Bottom-up approaches to estimate life cycle GHG emissions of fossil fuel production, transport, energy production, CO_2 capture and storage

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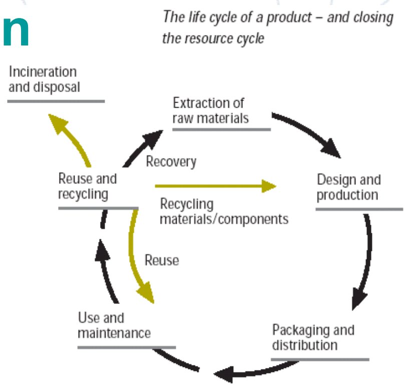
Outline

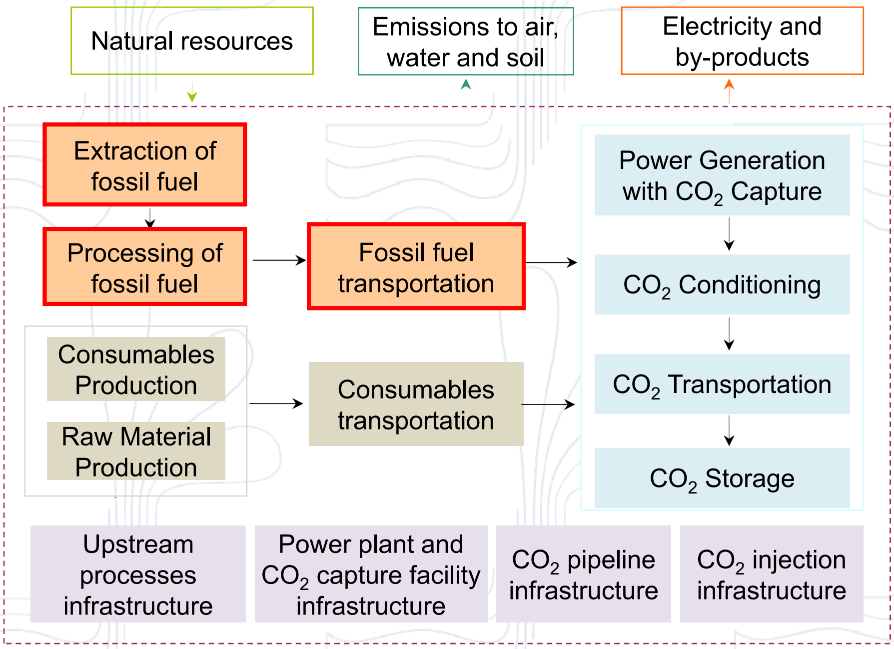
- Imperial College's Life cycle assessment (LCA) model
- LCA boundaries of CCS system
- Life cycle inventory (LCI) modelling
  - example LCI models for coal and gas
- Case study: Middle East natural gas production, LNG transport and power generation in the UK
- Limitations of current bottom-up studies used to inform emission factors
- Challenges of evaluating GHGs emissions across the value chain

Life Cycle Assessment definition



Life Cycle Assessment (LCA) is an objective process to evaluate the environmental burdens associated with a product, process, or activity by identifying energy and materials used and wastes released to the environment, and to evaluate and implement opportunities to affect environmental improvements.

Imperial College's LCA model (ICLCA) of fossil fuel production, transport, power generation value chains



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

Key advantages

- Covers conventional / unconventional fossil fuel value chains for coal and natural gas
- Accurate accounting of fuel/materials 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 development
- CCS network evolution optimisation and real options assessment

Approaches for life cycle inventory analysis

Published emission factors

Equipment manufacturer emission factors

Engineering calculations*

Process simulation or other computer modelling

Emissions monitoring over a range of conditions and deriving emission factors

Periodic or continuous monitoring of emissions or parameters for calculating emissions

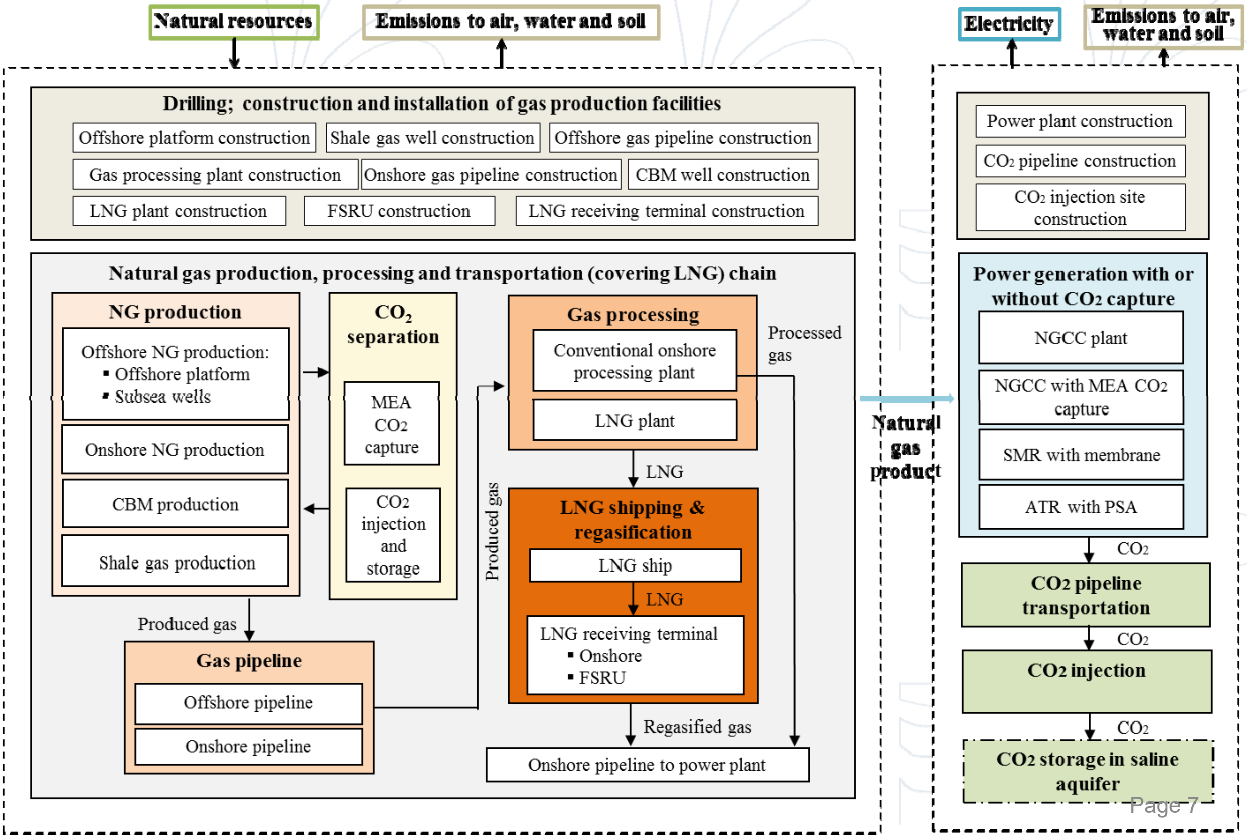
Improved accuracy

Additional data requirements

Higher cost

***: Engineering calculations are based on basic chemical or physical principles of a process, considering operational parameters.**

LCA model of the natural gas supply chain and power generation options



Unit processes in the offshore natural gas production LCI model

www.bp.com

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

Unit processes included in the gas processing plant LCI model

www.linde-le.de/
process_plants/gas_processing/index.php

Combustion equipment operation
Auxiliary boilers (natural gas fired)
Hot oil heaters (natural gas fired)
Gas turbines for recompression (natural gas fired)
Gas turbines for electrical generation (natural gas fired)
Flaring, pilot flaring (dry gas, low sulphur)
Emergency flaring (acid gas, low pressure)
Emergency flaring (acid gas, high pressure)
Tail gas incineration (acid gas)
Emergency fire water pump IC engines (diesel fired)
Venting equipment operation
Dehydration vents (including Kimray pump emissions)
Gas processing /sour gas treatment
Condensate storage tank operation
Compressor starts
Compressor blowdowns
Processing maintenance blowdowns
Fire incidents
Operation of equipment releasing fugitive emissions
Valves
Pump seals
Flanges
Compressor seals

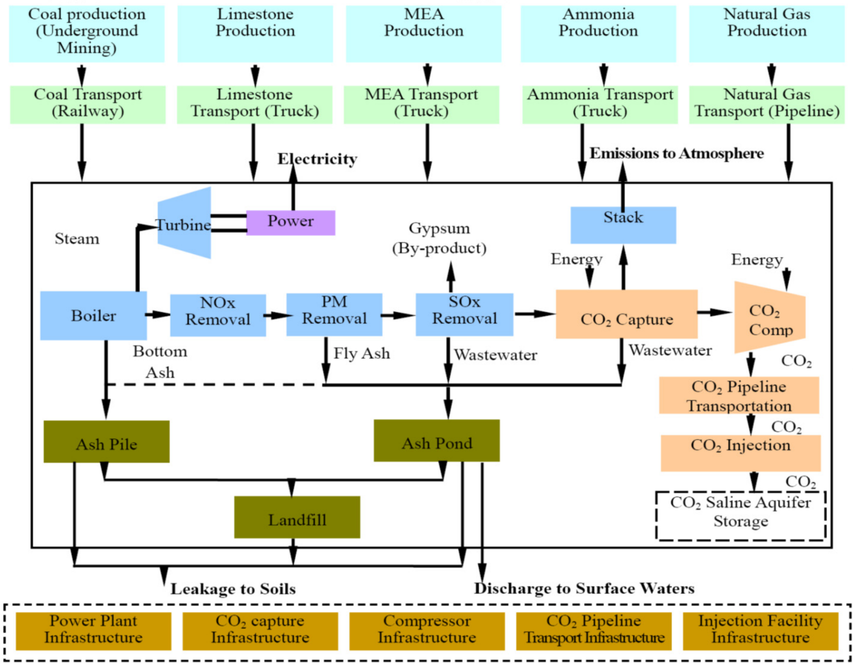
Unit processes included in the LNG Plant LCI model

Melkøya Norway (2008)
Photo: Eiliv Leren / Statoil

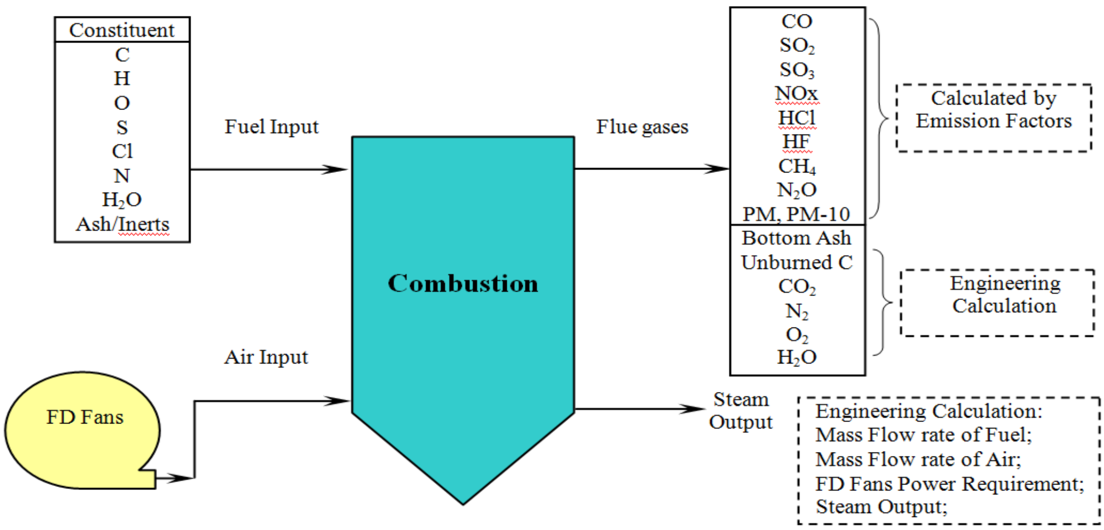
Combustion and venting equipment operation
Refrigeration compressor turbines
LNG facility power
Hot oil heater
Additional power for ship at berth
Acid gas venting (H_2S removal and CO_2 knock out) with incinerator
Methane in nitrogen purge
Operation of equipment releasing fugitive emissions
Valves, flanges, seals and connectors
Routine flaring
Purge gas flaring (dry gas, wet gas and marine faring)/Pilot flaring
Ship loading
Flash gas flaring
Non-routine flaring
Dry flaring
Wet flaring
Marine flaring

Life Cycle Model for CO_2 Capture and Geological Storage

Component LCI Models: Post-combustion CCS system



Coal combustion Life Cycle Inventory model



LCI results of coal combustion
PC wall-fired dry bottom boiler
1 MWh electricity generated

Materials	Mass flow (kg)
Coal	295.82
O_2	780.63
N_2	2,950.79

Energy (kW)	2.17

Combustion

Flue Gas Emissions (kg)

O_2	156.127	Antimony	4.16E-05
N_2	2,954.99	Arsenic	2.21E-03
H_2O	188.166	Beryllium	6.44E-04
CO_2	766.718	Cadmium	6.69E-05
PM	14.481	Chromium	7.92E-04
PM-10	3.331	Cobalt	2.90E-04
SO_2	3.417	Lead	5.46E-03
SO_3	0.025	Manganese	1.97E-03
S	0.025	Nickel	4.85E-04
NO	0.843	Selenium	2.78E-04
NO_2	0.044	Zinc	1.39E-02
CO	0.074	Copper	2.61E-03
HCl	0.178	Thallium	1.74E-04
HF	0.022	Vanadium	6.69E-03
CH_4	0.006	Barium	3.48E-02
N_2O	0.004	Silver	1.74E-05
TOC	8.875	Hg^0	1.88E-05
		Hg^{2+}	2.57E-05
		Hg_p	3.48E-05

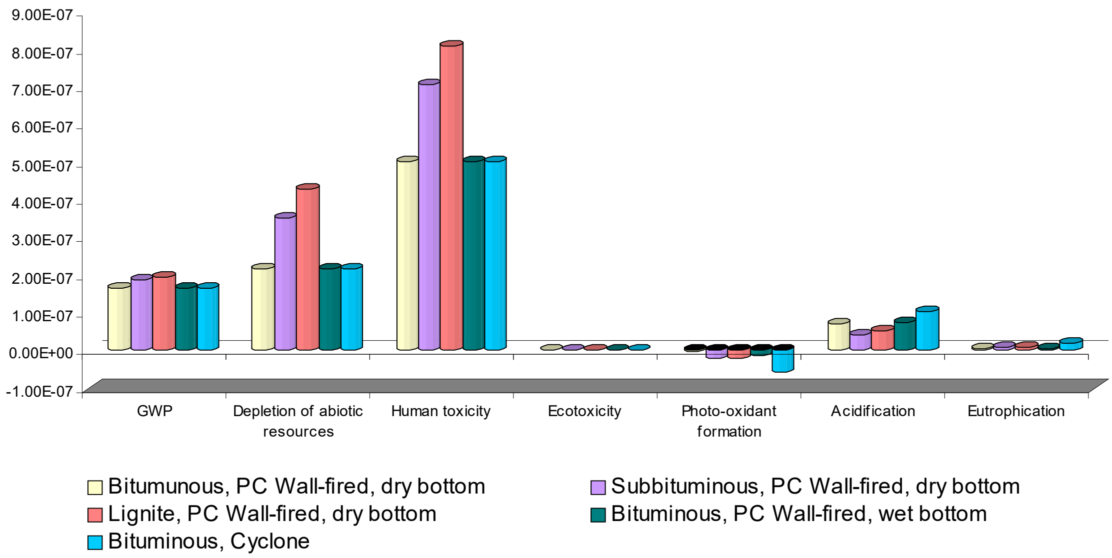
Steam	8100 MJ

Solid Releases (kg)	
Bottom ash	14.48
S (Bottom ash)	0.26
Unburnt carbon	2.11

Hg^0 is elemental mercury, Hg^{2+} is oxidised mercury and Hg_p is particle-bound mercury

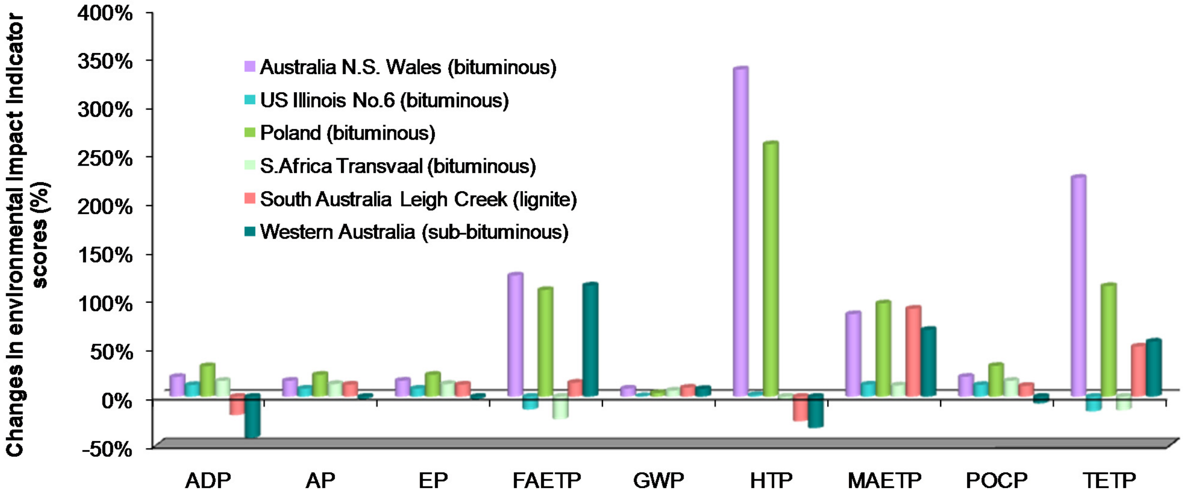
Coal combustion process LCI Model results

Normalised LCIA results of alternative coal and coal combustion technology options based on World 1995 normalisation scores



Sensitivity analysis: Plant level effect of coal type on life cycle impact indicator scores (post-combustion CO_2 capture with MEA, transport and injection)

the baseline case represents a 500 MW plant using a US Appalachian low sulphur bituminous coal



Case study: full chain analysis of Middle East natural gas to a UK power plant without/with CCS

Offshore natural gas production

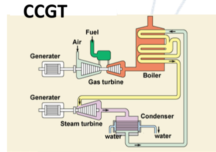
Gas processing and LNG plant

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

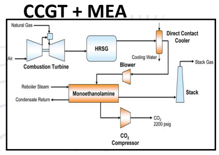
Receiving terminal at South Hook + onshore gas pipeline to power plant

Alternative gas power generation with/without CO_2 capture

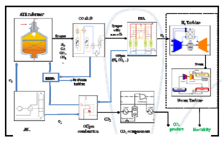
CCGT



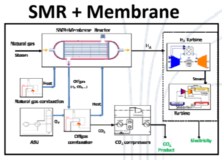
CCGT + MEA



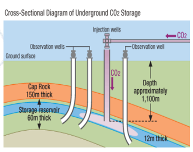
ATR with PSA



SMR + Membrane



CO_2 injection into saline aquifer

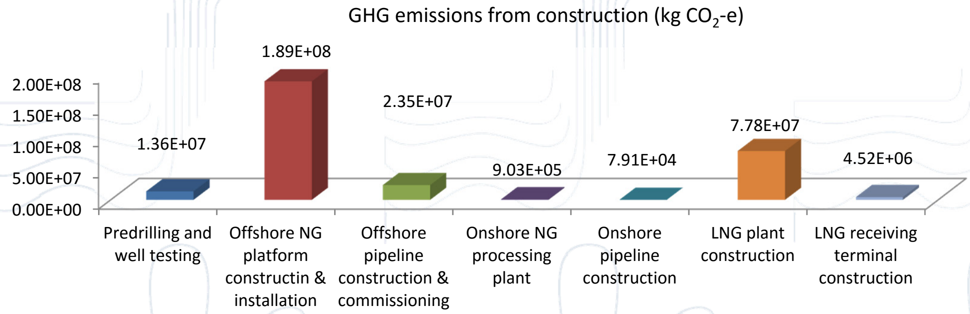


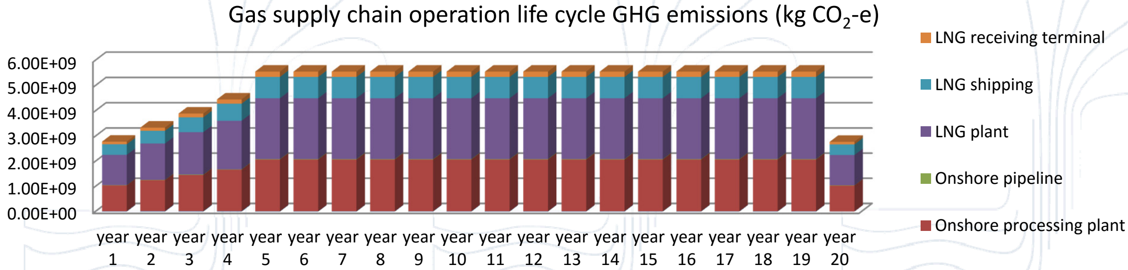
CO_2 pipeline transportation

Qatar North Field offshore production(1,730 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 (11,281 km) → Receiving terminal at South Hook (2×7.8MTPA) → onshore gas pipeline to power plant (100km) → Alternative Gas power generation with/without CO2 capture → CO2 pipeline transportation (300km) → CO2 injection into saline aquifer (161t/hr)

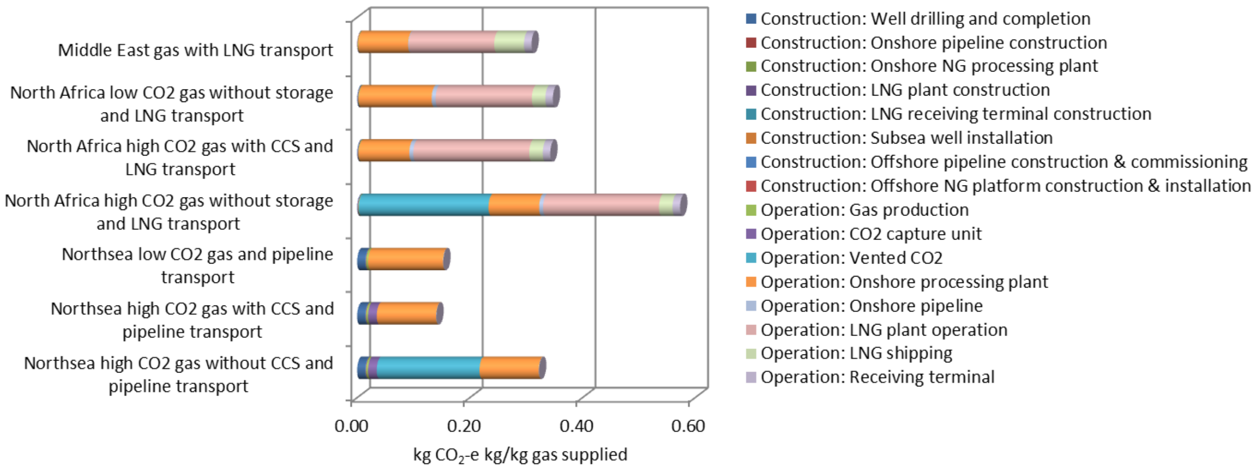
Case study: full chain analysis of Middle East natural gas to a UK power plant without/with CCS

GHG emissions from the gas supply chain



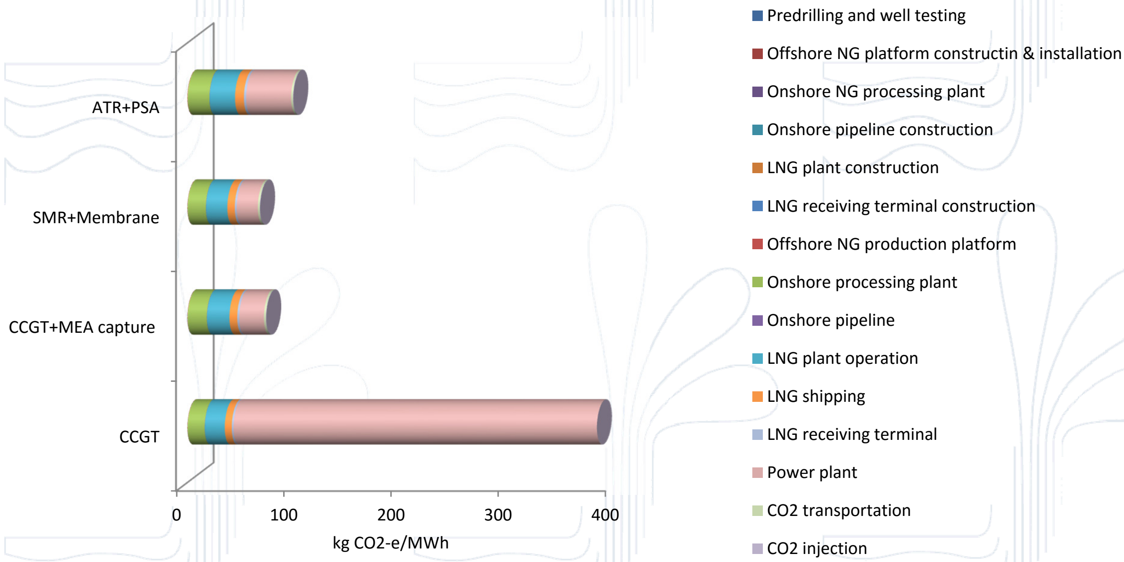


Comparison of GHG emissions for different gas supply options to the UK market

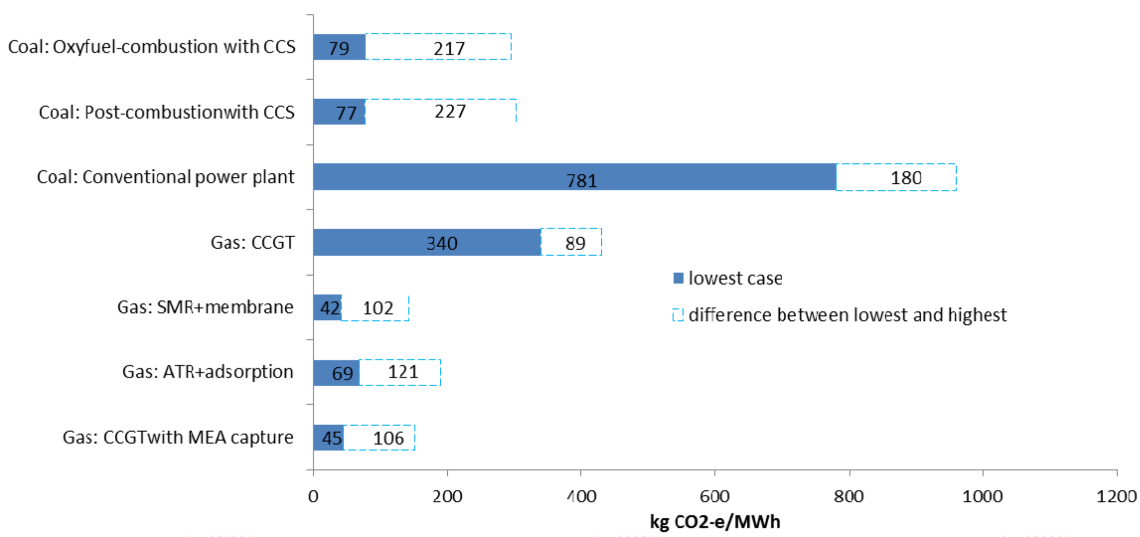


Case study: full chain analysis of Middle East natural gas to a UK power plant without/with CCS

Life cycle of GHG emissions for alternative power plant configurations with gas supplied from Middle East

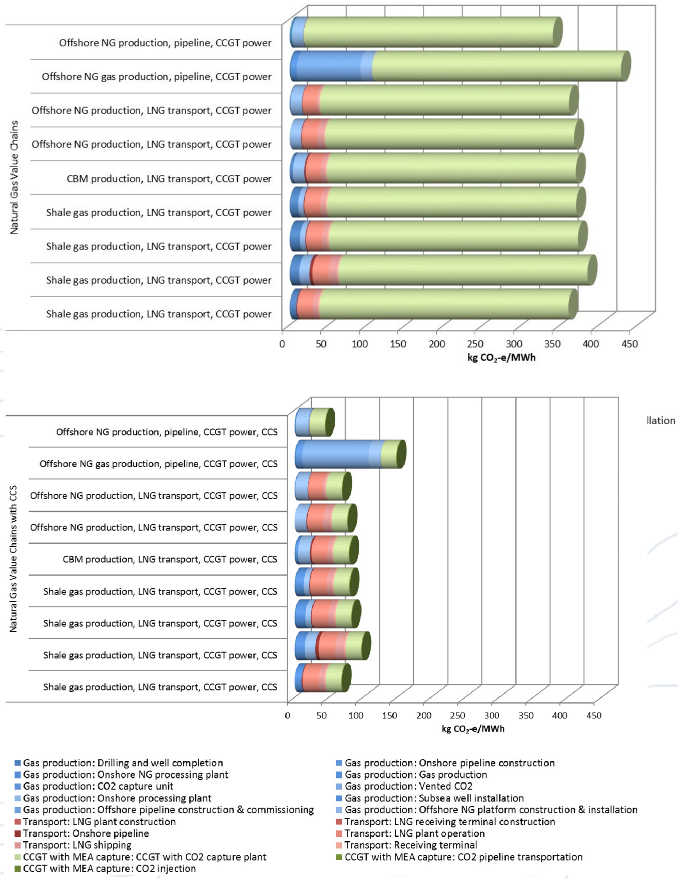


Comparison of GHG emissions for alternative coal and natural gas fired power plant configurations

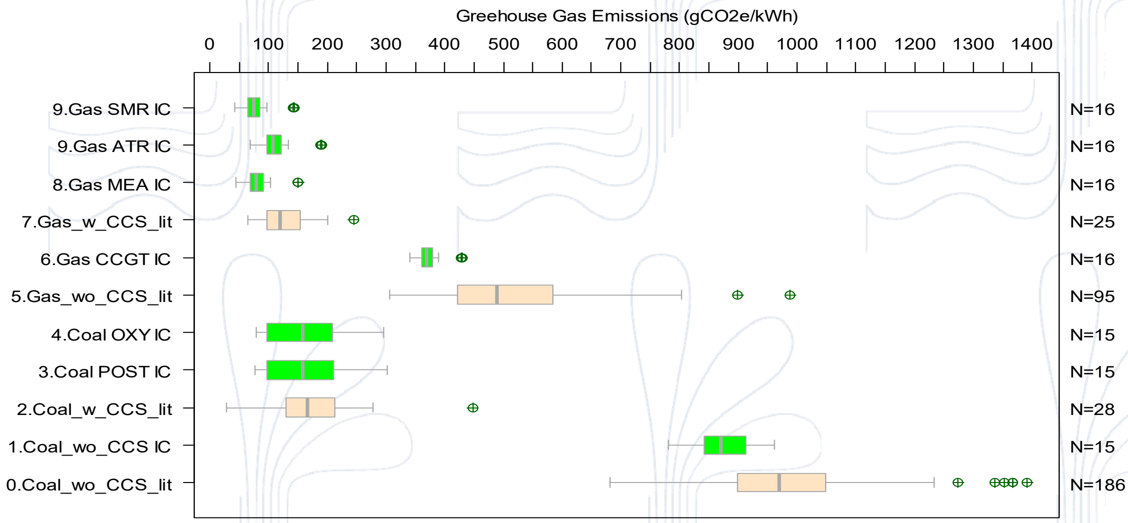


Comparison of GHG emissions for different natural gas power generation value chains around the world

and with CCS implementation



Comparison of GHG emissions for alternative coal and natural gas fired power plant configurations



N:Sample Size

Limitations of current bottom-up studies used to inform emission factors

- Current GHGs emissions factors and emission database are developed mainly considering North American conditions. There are limitations in applying these emission factors to operations outside these regions.
- GHGs emissions along the gas value chain are mainly from:
  - *Combustion sources*: mainly the use of fossil fuel to power the gas transport and gas processing. These emissions are not affected by emission factors and can be calculated or estimated. — **Low uncertainty**
  - *Vented methane*: emissions depend on the operational options and regional regulations (North American emission factors may not be appropriate); — **High uncertainty**
  - *Fugitive methane emissions*: emissions depend on the type of equipment used, operational options and regional regulations (same limitations as above for North American studies) — **Very high uncertainty**
- The ICLCA life cycle bottom-up approach can help overcome these limitations through a combination of monitoring and modelling and accounting for operational options, equipment used and regional regulations.

ICLCA approach compared to other approaches in literature

IPCC Tier 1, 2 and 3: emission factor approach which can generate average emissions with a range; covers key processes in the value chain; good at generating GDP related GHGs emissions.

Not suitable to evaluate emissions for a specific reservoir or a production chain.

API 2009 and 2004: bottom-up approach; emission factors based on unit process or equipment level; cover all the processes in the value chain; emission factors developed from measurements data and literature.

It is a database, not a model!

US EPA emission factors: emission factor approach, can generate average emissions with a range; cover key processes in the value chain; emission factors statistically summarised from measurements or monitoring data and industry emission reporting data for different years across US.

Focusing onshore emissions, not suitable to evaluate emissions for a specific reservoir or a production chain.

ICLCA approach compared to other approaches in literature

Industry emissions reporting: estimation and measurements for the company as a whole in a specific year. Based on a combination of emission factors, monitoring and own estimation tools; may be considered biased by environmental groups/NGOs in particular.

Majority of **literature studies in the public domain**:

- use average values or emission factors;
- focus on a given natural gas production method (CBM for example) or specific value chain sub-systems (LNG for example);
- variable boundary conditions and assumptions
- Site specific, can be fast outdated
- do not link the characteristics of the reservoir to GHGs emissions
- Do not consider the whole life of operations (lack of temporal representation)

ICLCA model: Life-cycle bottom-up approach

Model characteristics

- Emissions are accounted from a resource/reservoir's life cycle perspective, do not rely on not a single time/period snapshot or measurement
- Considers resource characteristics
- Allows to investigate the effect of operational choices (production methods, production rates, emission control methods etc)
- Uses simulation and engineering calculations at unit process level
- Methane, GHG and other environmental emissions can be traced back to equipment level
- Available monitoring data can be used to update/validate individual equipment or process emissions, update models currently used
- Allows to analyse reliably emissions from operations around the world
- Can be parameterised to the specifics of individual operations
- Compatible with main stream emission factors (API, 2009; EPA emission factors, 2012 and 2013) and latest emission regulations (US NSPS, 2012)

How bottom-up approaches can help address the challenges of evaluating GHGs emissions across the natural gas value chain

Life cycle bottom-up emissions analysis is needed to:

- quantify the relative uncertainty of emissions from combustion sources, vented gas, fugitive emissions
- Assess the impact of the following factors in methane/GHG emissions
  - geological conditions of production reservoir;
  - geographical location of the reservoir;
  - the operational options/requirements;
  - regional regulations;
  - monitoring/measurement methods;
  - emission modelling/estimation approaches;
  - different emission factors used;
- Relate emissions to specific equipment/processes, so targeted control can be implemented (this may differ from site to site and will also vary over time for the same operation)
- Assess emission reduction and cost for different emission control options

Further information:

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