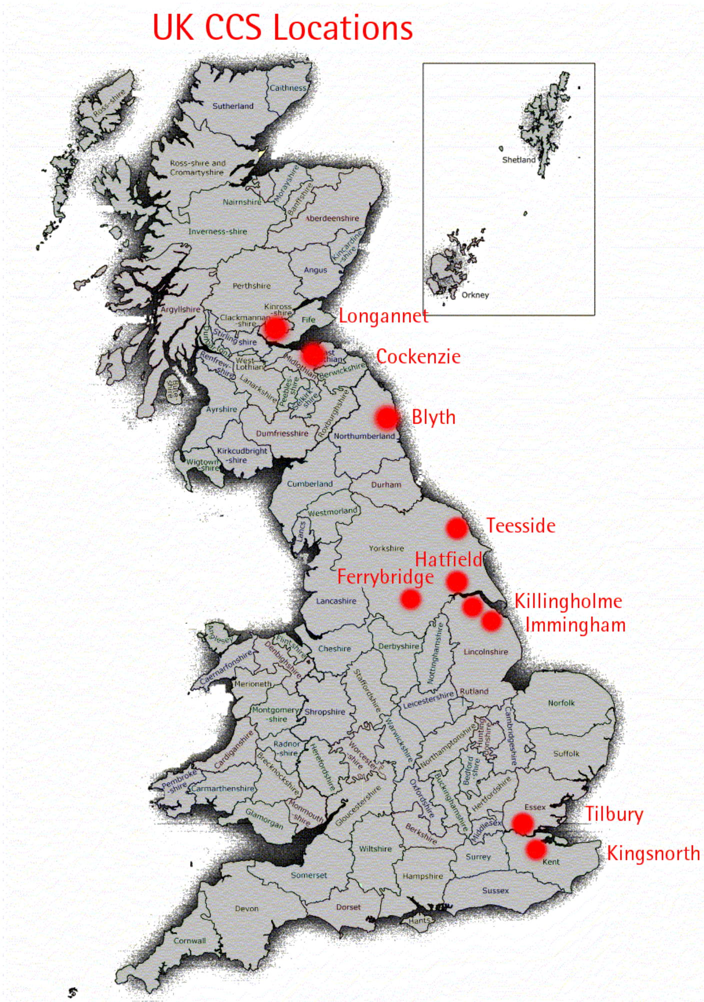
Carbon Capture & Storage Association

THE CARBON CAPTURE AND STORAGE ASSOCIATION (CCSA)

Proposed UK CCS Sites

(map source: The Association

of British Counties)



Oxygen-steam gasifiers-1

- Fixed-bed
  - Producers (P = 1 atm)
  - Lurgi
  - GSP (Lurgi copy)
  - BGL (slagging)
  - BGL Composite (hybrid fixed/ entrained)
- Fluidised bed
  - HTW (High-Temperature Winkler)
  - KRW (Kellogg-Rust-Westinghouse)
  - IGT U-GAS /CI

Oxygen-steam gasifiers-2

Entrained Flow

- Dry-feed upflow
  - Koppers-Totzek (P = 1 atm)
  - Prenflo (prev. Krupp-Koppers)
  - Shell SCGP (Shell Coal Gasif’n Process)
- Slurry-feed
  - Texaco/GE CVX (down-flow)
  - DESTEC E-GAS (prev. Dow) 2-stage up-flow
  - Siemens (ex-Noell-GSP) (down-flow)