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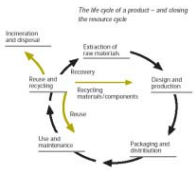
Life Cycle Assessment of alternative fossil fuel based power generation value chains

Dr Anna Korre
Minerals, Energy and Environmental Engineering Research
Department of Earth Science and Engineering
Royal School of Mines
Prince Consort Road
London, SW7 2BP

MERG



Imperial College's LCA model of fossil fuel power generation value chains

Key advantages

- Covers coal and conventional / unconventional natural gas based power generation value chains
- Accurate accounting of fuel/supply requirements and emissions (air, water, solid waste) per unit process/subsystem
- Modular structure allows combination of component processes to represent the specifics of any given value chain

Current developments

- Life cycle cost model for CO_2 storage
- CCS network evolution optimisation and real options assessment
- LCA modelling of the energy, water and food nexus

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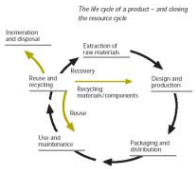
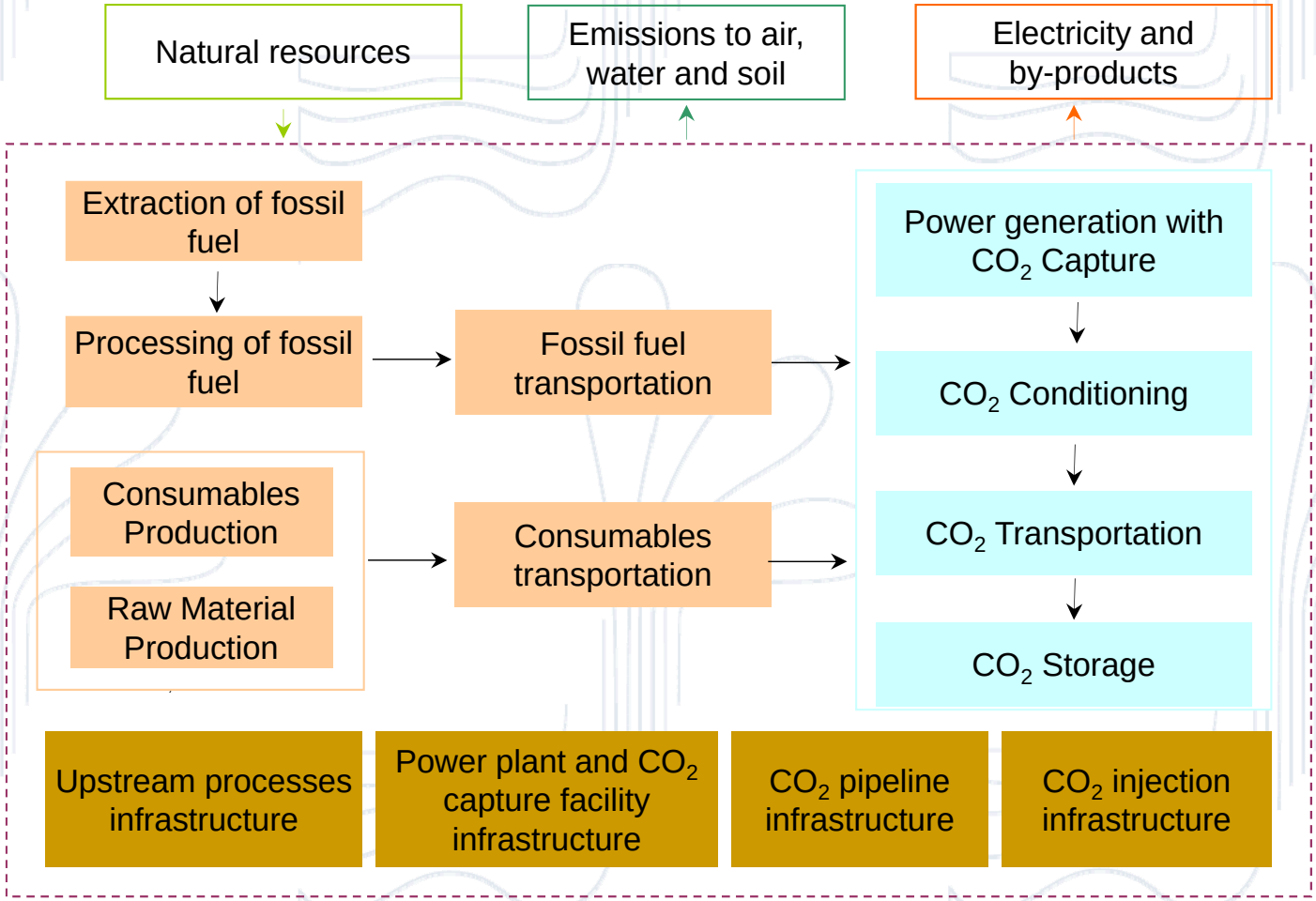


Life cycle impacts of energy production systems

- Developed a comprehensive LCA emissions analysis modelling system for fossil fuel production, transport, coal and gas-fired power plants fitted with CCS
- Aimed at comparing GHG and other emissions of technology alternatives on a fair basis.



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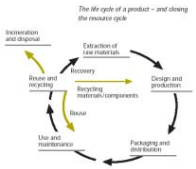
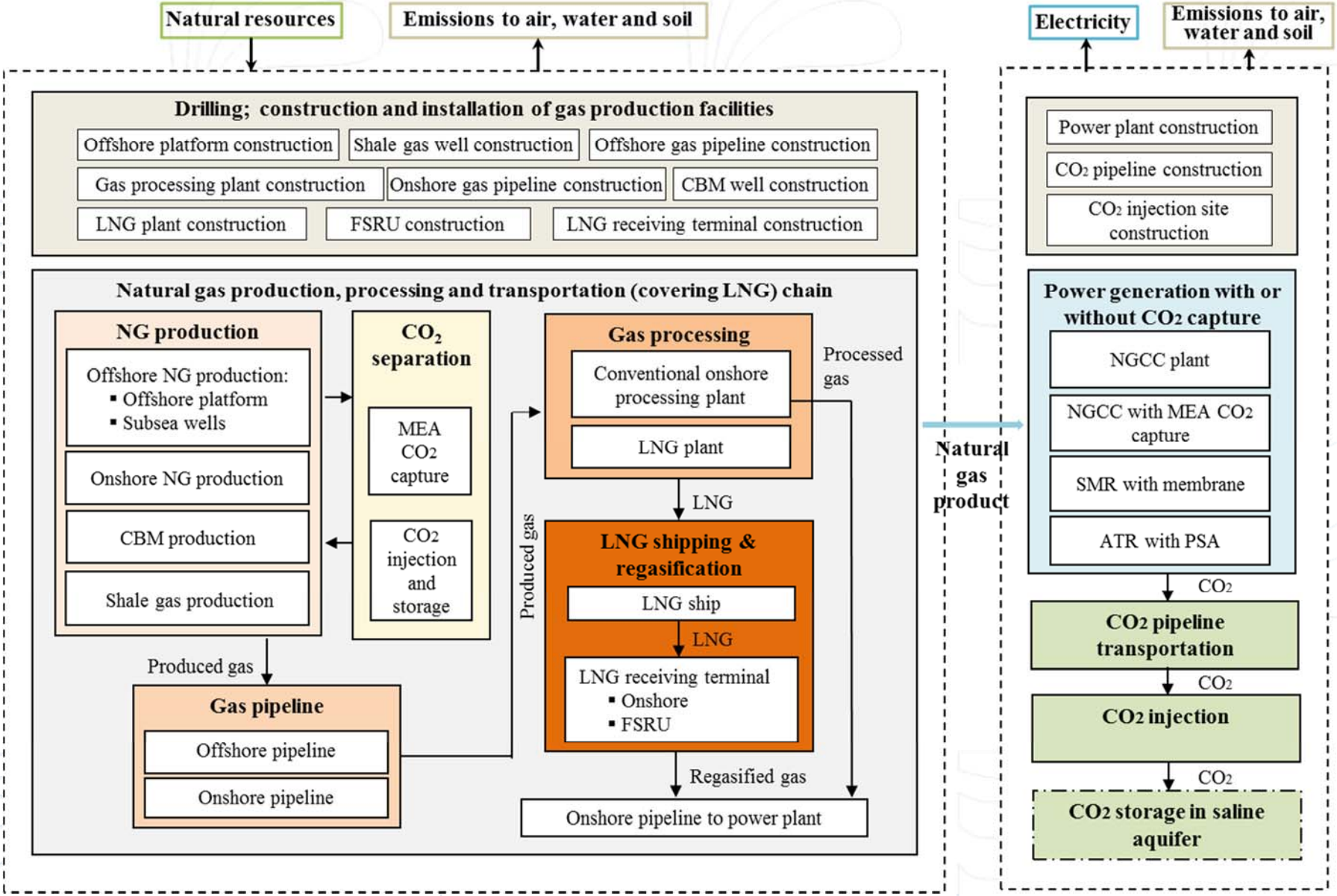


Life cycle impacts of energy production systems

Natural gas based value chain



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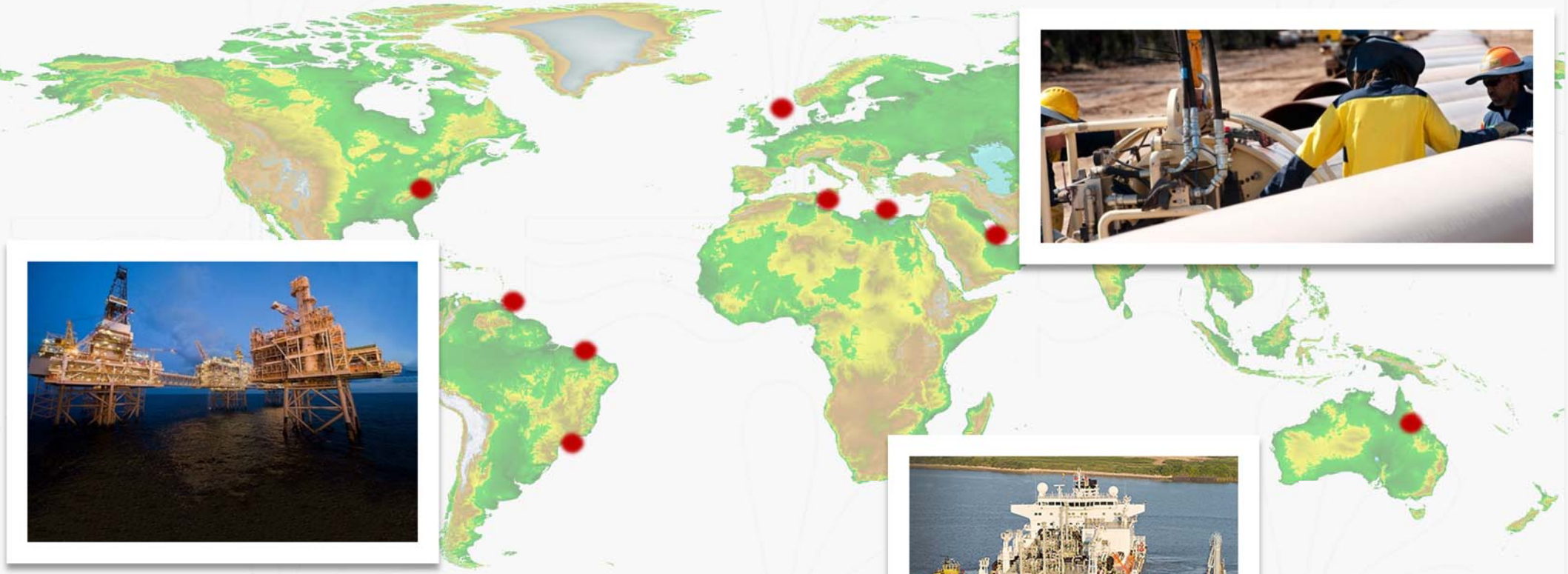
Life cycle impacts of energy production systems

Natural gas based value chain



- conventional, EOR/EGR, shale gas, coal seam gas resources
- pipeline and LNG transport

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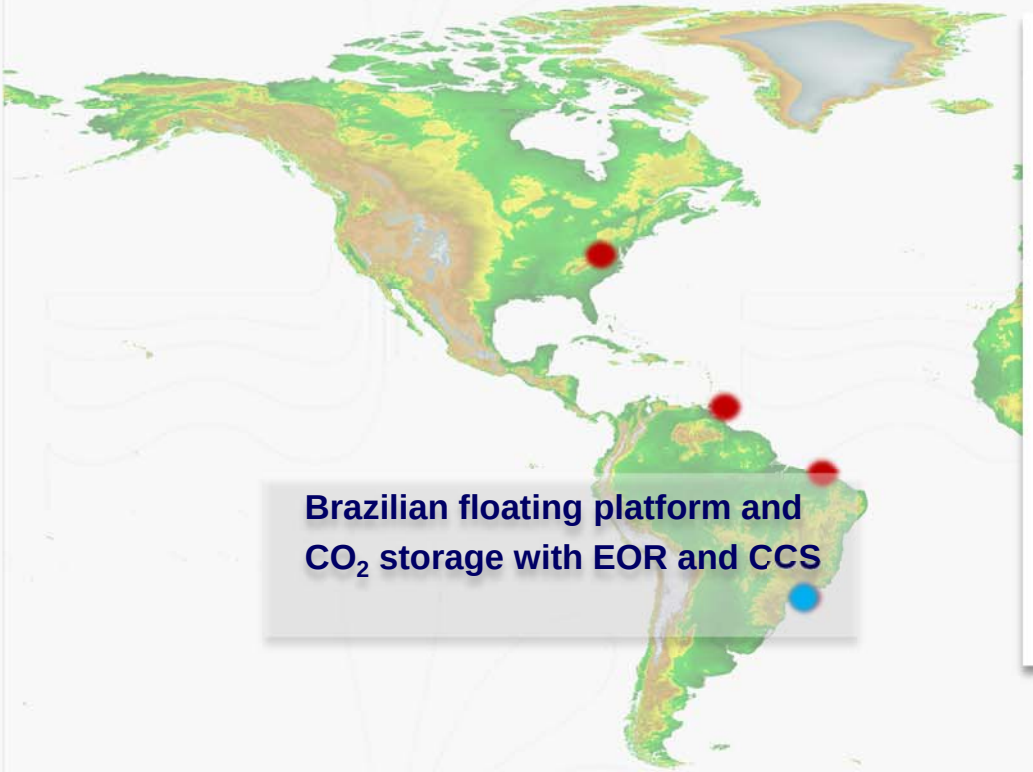
Emissions analysis of natural gas production



Brazilian floating platform and CO_2 storage with EOR and CCS

- combined gas cap and water drive reservoir
- oil with a small amount of gas and water are produced in the early years
- followed by significant amount of gas and water production including CO_2
- CO_2 is separated from the natural gas by chemical absorption
- CO_2 from the NG separation and the FPSO electricity generation is reinjected into the reservoir (WAG) is used for EOR

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Unit processes included in the offshore natural gas production LCI model

Platform drilling and production	**Reciprocating engine operation for HVAC**
	Drilling power generation
	Produced gas compression
	Emergency diesel engine operation
	Firewater pump operation
	Crane engine operation
	Emergency drilling
	Routine flaring
	Emergency flaring
Support vessels and transportation	Standby vessel operation
	Supply vessel operation
	Helicopter use
Routine maintenance	Production separator depressurisation (or blowndown)
	Gas pig launching
	Condensate pig launching
	Compressor blowndown
	Compressor starts
	Gas well workovers (tubing maintenance)
	Gathering gas pipeline blowndown
Non-routine maintenance	Emergency platform shutdown
	Pressure relief valves release
Other operations	Offshore gas well
	Completion
	Mud cuttings roll-off bins
Equipment leaks	Valve leakage
	Connector leakage
	Open end pipelines (OLEs) leakage
	Other leakage

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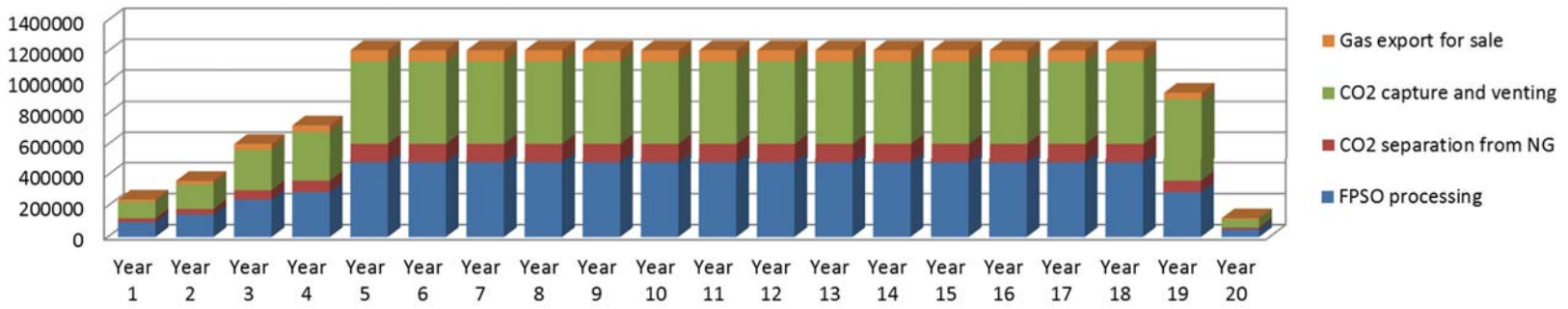
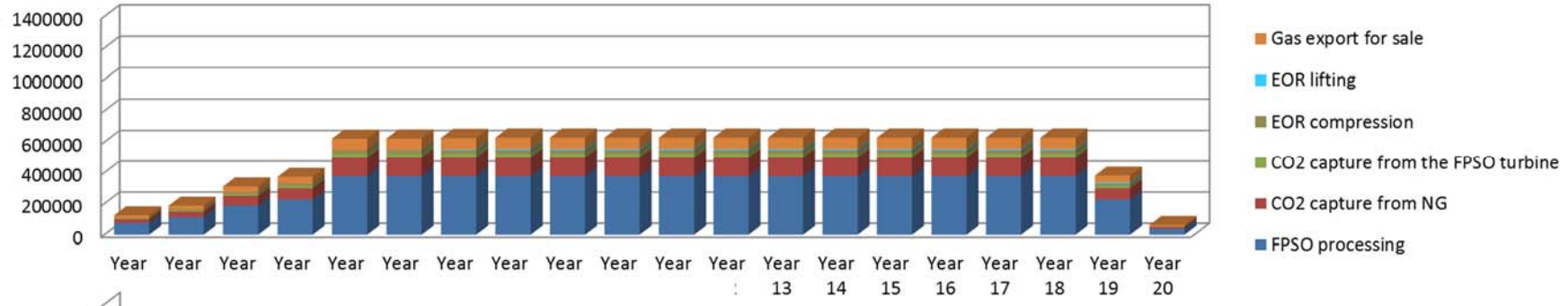
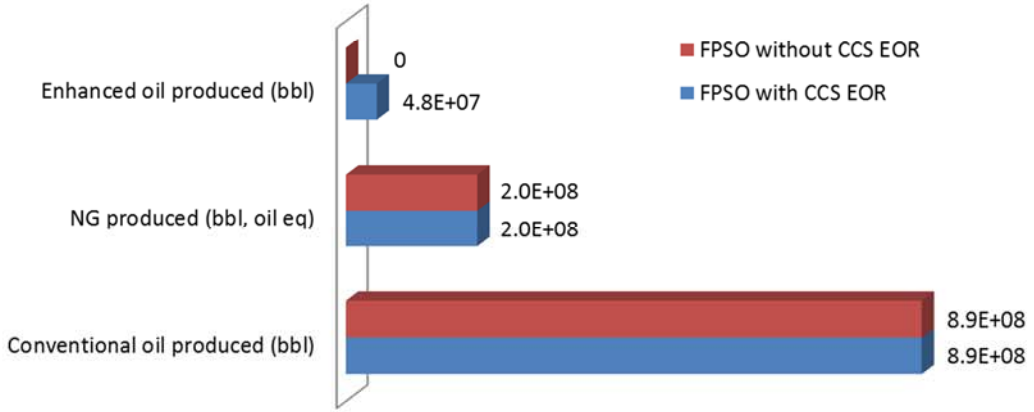
GHG emissions from the Brazilian FPSO without EOR (tonnes CO_2-e) per annum



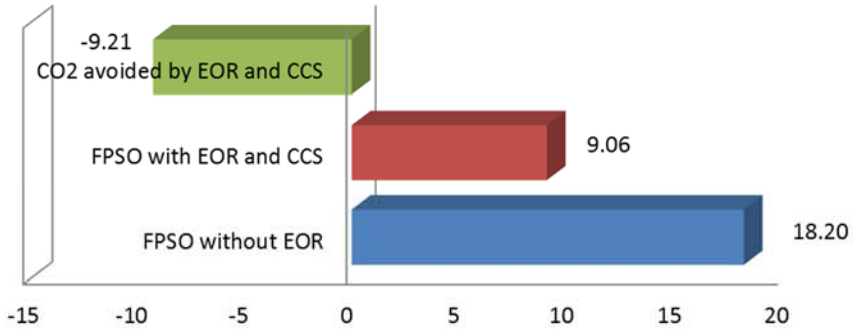
GHG emissions from the Brazilian FPSO with EOR and CCS (tonnes CO_2-e) per annum



Whole life of oil and gas production (bbl)



Life cycle GHG emissions (kg CO_2-e/bbl)



Emissions analysis of natural gas production

USA shale gas production and LNG transport to Europe via the southern seaboard

- Haynesville shale gas filed
- processing plant
- onshore pipeline to Lake Charles
- Lake Charles LNG plant
- LNG shipping
- LNG receiving terminal at Milford Haven, UK

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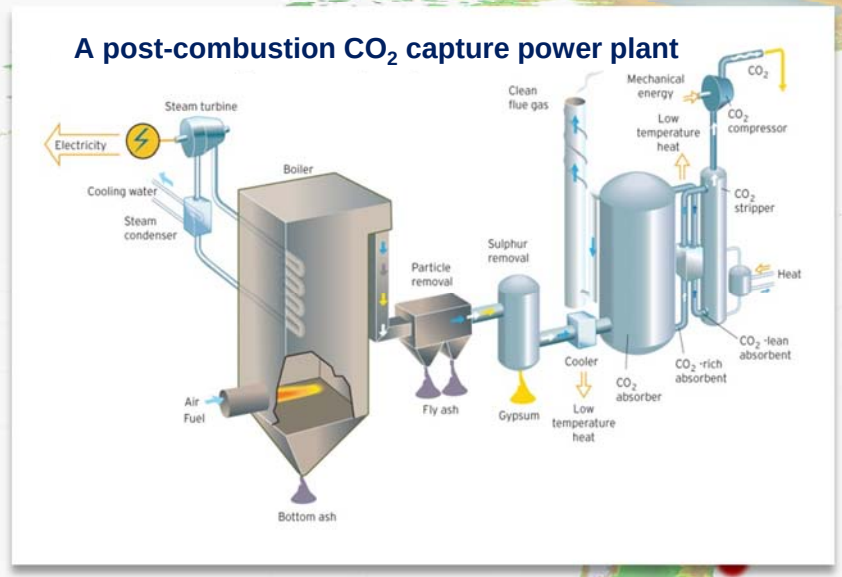
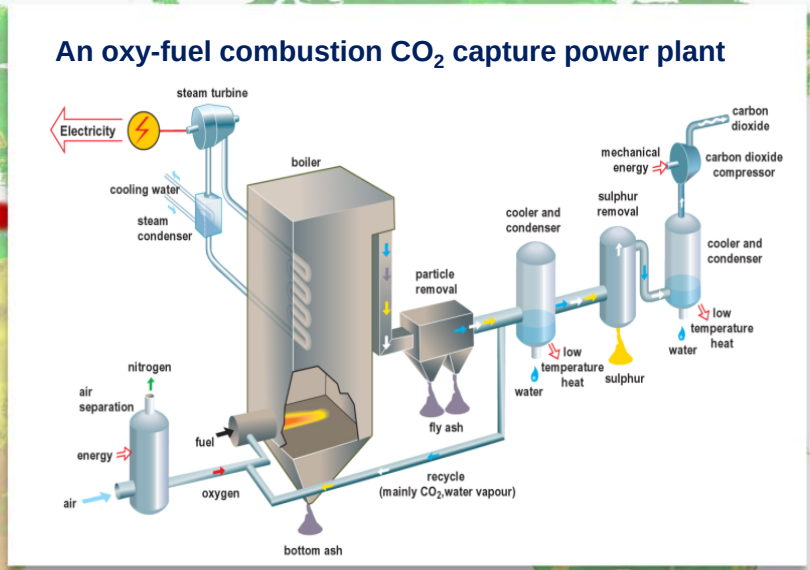
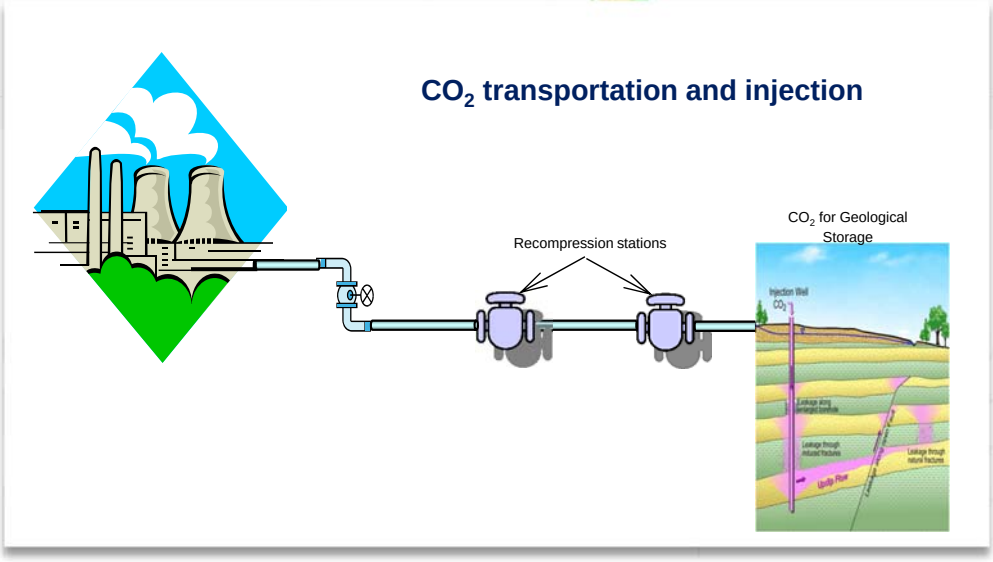
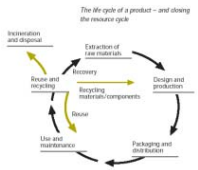
Life cycle emissions analysis of coal and natural based energy production without/with CO_2 capture and storage





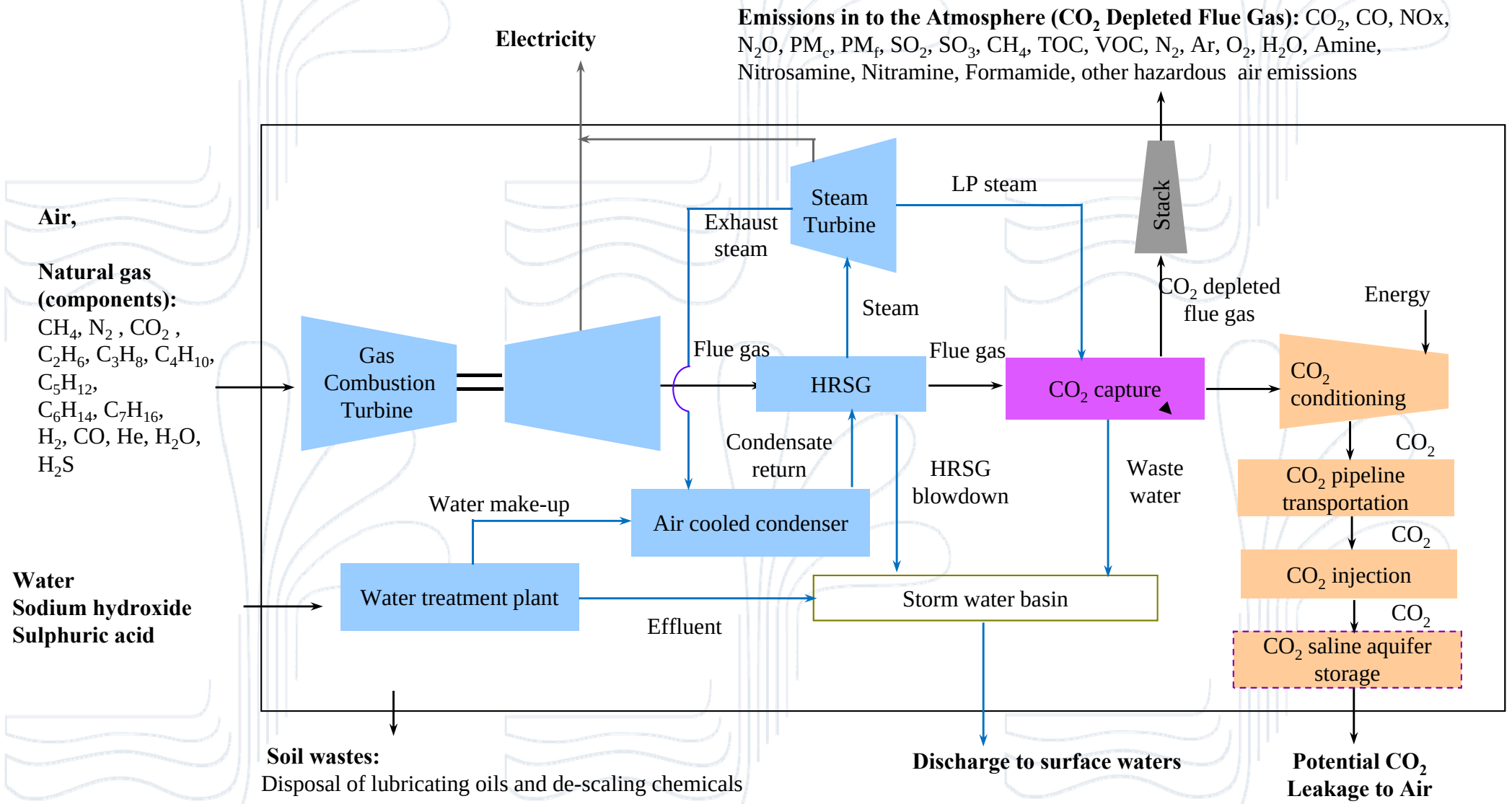


- alternative CO_2 capture options for power generation
- CO_2 transport and storage in saline formations, depleted fields, EOR/EGR



CCGT with post-combustion

CCS system and emissions



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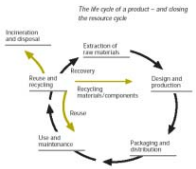


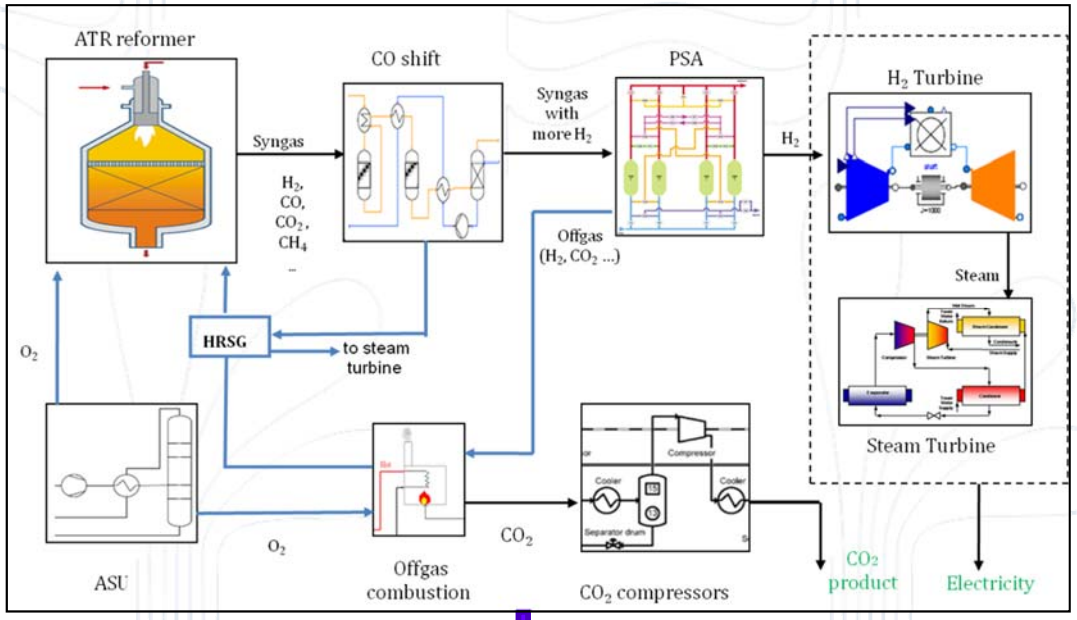
Auto-Thermal Reforming plant with Pressure Swing Adsorption CO_2 capture power plant

Configuration, inputs and outputs

ATR process: Steam/Carbon ratio	2
ATR process: O_2/Carbon ratio	0.5
PAS process: H_2 recovery ratio	95%
Hydrogen turbine: H_2 to electricity efficiency	60%

Natural Gas		
Component	**Formula**	**Mole fraction (%)**
Methane	CH_4	95.2
Nitrogen	N_2	1.3
Carbon dioxide	CO_2	0.7
Ethane	C_2H_6	2.5
Propane	C_3H_8	0.2
Butane	C_4H_{10}	0.06
Pentane	C_5H_{12}	0.02
Hexane	C_6H_{14}	0.02
HHV	Btu/scf	1014.52

Steam
O_2



Plant overall efficiency:	42.6%
Natural gas used per MW electricity generated:	158.49
GHG emissions kg/MW:	42.56
CO_2 captured and compressed kg/MW :	394.50

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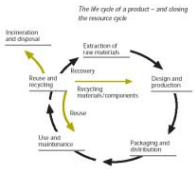
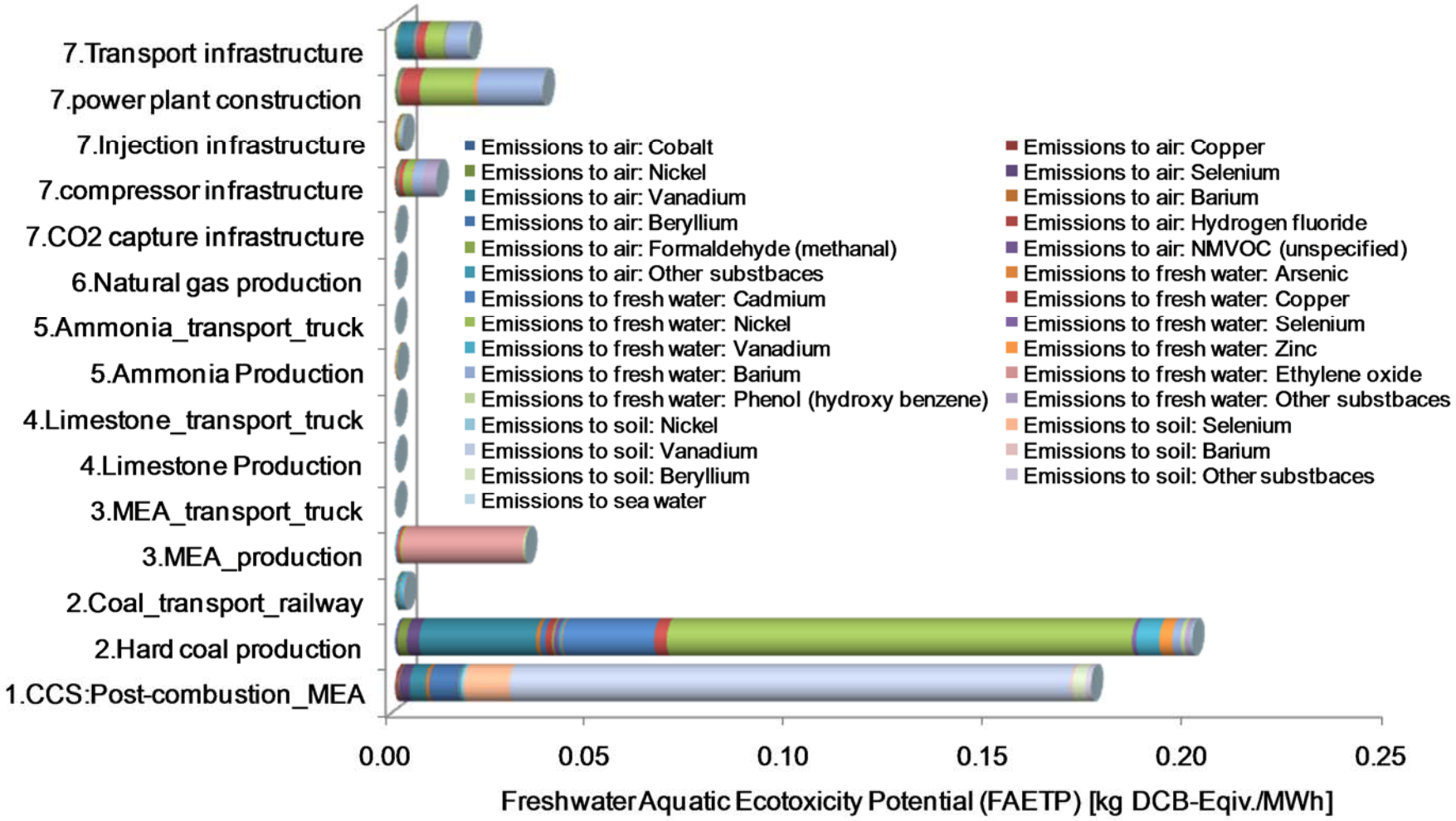


Freshwater aquatic ectoxicity poterntial for a 500 MW coal fired power plant with post-combustion capture, transport and injection



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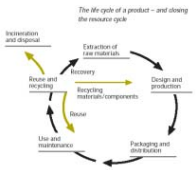


Life cycle impacts of energy production systems

Comparison of gas fired power plants with clean coal alternatives

A Case Study: full chain analysis of Qatar natural gas to a UK power plant without/with CCS

Qatar North Field offshore natual gas production

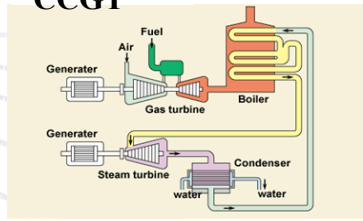
Gas processing and LNG plant at Ras Laffan

LNG shipping (Q-Max & Q-Flex): from Qatar to the UK via Suez

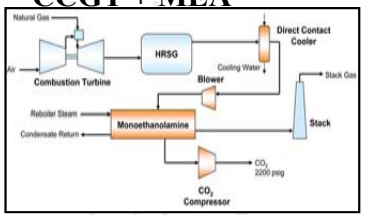
Receiving terminal at South Hook + onshore gas pipeline to power plant

Alternative gas power generation with/without CO_2 capture

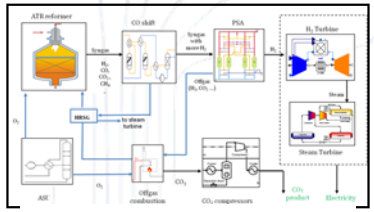
CCGT



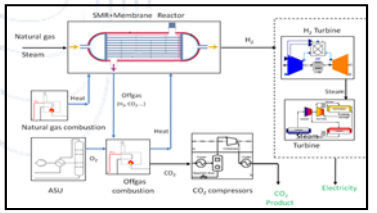
CCGT + MEA



ATR with PSA

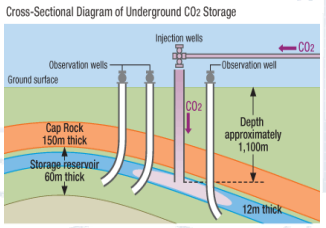


SMR + Membrane



CO_2 pipeline transportation

CO_2 injection into saline aquifer



Qatar North Field offshore production(1730 MMscf/day) → undersea pipeline (80 km)→ Gas processing and LNG plant at Ras Laffan (2×7.8MTPA) → LNG shipping (Q-Max & Q-Flex): from Qatar to the UK via Suez Canal (11281 km) → Receiving terminal at South Hook (2×7.8MTPA) → onshore gas pipeline to power plant (100km) → Alternative Gas power generation with/without CO_2 capture → CO_2 pipeline transportation (300km) → CO_2 injection into saline aquifer (161t/hr)

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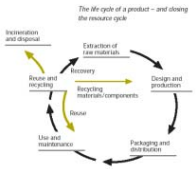
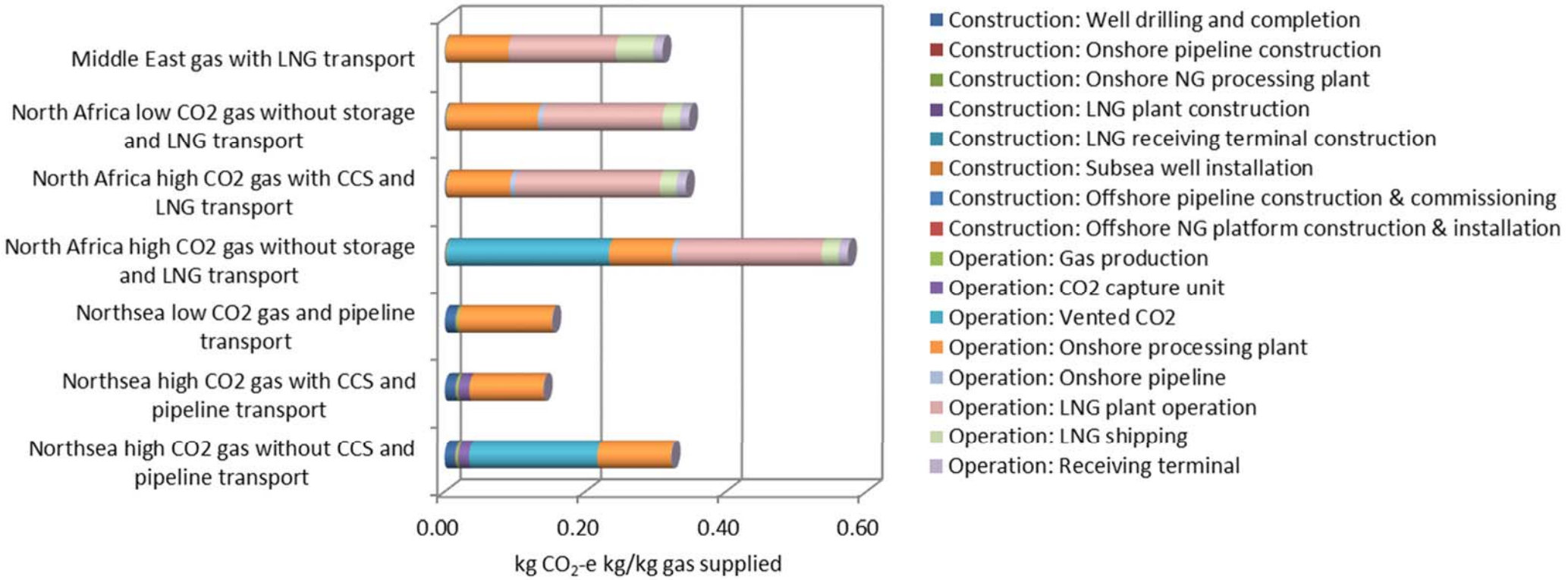


Comparison of GHG emissions for different gas supply options to the UK market



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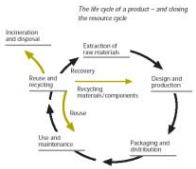

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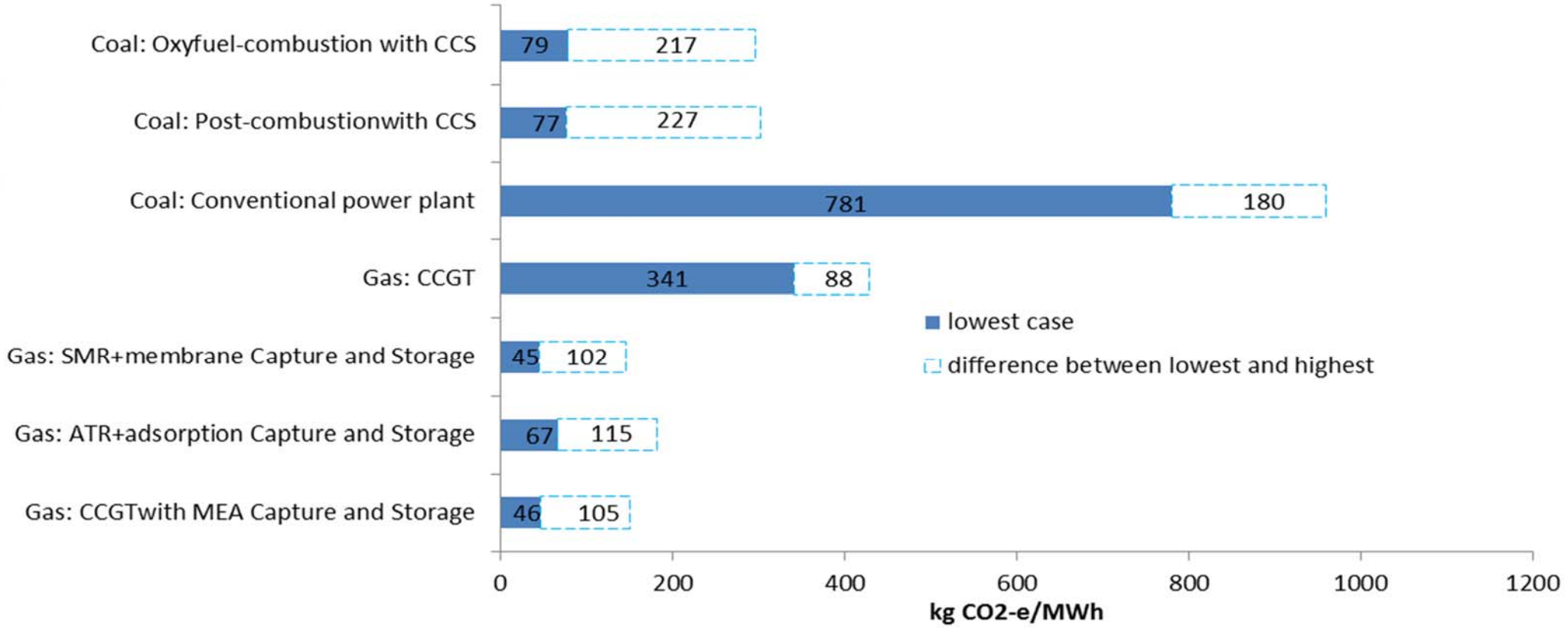

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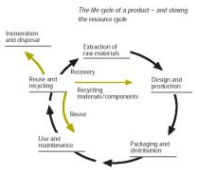

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- CCS network evolution optimisation and real options assessment
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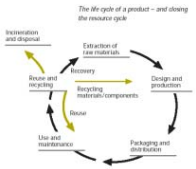
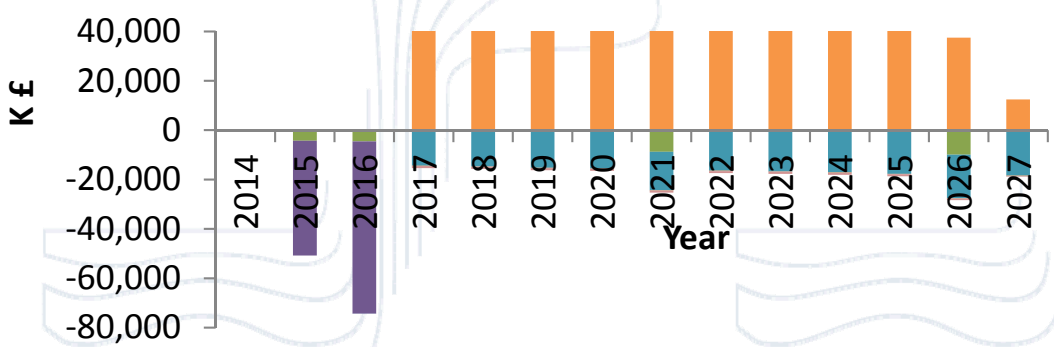
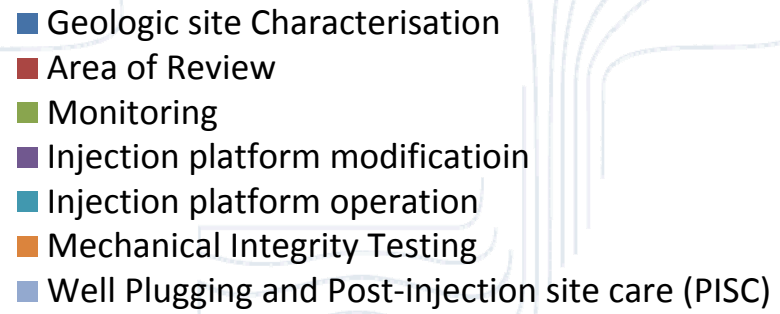
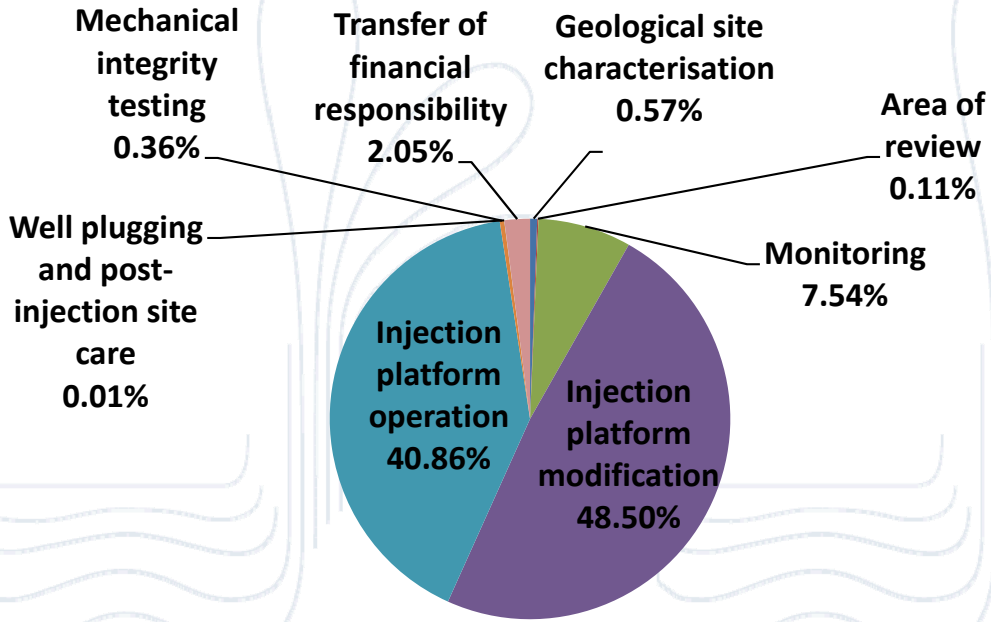


Life cycle cost modelling of CO_2 injection and storage







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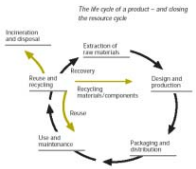
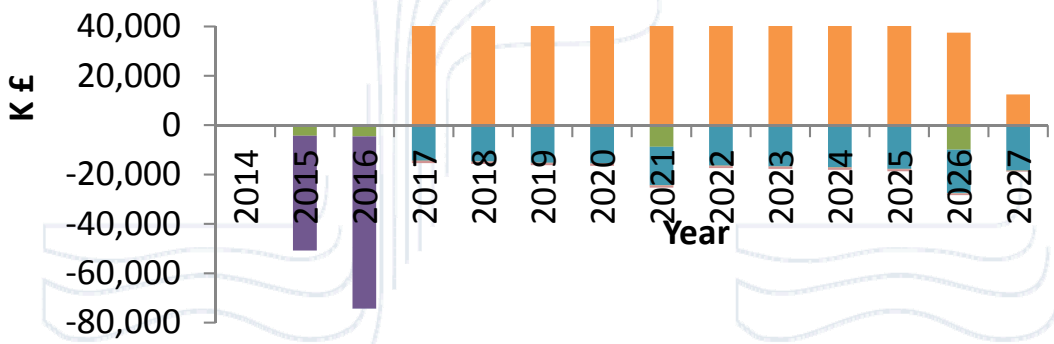
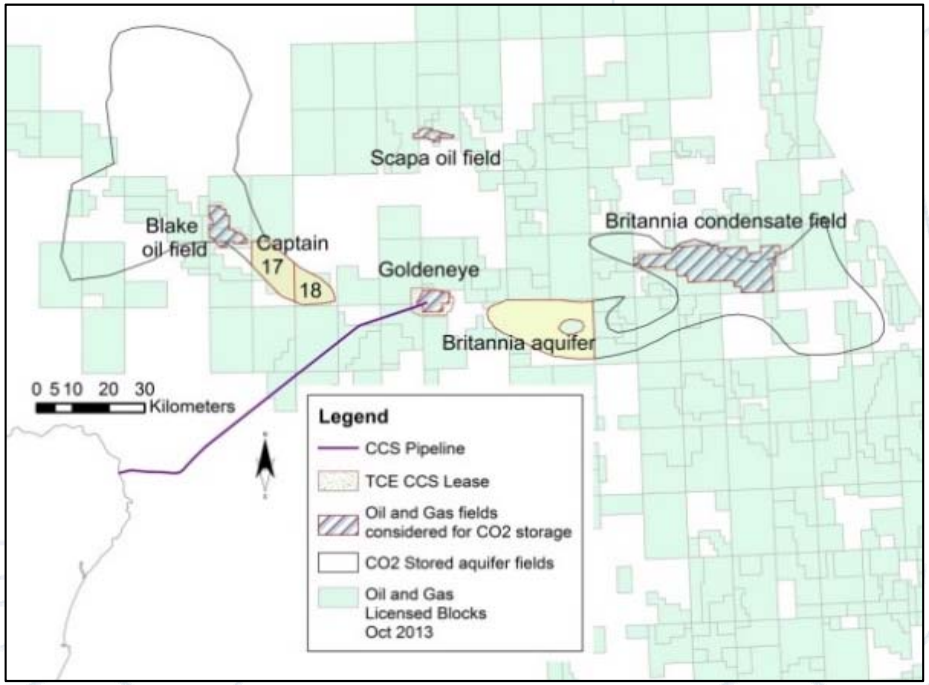
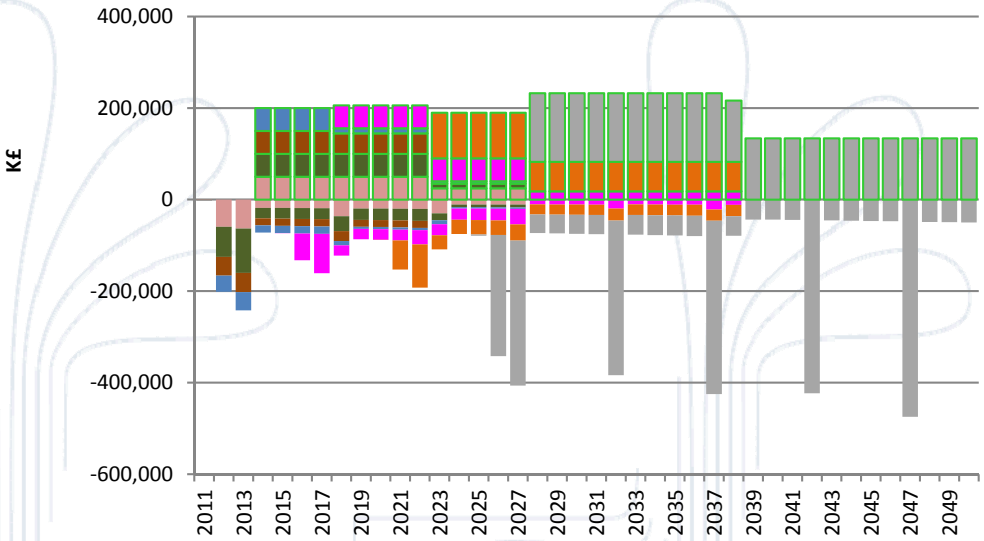


Life cycle cost modelling of CO_2 injection and storage



- Geologic site Characterisation
- Area of Review
- Monitoring
- Injection platform modificatioin
- Injection platform operation
- Mechanical Integrity Testing
- Well Plugging and Post-injection site care (PISC)





Open season leasing cashflow per storage site

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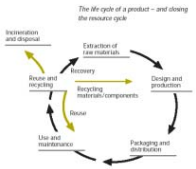
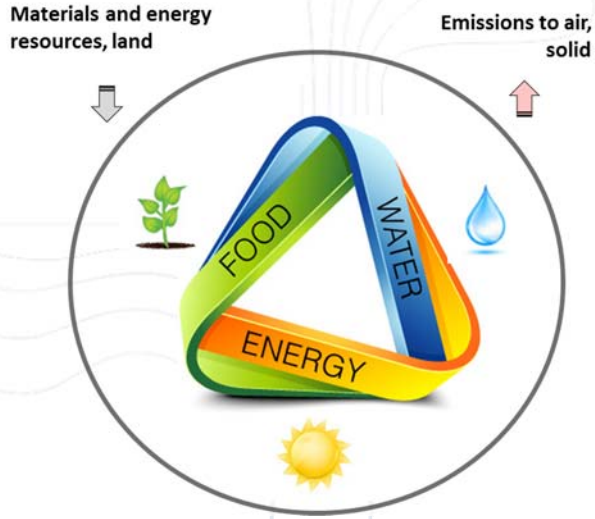


Energy, Water and Food Nexus LCA Model



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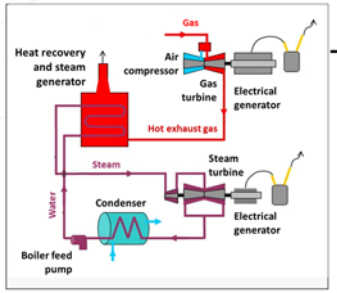
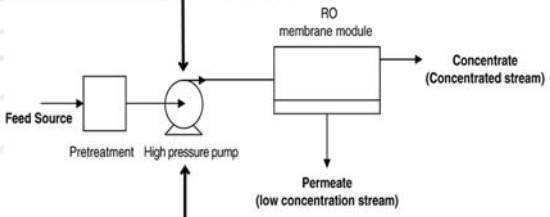


FLUE GASES (Kg/MWh)			
CO_2	338.567708	Ar	32.26393262
CO	0.900072272	O_2	85.09740814
NOx	0.797659686	H_2O	271.9328724
N_2O	0.00809087	1,3-Butadiened	0.001159691
$PM_{cond.}$	0.012675697	Acetaldehyde	0.107878272
$PM_{filt.}$	0.005124218	Acrolein	0.017260524
SO_2	0.00871117	Benzenee	0.032363482
SO_3	0.000458483	Ethyl benzene	0.086302618
Methane	0.023193829	Formaldehydef	1.914839334
TOC	0.029666525	Naphthalene	0.003506044
VOC	0.005663609	PAH	0.005933305
N_2	1866.261752	Propylene	0.078211747
		Toluene	0.350604385
		Xylenes	0.172605236

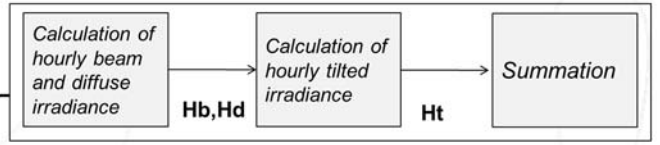


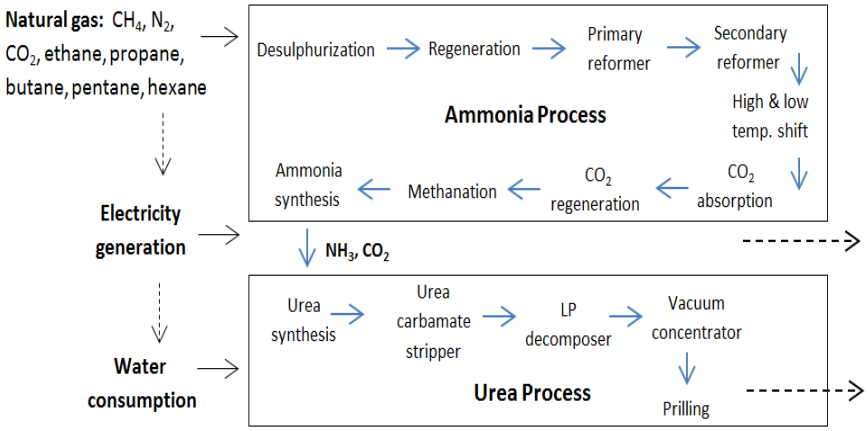
Reverse Osmosis Energy requirement

$$NDP = P_f - P_{os} - P_p - 0.5P_d + P_{osp}$$

Where; P_f is the feed pressure, P_p= permeate pressure, P_d = pressure drop across RO elements, P_{osp} is the osmotic pressure of permeate, NDP is the net driving pressure.

Solar PV





Operational Parameters:
Consumption of 0.567 ton NH_3 and 0.734 ton CO_2 per ton of urea produced

Emissions (air & water): CO_2, CO, NOx, N_2O, $PM_{cond.}$, $PM_{filt.}$, SO_2, SO_3, CH_4, TOC, VOC, N_2, Ar, O_2, H_2O, 1,3-butadiene, acetaldehyde, acrolein, Benzene, ethyl benzene, formaldehyde, naphthalene, PAH, propylene, toluene, xylenes, NH_3,

Urea (CON_2H_4)

- **CCGT, Solar PV**
- **Reverse Osmosis**
- **Fertiliser production and application, raising of livestock, vegetable and fruit production**
- **Water requirement for energy and food production**

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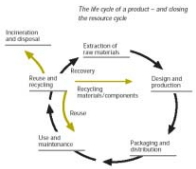
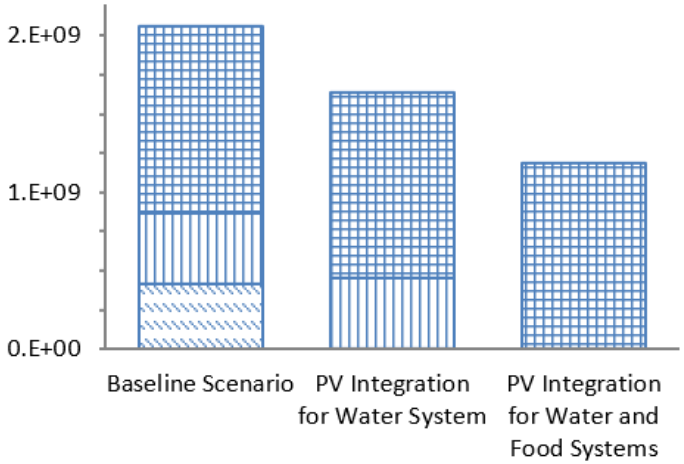
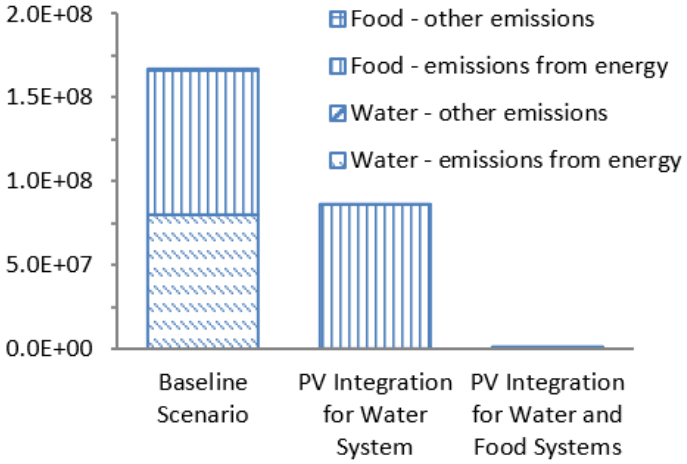


Energy, Water and Food Nexus LCA Model

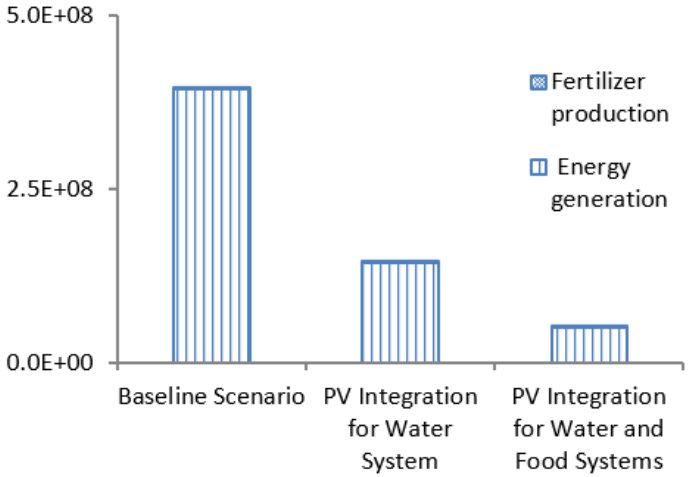
Total Global Warming Potential (kg CO_2 eq.)



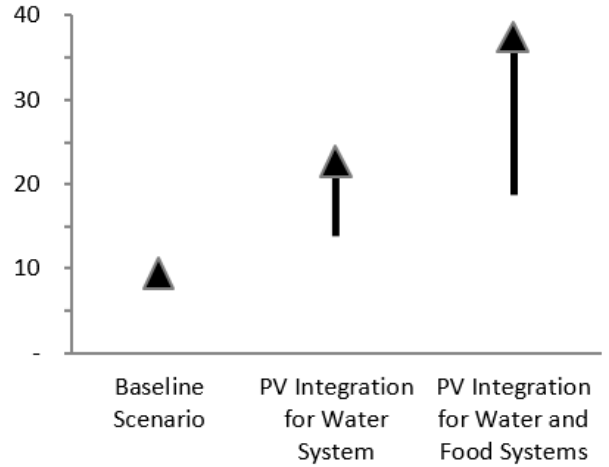
Total Human Toxicity Potential (kg 1, 4-DCB eq.)



Natural Gas Consumption (kg/year)



Total Land footprint ('000 Ha)



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Further information:

Dr Anna Korre
Imperial College London
Department of Earth Science and Engineering
Royal School of Mines, Prince Consort Road,
London SW7 2AZ, UK
Tel.: +44 (0)20 759 47372

a.korre@imperial.ac.uk