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Greenhouse Gas Emissions Study of Australian CSG to LNG

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APPEA

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Section 1 Executive Summary

1. EXECUTIVE SUMMARY

This report presents a life cycle comparison of the greenhouse gas (GHG) emissions of Australian liquefied natural gas (LNG) derived from coal seam gas (CSG) and Australian black coal, from extraction and processing in Australia to combustion in China for power generation. APPEA recognises the need for and importance of such a comparison in view of Australian and international commitments to reduce GHG emissions, the potential role of liquefied natural gas (LNG) as a less GHG intensive alternative to coal, an impending price on carbon in Australia, and conflicting public information regarding the relative GHG intensity of the two products. APPEA commissioned WorleyParsons to carry out an independent comparison.

A life cycle assessment (LCA) was conducted following internationally established standards and methods for LCA and GHG accounting. Export to China for power generation was chosen as a fair, like-for-like basis for comparison, with MWh of electricity produced selected as the functional unit. Using data from industry sources and public reports, the study compares life cycle GHG emissions from existing or projected normal operating conditions using commonly employed and proven technologies, including GHG mitigation. The base case comparison is for typical or representative GHG emissions scenarios for each product, while ranges are considered for variations in technology, operating or other conditions in extraction and processing and for efficiencies of power plant in final combustion. The analysis assumes that CSG/LNG projects apply best practice in GHG and environmental management, especially to the prevention of venting and leaks in upstream operations.

The general findings and conclusions were as follows:

- CSG/LNG is significantly less GHG intensive for most existing, commonly employed end-user combustion technologies and for most of the life cycle scenarios considered.
- The two products have different emissions profiles. For the export situation considered, most GHG emissions from coal (94%) will result from combustion in China, whereas extraction and processing in Australia accounts for only 2.7%. For CSG the respective figures are 74% and 22%.

Specific findings included the following:

- When comparing life cycle GHG emissions per MWh of electricity sent out from a power plant, the results are highly sensitive to assumptions about the thermal efficiencies that apply to power generation.
- On average, coal combusted in a subcritical, supercritical or ultra-supercritical pulverised coal plant produces respectively 87%, 51% and 43% more life cycle GHG emissions per MWh than CSG/LNG combusted in a combined cycle gas turbine (CCGT) plant (Table 1.1 and Figure 1.1).
- The corresponding numbers for the respective coal technologies compared to combustion on an open cycle gas turbine plant (OCGT) are 37%, 11% and 5% more GHG emissions per MWh. However this comparison is less important since OCGT is seldom used for baseload generation, and rather in smaller plants for peak shaving, emergency generation or remote locations.
- Sensitivity bands for uncertainties and ranges of power plant efficiency generates various best/worst case comparisons (Figure 1.1 and Table 1.2). For these atypical scenarios, electricity from coal is only less GHG intensive when best case coal is compared to a few worst CSG/LNG cases, mainly low efficiency OCGT combustion.
- Although no relevant CSG/black coal life cycle comparisons were found, the results are consistent with comparable elements of various LNG /coal comparisons.

Potential savings from combusting CSG/LNG instead of coal in power generation in China for simple substitution scenarios are as follows:

- For every life cycle tonne CO_2-e from CSG/LNG up to 0.87 tonnes CO_2-e may be avoided compared to electricity from coal (Tables 1.1 and 1.2). This maximum figure will decrease over time since large numbers of supercritical and ultra – supercritical plant are being constructed, but subcritical is likely to remain the dominant coal combustion technology in China.
- Considering savings from a 30 year 10 Mtpa CSG/LNG project (as expected for the Gladstone LNG development), if CSG/LNG is combusted in a CCGT plant instead of a subcritical coal plant, the life cycle emissions are 42.7 million tonnes (Mt) CO_2-e per annum, the annual savings 37.2 Mt CO_2-e and the project life savings 1114 Mt CO_2-e. For CSG/LNG combustion in a CCGT plant instead of a supercritical coal plant the annual savings and project life savings are 21.7 and 652 Mt CO2-e respectively.
- Considering global GHG emissions savings from CSG/LNG GHG emissions in Australia, if electricity is generated in China from CSG/LNG in CCGT instead of subcritical coal, then for every tonne CO_2-e emitted in Australia, 4.3 tonnes are avoided globally. For CCGT instead of supercritical coal 2.5 tonnes CO_2-e are avoided.

In conclusion, the results are sufficiently clear and robust to confirm that on a life cycle basis CSG/LNG produced for combustion in a Chinese power plant is less GHG intensive than coal for the stated assumptions and scenarios.

Table 1.1 Electricity generation GHG intensities - base case (units: tonnes CO2-e/MWh)

OPERATION		COAL SEAM GAS		BLACK COAL		
		BASE CASE		BASE CASE		
		OCGT	CCGT	SUBCRITICAL	SUPER CRITICAL	ULTRA SUPER CRITICAL
Assumed average efficiency (%)		39	53	33	41	43
Extraction and processing		0.15	0.11	0.03	0.02	0.02
Transport		0.01	0.01	0.03	0.03	0.03
Processing and power generation in China		0.59	0.43	0.96	0.78	0.74
Totals		**0.75**	**0.55**	**1.03**	**0.83**	**0.79**
Ranges	Min	0.64	0.49	0.75	0.61	0.58
	Max	0.84	0.64	1.56	1.26	1.20

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Figure 1.1. Base case GHG intensities and ranges

Note: Includes ranges from all life cycle emissions sources

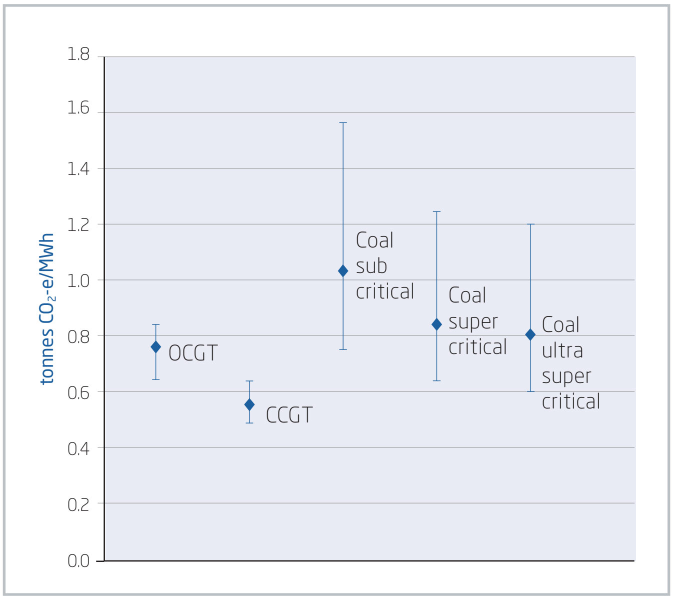


Table 1.2. Life cycle GHG savings from CSG/LNG instead of coal electricity generation

	INSTEAD OF	EMISSIONS AVOIDED (T CO_2-E/MWH) FOR EVERY LIFE CYCLE T CO2-E FROM CSG/LNG		
GAS TECHNOLOGY	**COAL TECHNOLOGY**	**BASE CASE**	**MAX**	**MIN**
CCGT	Subcritical	0.87	2.18	0.17
CCGT	Supercritical	0.51	1.57	-0.05
CCGT	Ultra supercritical	0.43	1.44	-0.10
OCGT	Subcritical	0.37	1.43	-0.11
OCGT	Supercritical	0.11	0.97	-0.27
OCGT	Ultra supercritical	0.05	0.88	-0.31

2. BACKGROUND TO THE STUDY

Coal seam gas or CSG is a form of natural gas extracted from coal seams. In recent decades it has become an important source of energy in the United States, Canada, and other countries. Australia has rich deposits and a major industry is being rapidly developed in Queensland to exploit this resource, especially for export as LNG.

Alongside the potential economic benefits of the CSG industry, proponents have pointed to the potential contribution of LNG to reducing global carbon emissions. LNG is widely regarded as a beneficial, cleaner burning (after re-gasification) alternative to coal and a transition fuel in the longer term shift to renewable energy (*IPCC, 2001*). However, some have stated (e.g. *Howarth, 2010)* that when production, transportation and fugitive emissions are included, life cycle GHG emissions from CSG approach those of coal. Such statements have been widely quoted in the media.

The economic benefits of the Australian coal industry are well known. Australia is already the world's largest exporter of black coal and a major expansion of the industry is under way in Queensland and New South Wales in response to increasing coal prices and demand for coal, especially from China. However, the export value and contribution to employment has, at least in the short term, overridden growing concerns about the industry's direct and indirect contribution to global greenhouse gas (GHG) emissions.

Debate regarding the relative GHG impacts of the two industries is likely to increase with an impending price on carbon in Australia and eventual international action to tackle climate change. It is already well-known, in general terms if not the details, that natural gas is more GHG intensive than coal in Australia since more processing is required. In earlier discussions on the Australian Government's Carbon Pollution Reduction Scheme (CPRS) the LNG industry argued (*e.g. Voelte, 2008)* that under a straight permitting scheme, it would have been required to buy more permits than coal for exported product. It claimed that this would have led to the perverse outcome of encouraging coal rather than LNG investment in Australia and so increasing total GHG emissions, since coal is highly GHG intensive in combustion. The relative GHG emissions associated with producing, transporting and using the two fuel types is an important issue for government and industry to understand and inform effective policy and investment decisions. There is accordingly an increased need for robust data and information.

For over 40 years, Life Cycle Assessment (LCA) has been used to objectively assess and compare the environmental impacts of products, recognising that impacts occur across all stages of the life cycle, and that single stage or issue comparisons do not tell the whole story. In commissioning this study, APPEA has recognised the value of conducting an independent life cycle assessment comparison to better inform debate and support its own position with respect to policy and programs.

3. GOAL, SCOPE AND METHODOLOGY

3.1 General approach

This study followed the approach set out in the International Standards for life cycle assessment ISO 14040:2006 and 14044:2006. Attachment 2 summarises the requirements of these standards, including the principles, issues covered (environmental only, not social and economic), systematic methodology and needs for fairness and objectivity.

GHG estimation followed the principles set out in the Greenhouse Gas Protocol (World Business Council for Sustainable Development and World Resources Institute 2004) and the methodologies and data provided by the National Greenhouse Accounts (NGA) Factors (Australian Government 2010 and earlier). This included consideration of materiality and uncertainty (see Attachment 3).

Attachment 1 provides a list of abbreviations and a glossary of terms

3.2 Goal

The goal of this study, as stated earlier, was to conduct a life cycle GHG comparison of LNG from coal seam gas and black coal from extraction in Australia to combustion in power plants in China.

3.3 Scope

The scope of this LCA is as follows as agreed with APPEA:

a) GHG emissions only

From a wider impact and policy perspective, GHG emissions are the most significant environmental issue for both the coal and CSG industries while recognising that other environmental impacts are potentially significant, especially at the local level. All six Kyoto gases are considered (Attachment 3) although only carbon dioxide, methane and nitrous oxide are relevant to this study.

b) Export streams to China only

To achieve a like-for-like comparison (since the CSG/LNG industry examined is export driven) this LCA only considers export streams of CSG and black coal for combustion in power plant in China. This simplifying assumption is realistic since most LNG and a large proportion of black coal is likely to follow this route during the life of CSG projects and of existing and new coal mines. It is recognised that some LNG will go to DomGas and other markets, and a substantial proportion of black coal is for power generation, metallurgical and other applications in international and domestic markets.

c) All life cycle stages from exploration to final combustion

This LCA considers the following stages of the life cycle of CSG and black coal exported to China (Table 3.1):

Table 3.1: Summary of life cycle stages and processes

LIFE CYCLE STAGE	CSG	BLACK COAL
Extraction and processing in Australia	Exploration, including pilot wells Construction of new projects • Gas fields • Pipelines • LNG Processing plant Upstream operations Operation of process plant	Exploration Construction of new mines (or expansion of existing projects) – open cut (OC) and underground (UG) Extraction Preparation (crushing, screening, washing)
Transport	Shipping to China	Rail transport to port Port handling Shipping to China
Processing in China	Regasification	Pulverisation (part of power station operations)
Combustion	In open cycle (OCGT) or combined cycle (CCGT) power plant	Combustion in pulverised fuel power plant (sub - super - and ultra supercritical)

The stages and processes are further discussed in Section 3.4.

d) Standard LCA approach

A standard attributional (see Glossary) LCA approach and methodology have been followed, including a staged approach for inventory analysis, impact assessment and interpretation (see Attachment 2). A life cycle inventory considers the amount of input and output for processes which occur during the life cycle of a product. Impact assessment estimates the environmental impacts with respect to the functional unit (see below). The impact is the global warming potential (GWP) measured as equivalent tonnes of carbon dioxide equivalent (tonnes CO_2-e) per MWh, using stated GWP factors for the greenhouse gases considered (Attachment 3, Section 2). In the interpretation, the results are analysed with an emphasis on identifying the 'hot spots' where most impacts occur, and any significant differences between the products.

e) Functional unit

As noted above, the functional unit for comparison is MWh of electricity sent out in China (electricity sent out takes account of internal energy use and losses in power plant).

f) Boundary

The boundary for the study is the stated activities and impacts across the product lifecycle, as illustrated in Figures 3.1 and 3.2. It includes all Scope 1 and 2 emissions (see Glossary in Attachment 1) for CSG or coal mining projects in Australia as well as Scope 3 emissions identified as potentially significant (see Section 3.4)

The inventory is compiled only from inputs and outputs that contribute to tonnes CO_2-e/tonne of saleable product

g) Timeline

The timeline for the comparison spans from the present, considering technologies currently applied or going onstream, while considering average emissions over the life of a project. For a CSG and coal project this is typically up to 30 years but for some coal projects much less. While there may be some technology changes over this time, especially improvements in end use combustion efficiency the technologies for both industries are generally well established and most GHG emissions can be readily estimated based on activity levels and other factors.

An important difference between the two industries is that the large scale CSG/LNG industry in Queensland is new and emissions are only projections subject to high uncertainties in some areas, whereas black coal is a large existing industry with extensive reporting of emissions. A like-for-like comparison is achieved by considering forecasts for CSG projects and for new coal projects reported in environmental impact statements (EISs).

h) Exclusions

Consideration of the following were outside the scope of work

- The impacts of new or unproven technologies, such as emerging clean coal and carbon capture and storage.
- The impacts of extreme (other than best practice) scenarios for CSG venting and leakage.
- Investigation of the Chinese energy market and the dynamics of relative demand for LNG and coal in power generation, including the influence of relative GHG intensity.

i) Delivery

The LCA was conducted in January-February 2011, and only includes data available during this period.

j) Peer review

As a public report this LCA has been peer reviewed.

Figure 3.1 High level LCA boundary for local CSG extraction, processing and combustion in China

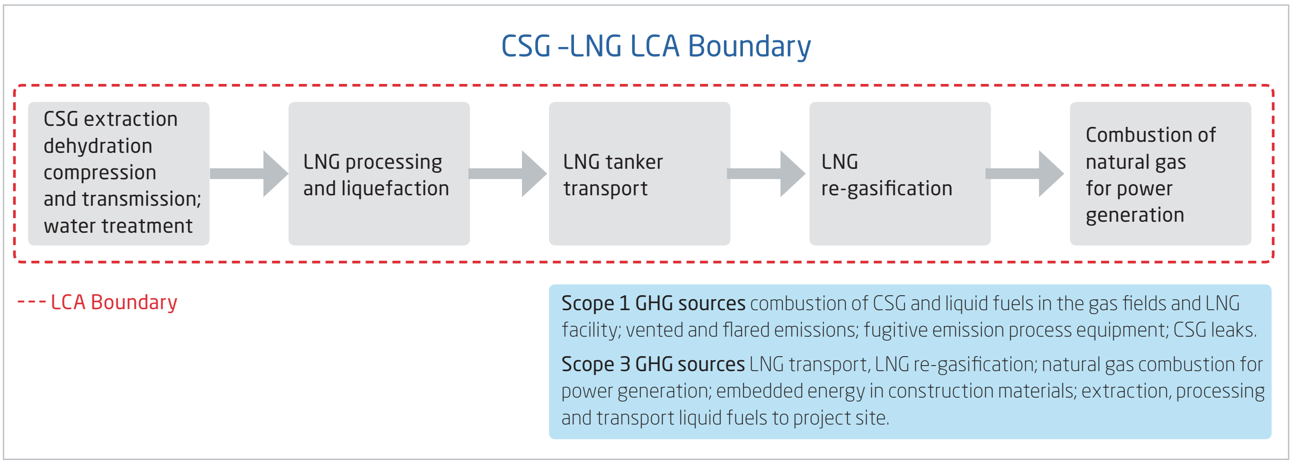
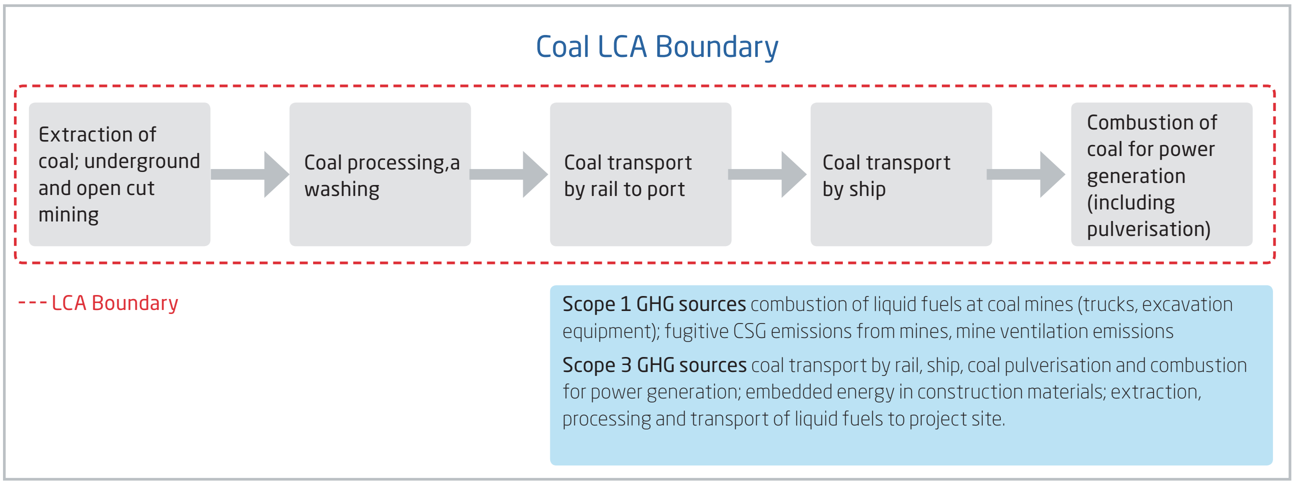


Figure 3.2 High level LCA boundary for coal extraction, processing and combustion in China



3.4 Life cycle inventory

a) General methodology

For both product streams an inventory of GHG emissions was developed as described in Attachment 4 for CSG/LNG and Attachment 5 for black coal. Each of these attachments presents:

- An industry overview to illustrate the context and range of situations
- A summary of life cycle processes and operations (with flow charts)
- Assumptions for the GHG inventory
- GHG inventory sources by emissions Scope
- LCA data sources and bases for estimates
- Base cases and scenarios

Life cycle inventories were developed and summary tables are presented in Attachments 6 and 7 for CSG/LNG and black coal respectively. These are broken down into stages and show GHG emissions for each life cycle stage and source.

b) Analytical tool

Spreadsheet analysis was used for developing the inventories and calculating the impacts., While the use of proprietary LCA software and general databases is essential for full LCA covering multiple environmental issues and complex systems, it was not considered necessary for this particular study:

- Being limited to a GHG comparison, the life cycle inventories are relatively simple.
- Best available and specific data was used from public and industry information sources, especially project Environmental Impact Statements (EIS), to produce a tailored LCA with local and specific data where appropriate as opposed to global data.
- While the use of software and databases may provide additional data on upstream product supply

emissions these were not considered to be material in relation to overall life cycle emissions.

c) Data sources

The data sources were as follows:

- As noted above, most data was derived from GHG forecasts submitted as part of Environmental Impact Statements (EIS) for a sample of CSG, coal mining, rail and port projects. Other data was derived from a range of industry sources as stated in each section and relevant National Greenhouse Accounts (NGA) Factors *(Australian Governmentm 2010)* or other stated emissions factors used to calculate GHG emissions. Derived emissions data from EISs is used directly or averaged in this study. It was not possible to calculate emissions from first principles in the coal cases due to lack of availability of underlying data.
- For CSG upstream and LNG process plant emissions, most data was drawn from the Santos Gladstone LNG ('GLNG') and Australia Pacific LNG ('APLNG') EISs, with supplementary information provided by Santos. Underlying the EIS estimates, raw data for LNG processing plant is derived from proprietary design and operating information while raw data for upstream emissions is based on project design and operational estimates.
- The main data source for black coal GHG emissions is the EIS for selected black coal projects. Fifteen mines, one rail and one port EIS were examined to generate the relevant data for Australian extraction, processing and transport operations and emissions. They were selected on the basis of availability, quality and covering a range of examples of mine types by underground or surface, variations in gassiness, distances to port and expansion or new mine projects. A list of the mines selected is shown in Attachment 5. It should be noted that the cases selected are intended to be illustrative, taking account of the above factors. Obtaining a statistically representative estimate for the entire coal mining industry was beyond the scope of work, if not impossible – there are nearly 200 existing mines and new projects (Attachment 5, Table A5.1) and data is not readily available for most. Furthermore as the LCA shows, this level of detail would have been unlikely to produce meaningful differences to the overall results given the dominance of end-user combustion emissions.

In all cases, data has been examined for quality, considering its validity, assumptions, consistency with similar estimates, reliability, materiality and uncertainty (see notes on materiality and uncertainty in Attachment 3).

d) Emissions inclusions and exclusions

Emissions included and excluded are shown in Tables 3.2 and 3.3 for CSG/LNG and coal respectively. The emphasis is on emissions which are material or significant, including Scope 1 and 2 emissions (see Glossary) in Australia and Scope 3 emissions from transport, processing and combustion in power generation. Scope 3 product supply chain emissions were included for completeness where data was available, although, as noted above these were immaterial as a proportion of overall emissions. Exploration, construction and embedded energy related GHG emissions and one-off or temporary GHG emissions are amortised over the life of a project.

It should be noted that coal EIS reports varied in inclusion of emissions types according to those considered by reporters to be relevant or material. While all included diesel use, fugitives and explosives and many use grid power, reporting of other emissions varied. Industry averages were developed from the cases available and included in the base case. Atypical emissions such as gas flaring from underground mines were noted but not included.

Table 3.2: Inclusions and exclusions for CSG/LNG

EMISSIONS SOURCE	NOTES
INCLUDED	
Gasfields and pipelines - exploration and construction – Diesel use – Venting and flaring – Land clearance – Scope 3 embedded, product supply chain, waste, transportation	Construction emissions were included for CSG/LNG on the grounds that the export industry involves a major construction undertaking. Data was also readily available from Santos' Gladstone LNG ('GLNG') and the Australia Pacific LNG ('APLNG') EISs. Even in this case, total construction emissions were around 1% of total annual life cycle emissions when amortised over a project life. Land clearance was included as areas cleared are significant for the 450 km pipeline and gas field.
LNG processing plant - construction – Diesel for plant and vehicles – Land clearance – Scope 3 embedded, product supply chain, waste, transportation	
Gasfields and pipeline operation – Gas use for power generation, pumps, compressors, dehydration, waste water treatment, general electricity consumption – Venting, flaring and leaks – Diesel for plant, vehicles – Scope 3 product supply, transportation, waste	S3 product supply etc emissions were included as data was readily available, although not material.
LNG plant operation – Gas use in power generation, liquefaction, acid gas removal, oil heaters etc – Venting, flaring and leaks – Diesel use in maintenance etc – Scope 3 product supply, transportation	Non process plant emissions were included as data was readily available, although not material.
Shipping to China LNG used for bulk carrier	
Regasification LNG used in regasification plant	
Combustion in China LNG used in gas turbine and power station systems	
EXCLUSIONS	
Use of grid power in upstream and downstream operations.	Use of grid power is an option but was not included in the EISs examined.
Pipeline distribution in China.	It was assumed that energy use in pipeline distribution is not material.

Table 3.3: Inclusions and exclusions for black coal

EMISSIONS SOURCE	NOTES
INCLUDED	
Coal mines - exploration and construction – Diesel use – Land clearance	Construction emissions for coal mines and rail transport infrastructure were considered but only to a limited extent since very little data was available. For all but one EIS, diesel emissions for construction were not referenced separately, since, most of the mine EISs are for expansions and, especially for open cut, construction and operational activities are similar. Only the Alpha Coal EIS specifically referenced construction emissions but did not provide a detailed breakdown. This is not typical in being a Greenfield development. For a typical project, mine construction diesel and land clearance emissions are assumed to be reflected in average annual operational emissions. See Glossary and Attachment 5 for explanation
Mine operation – Diesel use for plant, vehicles – Electricity consumption and production – Fugitives – Spontaneous combustion – Slow oxidation – Explosives – Land clearance – Scope 3 diesel, electricity	Land clearance was considered but for the base case was not material. Only one mine EIS (Clermont) provided an estimate. Others listed it as immaterial on the grounds of limited clearance (underground mines), offsetting by progressive rehabilitation, or non-forested areas with low carbon retention.
Rail transport Locomotive diesel use.	
Port handling Power use for conveyors, etc.	
Shipping Fuel used by carrier used in regasification plant.	
Combustion in China Fuel used in pulverised coal power station, including pulverisation and power station systems.	
EXCLUSIONS	
Embedded and supply chain emissions relating to rail, port handling, bulk carriers, and power plant in China.	Embedded emissions in non-Australian project capital equipment were not included on the grounds of immateriality (Frischenknect, 2004) especially when shared by multiple users and the emissions are not attributable to a project or the product stream being studied.
Scope 3 supply chain emissions embedded in materials , employee transport and waste relating to mine operations.	Chemicals and other materials are not used to any significant extent in coal mining and normal processing operations. Examples of materials used are oils used in maintenance and any chemicals used in wastewater treatment. Scope 3 emissions from such materials were not considered to be material compared to overall life cycle emissions.
Gas flaring.	As above, this was noted but not included as it is not typical.
Post-closure fugitive emissions.	Post-closure fugitive emissions from gassy underground mines were not included as they are not typical of or significant for most mines. They are nevertheless noted as a contributor to overall coal industry fugitive emissions.
Handling at a port in China and transportation to power plant in China.	Because of lack of data availability these have been excluded as a specific item. For simplicity it is assumed that a coal plant is near to the terminal and that emissions are immaterial as a proportion of total lifecycle emissions.

e) Base case inventories and ranges

Based on the data and ranges of possible GHG emissions, a typical or base case GHG emissions scenario was built up for each product stream, with a range for each GHG source.

Tables 3.6 and 3.7 show the base case emissions inventories for the respective life cycles and functional unit of MWh sent out, taking a base case of output emissions for 10 Mtpa of product for each life cycle stage for each product stream. For each emissions output, energy inputs have been back – calculated using the emissions factors stated in Attachment 3, Table A3.2, to illustrate the energy inputs that apply to each stage and total energy inputs. As noted in the limitations, the emissions are based on estimates in EISs based on fuel, electricity and other operational data rather than energy inputs.

These tables illustrate for CSG/LNG the significant energy inputs to upstream and downstream processing as well as to end use combustion, and for coal the dominance of end use combustion.

The outputs from the inventory tables 3.6 and 3.7 are used in calculating the impacts, as discussed in 3.5 and shown in Tables 4.1 and 5.1.

Assumptions for base case thermal efficiencies for the various types of power plant are derived from *WorleyParsons 2008* for gas turbines and from *International Energy Agency, 2006* for coal plant.

Scenarios for variations on the base case are presented in Tables 3.4 and 3.5 and ranges are further detailed in Attachments 4 to 7. Besides assumptions on power generation efficiency (the main variable) the ranges include:

- For CSG: Ranges for flaring and venting and for energy use for CSG compression, dehydration and water treatment.
- For coal: Ranges for fugitives (for open cut and underground mines), distances to port and calorific value.

The sensitivity of the results to variations in these factors is examined in the sensitivity analysis.

The following should be noted in relation to the base cases and scenarios:

- The base case is a typical case for comparison and, as noted above, not a calculated average or other statistical representation,. The total number and sample of CSG projects is small and, as noted above, the number of coal EIS available was fairly small.. The base case is also not intended to represent a particular project. The minima and maxima illustrate the broad range based on EISs examined and other estimates rather than considering every possible situation. They are also based on current technologies employed or proposed.
- The figures are mainly based on annual average GHG emissions for specific projects, recognising that some GHG emission types will vary from year to year depending on the stage of process development, production levels and other factors..
- The variations relate to scenarios not to uncertainties and accuracies in estimates which are considered separately.
- Although there are general differences between open cut and deep mines, especially in levels of fugitives, relative use of diesel and electricity and, for some underground mines, use of gas for power generation, there are some similarities e.g. in coal preparation plant. While reflecting these ranges in the analysis, the large open cut mines dominate the current and projected export industry and form the base case.

As noted in the scope, the scenarios do not include new or unproven technologies and extreme scenarios for venting and leaking and leaking of CSG.

Table 3.4 CSG base case and main scenarios for emissions per tonne of product
See Attachments 4 and 5 for details

FACTOR	BASE CASE	MINIMUM	MAXIMUM
OPERATIONS			
Gas fields general	Typical estimate from EIS	Lower than average estimate, especially for energy use by compressors	Higher than average estimate
Gas fields - flaring, venting	Typical estimate from EIS	Low estimate	Conservative estimate
Gas fields - Reverse osmosis for water treatment	Typical estimate from EIS	Low estimate	Conservative estimate
LNG plant	Typical estimate from EIS	Lower than average estimate	Higher than average estimate
END USE			
Combustion	CCGT of average efficiency. OCGT of average efficiency	Below average efficiency for a particular type of power plant.	Above average efficiency for a particular type of power plant.

1. *Under Queensland law, venting is only allowed where flaring is not technically possible or for safety reasons, for example an emergency pressure relief. The intent is to minimise releases of methane, a powerful greenhouse gas, and convert necessary releases to the less powerful carbon dioxide. The estimates assume that some venting and leaks will inevitably occur in any gas extraction, transmission and production system but that these will be avoided or minimised by applying best practice in operations, monitoring and maintenance. Santos and APLNG have policies of no CSG venting in their gas fields and these are reflected in their EIS estimates of greenhouse emissions.*
2. *The estimates for emissions from upstream power generation, compressors and other applications assume gas use as stated in the above EISs. It is noted that some proponents, including QCLNG, are now considering use of grid power for such upstream applications. The impacts on emissions of use of grid power was not included in this LCA and will depend on the technologies proposed. Impacts should be considered as part of GHG mitigation strategies.*

Table 3.5 Coal base case and scenarios for emissions per tonne of product
See Attachments 5 and 7 for details

FACTOR	BASE CASE	MINIMUM	MAXIMUM
OPERATIONS			
Fugitives	New, open cut, NSW	Expansion, shallow QLD	Deep, NSW, not captured
General operations	Typical estimate from EIS	Lower than average estimate	Higher than average estimate
TRANSPORT			
Rail to port	Average haul	Short haul	Long haul
END USE			
Combustion	Average efficiency sub-, super and ultra supercritical power plant Average carbon content coal	Below average efficiency for a particular type of power plant Lower carbon content	Above average efficiency for a particular type of power plant Higher carbon content

Table 3.6 Inventory summary- CSG/LNG

Note: The PJ energy figures relate to the energy input required for extraction, processing and transport of 10 Mtpa of CSG. These values should not be confused with energy values based on energy sent out from combustion in a power station in China.

INPUTS: ENERGY, MATERIALS INPUTS		BASE CASE	GHG OUTPUT	
SOURCES	ESTIMATED QUANTITIES PA	10 MTPA LNG PRODUCTION	SOURCE	TCO_2-E PA
Gasfields construction Diesel for stationary power generation and transport (amortised over construction period) Construction materials and pipes, various – over the project lifetime (amortised)	55,000 kL (2.2 PJ) 46,500 tonnes	**Gas fields** Gas field construction including land clearing and earth- and civil works	Diesel Land clearing (amortised) Materials - embedded emissions (amortised)	147,000 50,000 64,000
Gasfields operation Gas use for power generation (per annum)* Diesel (transport and stationary power generation - per annum)	100.1 PJ 0.25 PJ	CSG extraction, dehydration, compression	Gas use for power Venting/flaring/leaks Diesel	5,132,000 412,000 17,000
		↓		
Pipeline construction Diesel (transport and stationary power generation - per annum) Construction materials and pipes, various (amortised over project lifetime)	2,500kL (0.1 PJ) 18,000 tonnes	**Pipeline** Pipeline construction including earth and civil works	Diesel Land clearing (amortised) Materials - embedded emissions (amortised)	6,700 6,000 50,000
Pipeline operation		Gas transport without inline compression	Venting,flares. and leaks	5,000
		↓		
LNG plant construction Diesel (transport and stationary power generation - per annum) Construction materials and pipes, various (amortised over project lifetime) **LNG plant operation** Gas use for stationary power generation (per annum)* Diesel (transport and stationary power generation - per annum)	56,100 kL (2.2 PJ) 16,000 tonnes 52.8 PJ 0.8 PJ	**LNG plant** LNG plant construction including earth and civil works **Liquefaction** Power generation Acid gas removal Nitrogen removal Oil heaters	Diesel Land clearing Materials –embedded (amortised) Gas use for stationary power generation Flaring and venting Leaks Diesel	151,000 1,000 20,000 2,791,000 680,000 12,000 50,000

		↓		
Gas use (per annum)	6.4 PJ	Shipping	Gas use	936,545
		↓		
Gas use (per annum)	15.04 PJ	Regasification	Gas use	769,140
		↓		
Gas use (per annum)	501.3 PJ	End use combustion	Gas use	31,379,000
Total energy consumption (per annum)	**628.4 PJ**		**Total GHG emissions ($t\ CO_2$-e pa)**	**42,700,000**

** The use of grid electricity is not considered for this LCA but is an option for a CSG/LNG project.*

Table 3.7 Inventory summary - black coal

Note: The PJ energy figures relate to the energy input required for extraction, processing and transport of 10 Mtpa of black coal. These values should not be confused with energy values based on energy sent out from combustion in a power station in China.

INPUTS: ENERGY, MATERIALS INPUTS		BASE CASE	GHG OUTPUT	
SOURCES	ESTIMATED QUANTITIES ROUNDED	10 MTPA PRODUCTION OPEN CUT	SOURCE	TCO_2-E PA
Mining operations Use of diesel for plant and vehicles (per annum) Use of grid power (per annum) Explosives (per annum) Other materials (construction included in operational estimates)	42,600 kL (1.7 PJ) 174,800 MWh (0.63 PJ) 14,700 tonnes n/a	Coal mining Extraction, processing/washing	Diesel Grid power Explosives Fugitives Slow combustion Slow oxidation	115,000 180,000 2,500 375,200 18,500 1,800
		↓		
Diesel use	7600 kL (0.3 PJ)	Transport to port Rail	Diesel	20,500
		↓		
Power use	17,900 MWh (0.064 PJ)	Port handling	Grid power	16,100
		↓		
Diesel/HFO use	292,900 kL (11.3 PJ)	Shipping Coal bulk carrier	Fuel use	791,000
		↓		
Coal use	270 PJ	End use combustion	Combustion, power station systems	23,880,000
Total energy consumption (per annum)	**283.3 PJ**		**Total GHG emissions (t CO2-e pa)**	**25,400,000**

3.5 Impact assessment

a) Emissions intensities

Life cycle GHG missions intensities expressed as tonnes CO_2-e/MWh and tonnes CO_2-e/GJ are are summarised in Sections 4 to 6 below and detailed in Attachments 6 and 7. These are calculated on the basis of emissions per tonne of product and relevant GHG emissions factors.

GHG emissions were converted to CO_2-e using global warming potential (GWP) factors stated in NGA Factors 2010 (see Attachment 3, Section 2).

b) Sensitivity analysis

The sensitivity of the results was examined for the effect of higher levels of uncertainty in GHG emissions sources, specifically CSG upstream fugitives, venting, compression and dehydration, and water treatment fugitives from coal and efficiencies of combustion technology.

c) Uncertainty analysis

Uncertainties in the results were estimated using the National Greenhouse and Energy Reporting (Measurement) Determination 2008. Some of the EISs also included uncertainty analysis..

3.6 Limitations

a) Inventory coverage and gaps

There are considered to be no significant gaps in the inventory with respect to boundary, coverage and materiality (see Inclusions and Exclusions (Section 3.4 (e)). However, as noted in this section, very little data was identified for coal mine construction emissions. Also, as noted above, use of LCA software and libraries may have generated data on upstream embedded and product supply emissions but these are not significant as a proportion of total life cycle emissions.

b) Data quality

An inherent limitation is that the estimates are based on forecasts in EISs and is dependent on accuracies and uncertainties in these estimates, including assumed activity levels. Life cycle process flow data was not available to undertake detailed mass and energy balances.

However, the coal life cycle estimates and those for downstream LNG are based on well established operational experience, and the EIS examined were prepared to professional standards using NGA and other established GHG emissions factors.

Large scale CSG production is a new industry in Australia, the main uncertainties in data quality relate to emissions from upstream venting and leakage and energy use in compression and dehydration.

4. RESULTS AND ANALYSIS – COAL SEAM GAS

4.1 Base case GHG emissions and intensity

For the base case, Table 4.1 draws on the emissions inventory summarised in Table 3.6. It summarises the GHG emissions in annual tonnes CO_2-e, tonnes CO_2-e per tonne of product and for tonnes CO_2-e per MWh sent out. Attachment 6 presents more detailed breakdowns for each activity. Figure 4.1 shows the emissions percentages for each main stage of the life cycle and Figure 4.2 illustrates the life cycle GHG intensities for two gas-fired power generation technologies. Attachment 6 presents more detailed breakdowns for each activity.

Table 4.1 GHG Emission intensities for CSG production and combustion – base case

ACTIVITY	GHG EMISSIONS INTENSITY			
Base case is 10Mtpa, 3 train production	tonne CO2-e/ tonne product	%	OCGT 39% efficiency tonne CO2-e/MWh	CCGT 53% efficiency tonne CO2-e/MWh
CONSTRUCTION				
Gas fields	0.026	0.61	0.006	0.004
Pipeline	0.006	0.15	0.001	0.001
LNG plant	0.017	0.40	0.003	0.002
OPERATIONS				
Gas fields	0.551	12.9	0.085	0.063
Pipeline	0.001	0.01	0,0001	0.0001
LNG plant	0.353	8.29	0.055	0.040
TRANSPORT				
Shipping to China	0.094	2.19	0.015	0.011
END USE				
Regasification	0.077	1.81	0.012	0.009
Combustion	3.138	73.64	0.578	0.425
TOTAL – all sources	**4.268**	**100.0**	**0.75**	**0.55**

4.2 Interpretation

Table 4.1, Figure 4.1, Figure 4.2 and supporting analysis in Attachment 6, clearly show the following for the base case.

- The majority of GHG emissions occur in end use combustion (74%) but extraction and processing in Australia accounts for a significant component (22%).
- Of extraction and processing activities, gas fields operation (13%) and LNG plant operation (8.3%) are the most significant but these are relatively small as proportions of the total. Upstream emissions arise from energy use in compression and other processes, and from venting flaring and leaks. LNG Plant emissions especially arise from liquefaction and power generation.
- Even for the major level of engineering involved in upstream and LNG process plant development, construction GHG emissions (including fuel use and embedded energy related emissions in materials) only accounts for 1.3% of total GHG emissions.

Figure 4.1 Life cycle GHG emissions percentages - CSG/LNG

Based on tonnes CO2-e / tonne LNG

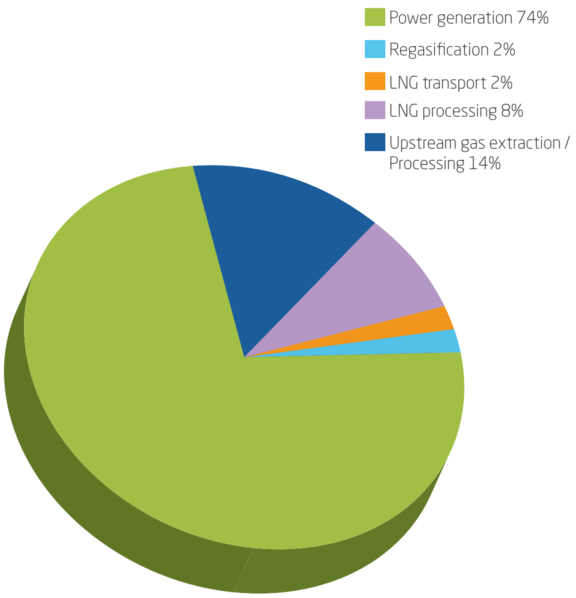
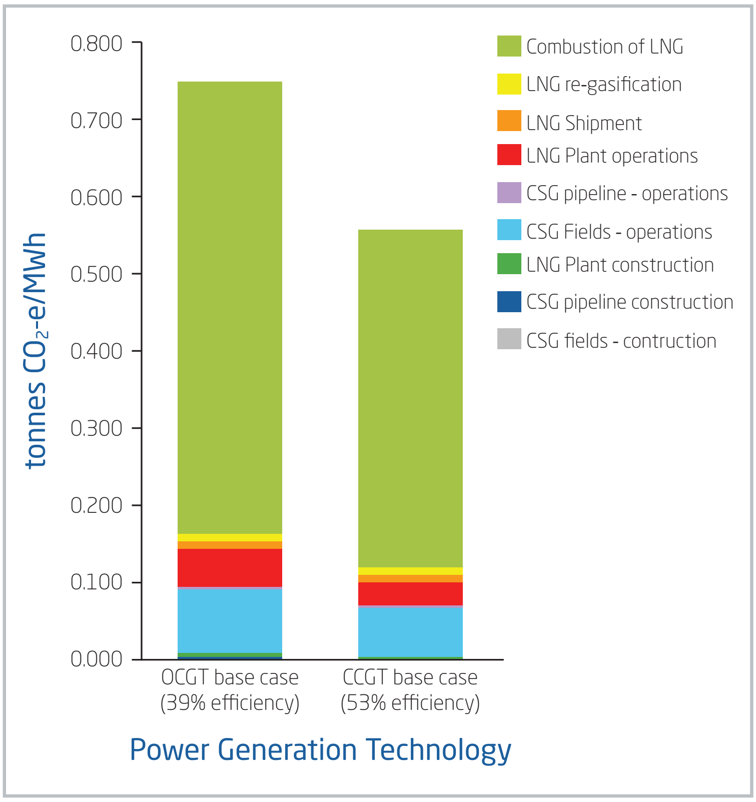


Figure 4.2 Comparison of GHG intensities for two gas-fired power generation technologies



4.3 Sensitivity analysis

The base case results were tested for sensitivity to the following :

a) Higher and lower efficiency OCGT and CCGT power plant (around ±4% for each, with minor variations).

b) ±50% in use of energy for upstream compressor stations in the CSG fields: This captures uncertainty in the number of operating gas wells and the volume of CSG processed, and hence the number of compressor and power generation turbines used in the CSG fields.

c) ±50% in flaring and venting emissions from the CSG fields: This captures the uncertainty in the number of operating gas wells and the volume of gas extracted in any given year, and hence the amount of gas flared and vented.

d) ± 50% in use of energy for reverse osmosis (RO) water treatment (in the worst case assuming 100% of water is treated): This is to capture the uncertainty in the number of operating gas wells and hence the volume of associated water that is to be treated.

e) Alternative LNG process plant designs (Bechtel/Conoco Philips and Foster Wheeler/Air Products).

The ±50% sensitivities in activities b) – d) are arbitrary, based on engineering experience and the data presented in the GLNG and APLNG EISs. Because of the limited amount of data available, a conservative approach to the sensitivity analysis was chosen.

Figure 4.2 shows the impact of the efficiency of the power generation technology on the lifecycle GHG emission intensity. The results are sensitive to power generation efficiency, with an average 13% variation in GHG intensity for OCGT and a 14% variation for CCGT. The overall result is that on average open cycle power gas turbine technology is less efficient than closed cycle gas turbine technology for power generation.

Figure 4.4 shows the sensitivity of the GHG intensity for OCGT power generation to various upstream and downstream operating parameters. The total life cycle GHG emissions were mostly influenced by energy use by upstream compressor turbine use. A ±50% variation in upstream compressor use resulted in a ±5% change in total lifecycle GHG intensity. Energy use by upstream associated water treatment with reverse osmosis technology, and upstream venting and flaring GHG emissions had relatively little impact (< 1% change) on the overall GHG intensity. Similarly, variations in the design of the LNG processing plant had little impact on the overall GHG intensity.

Figure 4.3

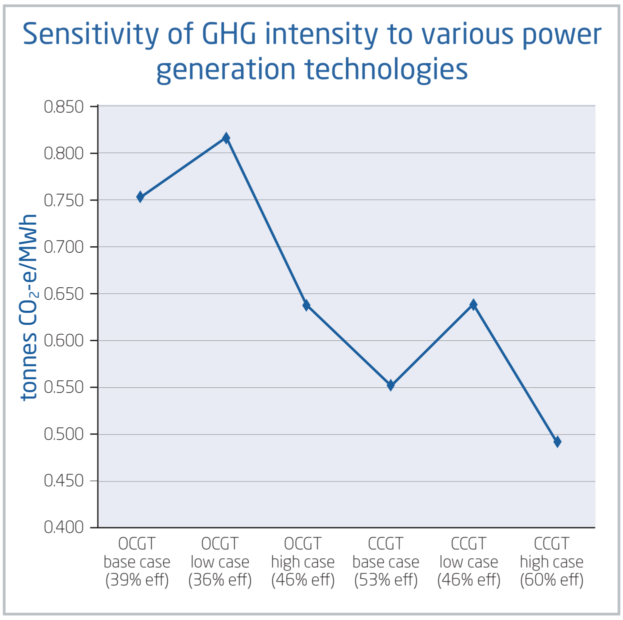
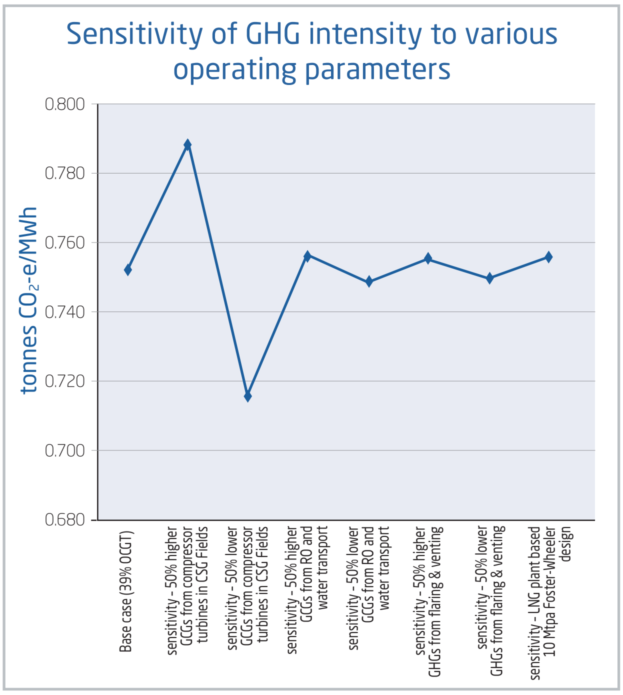


Figure 4.4



As stated earlier, these sensitivity tests are based on the information contained in a limited number of detailed EISs. The EIS show which activities are projected to give rise to the largest source of GHG emissions. These projections in turn are based on the operations of a small number of pilot plants. The large scale CSG developments may in practice give rise to GHG emissions sources that have not been considered here. Nevertheless, the best available data has been used for this analysis.

4.4 Uncertainty

Attachment 4 Section 8 provides an uncertainty analysis using the National Greenhouse and Energy Reporting (Measurement) Determination 2008 and figures derived from analyses in EISs, stated in NGA factors, or estimated from operational scenarios. For most of the life cycle GHG emissions, aggregate uncertainties (based on activity and emission factor uncertainty) are around ±10%, with higher certainty in end use combustion ±5%, and higher uncertainty (±50%) in compressor stations, flaring/venting and water treatment related GHGs. Because of the dominance of end-use combustion, the cumulative uncertainty is estimated to be within ±10% in terms of tonnes CO_2-e/MWh.

4.5 Comparative analysis

No other life cycle assessments of CSG have been identified. However, some LCA work has been done for LNG from various sources, where the life cycle is comparable to the present study except for upstream operations and for emissions and feed gas compositions: CSG is nearly all methane, whereas offshore gas contains condensates, other hydrocarbons and significant quantities of carbon dioxide, and nitrogen.

- WorleyParsons (2008) found average life cycle emissions intensities of 0.60 and 0.44 t CO_2-e per MWh sent out for OCGT and CCGT respectively, based on a limited comparison between NW Shelf LNG and NSW black coal.
- PACE (2009) found a typical GHG emissions intensity of 0.49 t CO_2-e per MWh for a modern CCGT plant.
- Jaramillo et al (2006) found emissions intensities of 0.45-1.04 t CO_2-e per MWh for current technologies.

When considering the generally higher level of upstream processing for CSG, the results are consistent with these other studies.

In addition, downstream life cycle assessments for liquefaction, shipping and re-gasification showed the following results:

- Okamura (2007) found average emission intensities of 0.01 t CO_2-e per GJ.
- Barnett (2010) found average emission intensities of 0.006 t CO_2-e per GJ.

The corresponding average results for the present study for these phases of the life cycle was 0.009 t CO_2-e per GJ.

Section 6 provides a comparison with the results for coal.

5. RESULTS AND ANALYSIS – BLACK COAL

5.1 Base case GHG emissions

For the base case, Table 5.1 draws on the emissions inventory summarised in Table 3.7. It summarises the GHG emissions in annual tonnes CO_2-e, tonnes CO_2-e per tonne of product and for tonnes CO_2-e per MWh sent out. Figure 5.1 shows the emissions percentages for each main stage of the life cycle and Figure 5.2 illustrates the life cycle GHG intensities for various coal-fired power generation technologies. Attachment 7 presents more detailed breakdowns for each activity.

Table 5.1 Base case emissions

ACTIVITY	GHG EMISSIONS INTENSITY				
	Base case tonnes CO_2-e / tonne product coal	%	**Subcritical** 33% efficiency tonne CO_2-e / MWh	**Supercritical** 41% efficiency tonne CO2-e / MWh	**Ultra super critical** 43% efficiency tonne CO2-e / MWh
MINING					
Mine fugitives	0.0375	1.47	0.0152	0.0122	0.0116
Mine diesel use	0.0114	0.40	0.0046	0.0037	0.0035
Explosives	0.00025	0.01	0.0001	0.0001	0.0001
Slow oxidation	0.00018	0.01	0.0001	0.0001	0.0001
Power consumption	0.0157	0.62	0.0063	0.0051	0.0049
Spontaneous combustion	0.00185	0.07	0.0007	0.0006	0.0006
Scope 3 fuel and electricity	0.0029	0.11	0.0012	0.0009	0.0009
TRANSPORT					
Rail operations	0.00205	0.08	0.0008	0.0007	0.0006
Port handling	0.00161	0.06	0.0007	0.0005	0.0005
Shipping	0.0791	3.11	0.0320	0.0257	0.0245
END USE					
Combustion	2.388	94.02	0.9647	0.7765	0.7403
TOTAL – ALL SOURCES	**2.540**	**100**	**1.026**	**0.826**	**0.788**

5.2 Interpretation

Table 5.1, Figure 5.1 and supporting analysis in Attachment 7, clearly show the following for the base case.

- The majority of GHG emissions occur in end use combustion (94%). Extraction and processing in Australia accounts for a small component (2.7%).
- Of extraction and processing activities, fugitive emissions (1.5%) is the largest single contributor, followed by use of fuel and power (1.2%).
- Transport accounts for 3.25 % of which the majority is for shipping.

Figure 5.1 Life cycle GHG emissions percentages - black coal

Based on tonnes CO2-e / tonne product coal

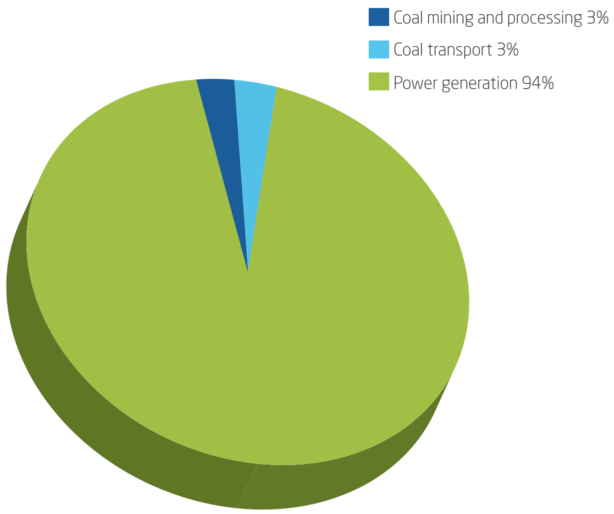
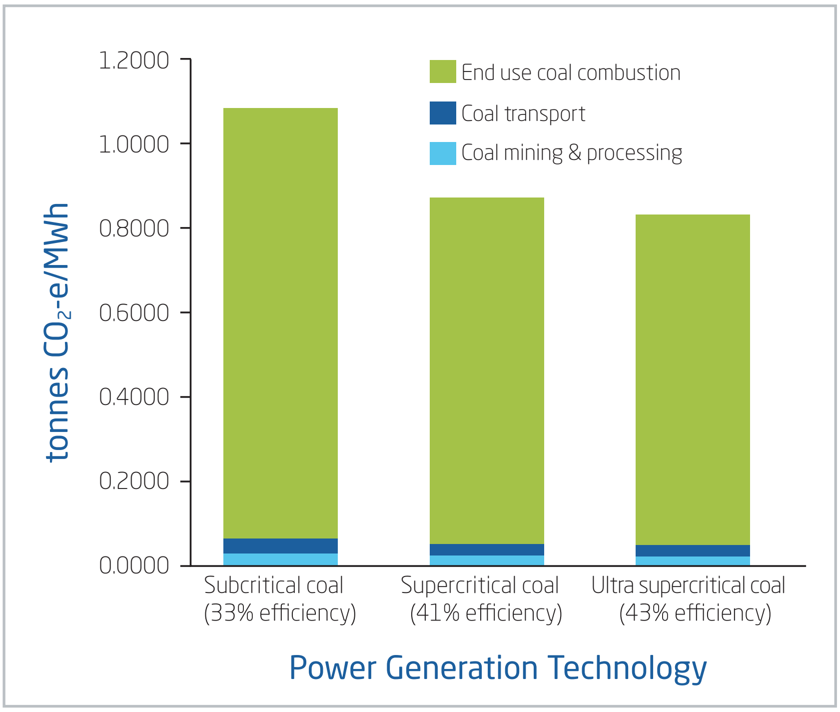


Figure 5.2 Comparison of GHG intensities for various coal-fired power generation technologies



5.3 Sensitivity analysis

The base case results were tested for sensitivity to the following:

a) Higher and lower efficiency power plant (around ±4% for each, with minor variations).
b) ± 50% in fugitive emissions.
c) ± 100% in rail distance to port.
d) ± 50% in fuel and power use in mining.

The ±4% for power plant was based on research in WorleyParsons 2008. The ± 50% for b) to d) was arbitrary as discussed for CSG/LNG

The analysis found that the total life cycle GHG emissions were significantly influenced by normal ranges of power plant efficiency (±11%).

However variations in factors b), c) and d) had no significant impact (<1%) on GHG emissions intensity and minor differences in factor a) had a negligible impact on overall emissions.

5.4 Uncertainty

Attachment 5, Section 8 provides an uncertainty analysis using National Greenhouse and Energy Reporting (Measurement) Determination 2008 and figures derived from analyses in EISs, stated in NGA factors, or estimated from operational scenarios. For most of the life cycle GHG emissions, aggregate uncertainties (based on activity and emission factor uncertainty) are around ±10%, with higher certainty in end use combustion ±5%, and higher uncertainty (±50%) in fugitive emissions.

Because of the dominance of end-use combustion, the cumulative uncertainty is estimated to be within ±5% in terms of GHG intensity, tonnes CO_2-e/MWh.

5.5 Comparative analysis

Few life cycle assessments of coal have been undertaken and still less for the export of Australian black coal. Available studies show comparable results for relevant components:

- WorleyParsons (2008) found average emissions intensities of 1.02, 0.77 and 0.72 tonnes CO_2-e per MWh sent out, respectively for sub-, super- and ultra super critical combustion based on a limited comparison between NW Shelf LNG and NSW black coal.
- PACE (2009) found a typical GHG emissions intensities of 1.24, 0.85 and 0.82 tonnes CO_2-e per MWh respectively for current US mix, advanced ultra critical and integrated gasification plant.
- Jaramillo et al (2006) found emissions intensities of 0.91-1.14 t CO_2-e per MWh for current common technologies in the US and as low as 0.11 t CO_2-e per MWh for advanced power plant technology.

Section 6 provides a comparison with the results for CSG/LNG.

Section 6 Comparison

6. COMPARISON

6.1 Relative GHG intensities

The results for each product stream are compared in Tables 6.1 to 6.3 and Figure 7, drawing on the emissions inventories in Tables 3.6 and 3.7 and impacts in Table 4.1 and 5.1 The assessment shows that:

- CSG/LNG is significantly less GHG intensive for most existing, commonly employed end-use combustion technologies. and for most of the life cycle scenarios considered (table 6.2).
- CSG and coal have different emissions profiles. For the export situation considered, most GHG emissions from coal (94%) will result from combustion in China, whereas extraction and processing in Australia accounts for only 2.7%. For CSG the respective figures are 74% and 22% (Table 6.1).
- When considering emissions per MWh of electricity sent out (Table 6.2) the results are highly sensitive to assumptions about the technology employed and the thermal efficiencies that apply topower generation.
- On average, coal combusted in a subcritical, supercritical or ultra-supercritical pulverised coal plant produces respectively 87%, 51% and 43% more life cycle GHG emissions per MWh than CSG/LNG combusted in a combined cycle gas turbine (CCGT) plant (Table 6.2) That is, when used for electricity generation in China, for every life cycle tonne CO_2-e from CSG/LNG up to 0.87 tonnes CO_2-e may be avoided compared to electricity from coal. This maximum figure will decrease over time since large numbers of large supercritical and ultra-supercritical plant are being constructed, but subcritical is likely to remain the dominant coal combustion technology in China.
- The corresponding numbers for the respective coal technologies compared to combustion on an open cycle gas turbine plant are 37%, 11% and 5% more GHG emissions per MWh (Table 6.2). However this comparison is less important since OCGT tends to be only used in smaller plant for peak shaving, emergency generation or remote locations.
- When considering life cycle GHG emissions per GJ of fuel, the overall GHG intensity of coal combustion is 0.09 tonnes CO_2-e /GJ, when exported to China compared to CSG/LNG which has an intensity of 0.08 tonnes CO_2-e /GJ (Table 6.3), so CSG/LNG is approximately 14% less GHG intensive than coal against this measure.
- Although no relevant CSG/black coal life cycle comparisons were found, the results are consistent with comparable elements of various LNG /coal comparisons.

When considering emissions avoided by switching from coal to CSG/LNG for simple substitution scenarios:

- For every life cycle tonne CO_2-e from CSG/LNG up to 0.87 tonnes CO_2-e may be avoided (Table 6.2)
- Considering savings from a 30 year 10 Mtpa CSG/LNG project (as expected for the Gladstone LNG development), if CSG/LNG is combusted in a CCGT plant instead of a subcritical coal plant, the life cycle emissions are 42.7 million tonnes (Mt) CO_2-e per annum, the annual savings 37.2 Mt CO2-e and the project life savings 1114 Mt CO_2 -e. For CSG/LNG combustion in a CCGT plant instead of a supercritical coal plant the annual savings and project life savings are 21.7 and 652 Mt CO_2-e respectively.
- Considering global emissions savings from CSG/LNG GHG emissions in Australia, if electricity is generated in China from CSG/LNG in CCGT instead of subcritical coal, then for every tonne CO_2-e emitted in Australia, 4.3 tonnes are avoided globally. For supercritical coal 2.5 tonnes CO_2-e are avoided (Table 6.4).

Considering the absolute potential GHG impacts and benefits of CSG industry expansion is outside the scope of this study, as is considering how much large scale substitution for coal is likely to occur and, if so, how it will contribute to proposed and necessary GHG reduction trajectories

When making switching or displacement comparisons it is important to note that, since China is rapidly expanding its power generation capacity, gas fired power is likely to add to capacity rather than compete against coal. An existing coal fired plant will not be taken off line and replaced by a gas fired plant and, in general, large supercritical and ultra-supercritical plants of up to 1000MW are being built to replace redundant small, inefficient coal plants.

While end user combustion emissions dominate both product streams and the emissions from other stages are much smaller, they are nevertheless significant in absolute terms, especially those for upstream CSG/LNG. While best practice technology is assumed, all stages and processes for both products will present opportunities for GHG emissions mitigation.

Table 6.1 GHG intensities – units of tonnes CO_2-e/tonne product
Rounded

OPERATION		COAL SEAM GAS		BLACK COAL	
		Base case tonnes CO_2-e / tonne product	%	**Base case** tonnes CO_2-e / tonne product	%
Extraction and processing		0.96	22.5	0.07	2.6
Transport		0.09	2.1	0.08	3.2
Processing and power generation in China		3.22	75.4	2.39	94.2
TOTALS		**4.27**	100	**2.54**	100
Ranges	Min Max	4.15 4.29		1.86 3.86	

Note: These figures are independent of combustion technology.

Table 6.2 Electricity generation GHG intensities – units: tonnes CO_2-e/MWh
Rounded

OPERATION		COAL SEAM GAS		BLACK COAL		
		Base case		**Base case**		
		OCGT	**CCGT**	**Sub-critical**	**Super critical**	**Ultra super critical**
Assumed average efficiency (%)		39	53	33	41	43
Extraction and processing		0.14	0.10	0.03	0.02	0.02
Transport		0.02	0.01	0.03	0.03	0.03
Processing and power generation in China		0.59	0.43	0.97	0.78	0.74
TOTALS		**0.75**	**0.55**	**1.03**	**0.83**	**0.79**
Ranges	Min Max	0.64 0.84	0.49 0.64	0.75 1.56	0.61 1.26	0.58 1.20

Table 6.3 Electricity generation GHG intensities – units: tonnes CO_2-e/GJ exported
Rounded

OPERATION	COAL SEAM GAS	BLACK COAL
Extraction and processing	0.015	0.0026
Transport	0.002	0.0031
Processing and power generation in China	0.064	0.088
TOTALS	**0.081**	**0.094**

Note: These figures are a function of the fuel type and are irrespective of end-user combustion technology.

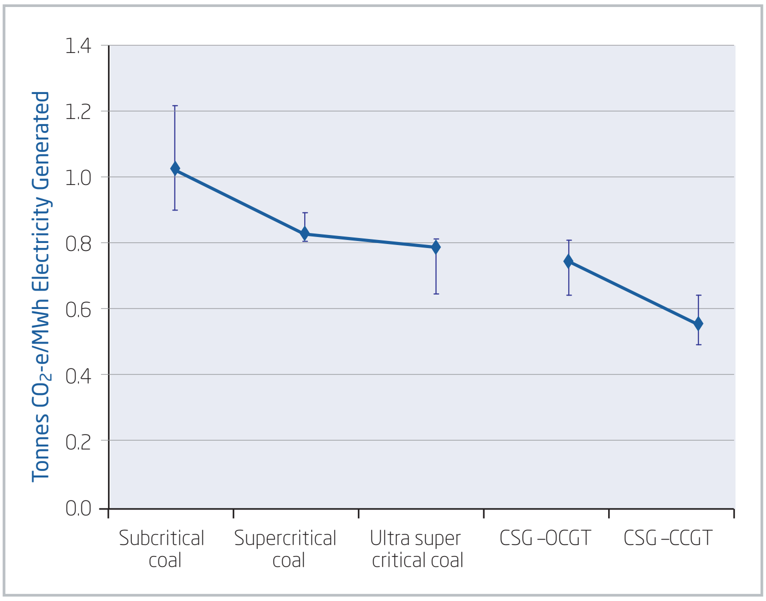
Table 6.4: Example scenarios of Australian-Global emissions relationship for CSG/LNG

Scenario	Case	Technology	Global lifecycle GHG intensity	Australian component of the GHG intensity	Emissions ratio (Global change in emissions: Australian emissions)
	C	-	Tonnes CO_2-e / MWh	Tonnes CO_2-e / MWh	Tonnes CO2-e / tonnes CO_2-e
1. New power generation plant in China	Base case - coal	Supercritical	0.826	0.024	-
	CSG/LNG switching	CCGT	0.55	0.11	**-2.5 : +1** [1]
2. New power generation plant in China	Base case - coal	Subcritical	1.026	0.03	-
	CSG/LNG switching	CCGT	0.55	0.11	**-4.3 : +1** [2]

Notes:

1. *This shows that for the utilisation of CSG/LNG for a new power generation plant in China in place of coal, 2.5 tonnes of CO_2-e are saved globally, at the expense of every tonne of CO_2-e emitted in Australia.*
2. *This shows that for the replacement of a current coal-fired power generation plant in China with a CSG/LNG power plant, 4.3 tonnes of CO_2-e are saved globally, at the expense of every tonne of CO_2-e emitted in Australia.*
3. *'Global' means total life cycle emissions.*

Figure 6.1: Life cycle GHG intensities of CSG and black coal
The error bars show intensities for various ranges of efficiencies for end use combustion



Note: The ranges shown here reflect ranges in efficiencies of power plant whereas those in Figure 1.1 relect ranges across all emission sources.

6.2 Uncertainties and sensitivities

Estimates for most of the elements were, when considering the basis for calculation, reliable to within 5-10%. Exceptions, where an estimated 50% uncertainty is possible are:

- For CSG: GHG emissions from flaring and venting in the CSG fields, from compressor turbines in the CSG fields and from energy use for RO in water treatment.
- For coal: fugitive emissions from mines.

Considering sensitivity bands for uncertainties and ranges of power plant efficiency generates various best/worst case comparisons. For these atypical scenarios, electricity from coal is only less GHG intensive when best case coal is compared to a few worst CSG/LNG cases, mainly low efficiency OCGT combustion.

If the worst CSG case scenario of 50% higher GHG emissions from the operation of power generation and compressor turbines in the CSG fields is assumed, this leads to an increase in the GHG intensity of CSG/LNG with base case OCGT generation (i.e. with 39% efficiency) of 0.8 tonnes CO_2-e/MWh (i.e. 7% higher GHG emissions than the base OCGT case). When this worst case scenario for CSG/LNG is compared with the subcritical coal base case, the coal lifecycle GHG emissions are now 28% higher compared with 37% higher for the base OCGT case.

If we take an even more conservative assumption of combining 50% higher GHG emissions from the operation of power generation and compressor turbines in the CSG fields and the low OCGT efficiency of 36%, this leads to an intensity of 0.84 tonnes CO_2-e/MWh (i.e. 12% higher GHG emissions than the base OCGT case). Comparing this to subcritical coal-fired generation shows that coal fired generation is still 22% higher in GHG emissions intensity than CSG/LNG. However, under this worst case scenario, supercritical and ultra supercritical coal fired generation on a lifecycle basis would be superior, with CSG/LNG being 2% and 6% more GHG intensive.

7. CONCLUSIONS

The results are sufficiently clear and robust to confirm that on a life cycle basis CSG/LNG produced for combustion in a Chinese power plant is less GHG intensive than coal, based on the stated assumptions and scenarios, including the application of best practice in GHG and environmental management.

Depending on the end combustion technology, switching from coal to CSG/LNG for electricity generation avoids up to 0.87 tonnes CO_2-e for every life cycle tonne CO_2-e from CSG/LNG, and up to 4.5 tonnes CO_2-e for every tonne CO_2-e emitted from CSG/LNG in Australia.

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ATTACHMENT 1 ABBREVIATIONS

BOG	Boil Off Gas
AGRU	Acid Gas Removal Unit
ANFO	Ammonium nitrate/fuel oil
CO_2	Carbon dioxide
CH_4	Methane
CSG	Coal seam gas
CCGT	Combined cycle gas turbine
DCCEE	Department of Climate Change and Energy Efficiency
EIS	Environmental Impact Statement
GHG	Greenhouse gas(es)
GJ	gigajoule (10^9 joules)
GWP	Global warming potential
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
LCA	Life cycle assessment
LCI	Life cycle inventory
LNG	Liquefied natural gas
NGA	National Greenhouse Accounts
NGER	National Greenhouse and Energy Reporting
NRU	Nitrogen Removal Unit
MOF	Material Offloading Facility
Mtpa	million tonnes per annum
Mt CO_2-e	million tonnes CO_2-equivalent
OCGT	Open cycle gas turbine
OC	Open cut
N_2O	Nitrous oxide
NGA(F)	National Greenhouse Accounts (Factors)
PJ	petajoule (1^{015} joules)
ROM	Run of mine (production of a mine before processing)
t CO_2-e	tonnes CO_2- equivalent
TJ	terajoule (10^{12} joules)
UG	Underground
UNFCCC	United Nations Framework Convention on Climate Change

GLOSSARY OF TERMS

Attributional LCA	An attributional LCA aims to describe the environmental properties of a life cycle and its subsystems. In contrast, a consequential LCA describes the effects of changes within a life cycle.
Carbon dioxide equivalent	The key greenhouse gases in this Project are carbon dioxide, methane and nitrous oxide. To simplify the accounting of GHGs, the unit of a carbon dioxide equivalent or CO2-e is used. This ensures that the global warming potential of each gas is accounted for. Carbon dioxide has a global warming potential of 1, methane has a global warming potential of 21, and nitrous oxide has a global warming potential of 310.
Brown coal	Lower ranking types of coal used almost exclusively as fuel for electric power generation and with a very low energy density.
Black coal	Higher ranking types of coal used for steel production as well as electricity generation and with a higher energy density than brown coal.
Boil off gas (BOG)	LNG is stored at its boiling point at normal atmospheric pressure. As LNG absorbs heat a small portion evaporates. BOG from transfer to and from ships can be used as fuel for turbines or re-liquefied.
Coal seam gas (CSG)	A form of natural gas deliberately extracted from coal beds and used as an energy source.
Coal seam methane	The methane extracted as part of coal seam gas. Also refers to methane vented from coal mines or natural fugitives.
Decommissioned mines	Abandoned underground mines whose economically viable coal resources have been exhausted.
Downstream	A term used to describe activities along the gas value chain. Downstream typically refers to liquefaction, shipping and re-gasification.
Efficiency (of a power plant)	The efficiency of the thermodynamic process of a power plant describes how much of the energy fed into the cycle is converted into electrical energy. The greater the output of electrical energy for a given amount of energy input, the higher the efficiency.
Emission factor	When estimating GHG emissions, a measure of the average quantity of GHG emissions released to atmosphere by a specific process, fuel, equipment or source.
Exported	Produced for export to international customers, in this case to China.
Flaring	Burning of surplus combustible vapours for disposal or as a safety measure to release pressure. Flaring reduces GHG emissions compared to venting methane because methane has a GWP 21 times higher than carbon dioxide.

Fugitive emissions	Uncontrolled releases of gases to the air, in this context releases of methane as a result of mining or gas extraction activities.
Global warming potential	The GWP is a measure of the amount of infrared radiation captured by a gas in comparison to an equivalent mass of $CO2$ over a fixed lifetime. The GWP factors specified in the NGA Factors are: carbon dioxide 1, methane 21 and nitrous oxide 310.
Greenhouse gas	A greenhouse gas (GHG) is a gas in the atmosphere that absorbs and emits radiation within the thermal infrared range. There are various naturally occurring greenhouse gases. Anthropogenic greenhouse gases included within the Kyoto Protocol are carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O) and various perflurocarbons and hydrofluorocarbons.
Life cycle assessment	The compilation and evaluation of the inputs, outputs and potential environmental impacts for a product throughout its life cycle.
LNG Train	An LNG train is the term used to describe the liquefaction and purification facilities in a liquefied natural gas plant.
Metallurgical coal	Coal suitable for making steel; includes coking coal and other types of coal.
Re-gasification	The reconversion (warming) of LNG to a gas for pipeline distribution.
Run-of-mine production	Total volume (tonnage) of coal extracted from a mine prior to cleaning and classification.
Saleable production	Amount (tonnage) of coal extracted that can be sold after cleaning and classification.
Scope 1 emission	Refers to direct greenhouse gas emissions arising from generation of heat, steam and electricity from fuel combustion; manufacturing processes that produce emissions; transport of materials, waste and people; fugitive or unintentional releases of greenhouse gases from pipes and joints; and on-site waste management.
Scope 2 emission	Refers to emissions from the generation of electricity purchased and consumed by an end user
Scope 3 emission	Refers to emissions related to the activities of the reporting entity but arising outside the reporting boundary.
Sent out	Refers to electricity sent the grid after power station internal use and losses of electricity generated,
Slow oxidation	Non-combustion release of carbon dioxide from exposed coal surfaces.
Spontaneous combustion	Combustion of carbonaceous material in spoil heaps as a result of self- heating. Can be avoided by good management. Can also occur in product in transport and storage (although there are no additional emissions form this as the product would be burnt in any event).

Sub-, super- and ultra-supercritical pulverised coal power plant	Conventional (subcritical) pulverised coal-fired power plants make water boil to generate steam that activates a turbine. Supercritical (SC) and ultra-supercritical (USC) power plants operate at temperatures and pressures above the critical point of water, i.e. above the temperature and pressure at which the liquid and gas phases of water coexist in equilibrium. At this point there is no difference between water gas and liquid water. This results in higher efficiencies.
Transition fuel	As the world moves toward cleaner energy sources such as renewable energy (e.g. solar, wind and wave power), fossil fuels will continue to be used to provide energy generation. Black coal is currently the most greenhouse gas intensive fuel, but LNG is less intensive and is seen by some as part of the transition to cleaner, renewable energy sources.
Thermal coal	Coal used as fuel for electric power generation. It is also referred to as steaming coal.
Upstream	A term used to describe activities along the gas value chain. Upstream typically refers to exploration, development and production of gas.
Venting	Release of gas to atmosphere, deliberately for operational (where flaring or capture is not possible) or safety reasons, or as a result of leaks.

ATTACHEMENT 2
REQUIREMENTS FOR AN LCA

1. RELEVANT STANDARDS

The principles and approach for conducting a life cycle assessment are set out in International Standard ISO 14040:2006 *Environmental Management – Life cycle assessment – principles and framework and ISO* 14044:2006 *Environmental Management – Life cycle assessment – principles and framework.*

2. DEFINITION

A life cycle assessment is defined as the compilation and evaluation of the inputs, outputs and potential environmental impacts for a product throughout its life cycle.

3. PRINCIPLES

ISO 14040 clause 4.1 states that the principles in Table A2.1 are fundamental and should be used as guidance for decisions relating to both the planning and the conducting of an LCA.

Table A2.1 LCA principles

PRINCIPLE	REQUIREMENTS OF THE STANDARDS
Life cycle perspective	LCA considers the entire life cycle of a product, from raw material extraction and acquisition, through energy and material production and manufacturing, to use and end of life treatment and final disposal. Through such a systematic overview and perspective, the shifting of a potential environmental burden between life cycle stages or individual processes can be identified and possibly avoided.
Environmental focus	LCA addresses the environmental aspects and impacts of a product system. Economic and social aspects and impacts are, typically, outside the scope of the LCA. Other tools may be combined with LCA for more extensive assessments.
Relative approach and functional unit:	LCA is a relative approach, which is structured around a functional unit. This functional unit defines what is being studied. All subsequent analyses are then relative to that functional unit, as all inputs and outputs in the life cycle inventory (LCI) and consequently the life cycle impact assessment (LCIA) profile are related to the functional unit.
Iterative approach	LCA is an iterative technique. The individual phases of an LCA use results of the other phases. The iterative approach within and between the phases contributes to the comprehensiveness and consistency of the study and the reported results.
Transparency	Due to the inherent complexity in LCA, transparency is an important guiding principle in executing LCAs, in order to ensure a proper interpretation of the results.
Comprehensiveness	LCA considers all attributes or aspects of natural environment, human health and resources. By considering all attributes and aspects within one study in a cross-media perspective, potential trade-offs can be identified and assessed.
Priority of scientific approach	Decisions within an LCA are preferably based on natural science. If this is not possible, other scientific approaches (e.g. from social and economic sciences) may be used or international conventions may be referred to. If neither a scientific basis exists nor a justification based on other scientific approaches or international conventions is possible, then, as appropriate, decisions may be based on value choices.

4. KEY FEATURES

The Standards specify some key features which further define an LCA and state the requirements for conducting an LCA

Table A2.2 key features of an LCA

ISSUE	DETAILS
Systematic	An LCA assesses, in a systematic way, the environmental aspects and impacts of product systems, from raw material acquisition to final disposal, in accordance with the stated goal and scope.
Relative	The relative nature of LCA is due to the functional unit feature of the methodology.
Detail	The depth of detail and time frame of an LCA may vary to a large extent, depending on the goal and scope definition.
Respect for commercial confidentially	Provisions are made, depending on the intended application of the LCA, to respect confidentiality and proprietary matters.
Method and content	LCA methodology is open to the inclusion of new scientific findings and improvements in the state-of-the art of the technique. An LCA is different from many other techniques (such as environmental performance evaluation, environmental impact assessment and risk assessment) as it is a relative approach based on a functional unit; LCA may, however, use information gathered by these other techniques. An LCA is different from many other techniques (such as environmental performance evaluation, environmental impact assessment and risk assessment) as it is a relative approach based on a functional unit; LCA may, however, use information gathered by these other techniques. LCA addresses potential environmental impacts; LCA does not predict absolute or precise environmental impacts due to: – the relative expression of potential environmental impacts to a reference unit; – the integration of environmental data over space and time; – the inherent uncertainty in modelling of environmental impacts; and – the fact that some possible environmental impacts are clearly future impacts. The life cycle impact assessment (LCIA) phase (see below), in conjunction with other LCA phases, provides a system-wide perspective of environmental and resource issues for one or more product system(s). LCIA assigns life cycle inventory (LCI) results to impact categories; for each impact category, a life cycle impact category indicator is selected and the category indicator result (indicator result) is calculated; the collection of indicator results (LCIA results) or the LCIA profile provides information on the environmental issues associated with the inputs and outputs of the product system.
Interpretation	Life cycle interpretation uses a systematic procedure to identify, qualify, check, evaluate and present the conclusions based on the findings of an LCA, in order to meet the requirements of the application as described in the goal and scope of the study. Life cycle interpretation uses an iterative procedure both within the interpretation phase and with the other phases of an LCA. Life cycle interpretation makes provisions for links between LCA and other techniques for environmental management by emphasizing the strengths and limits of an LCA in relation to its goal and scope definition.
Public reports	Specific requirements (peer review) are applied to LCA that are intended to be used in comparative assertions intended to be disclosed to the public;

5. LCA METHOLOGY

ISO 14040 and ISO 14044 specify a staged approach as shown in Figure A2.1

Figure A2.1. Staged approach for an LCA

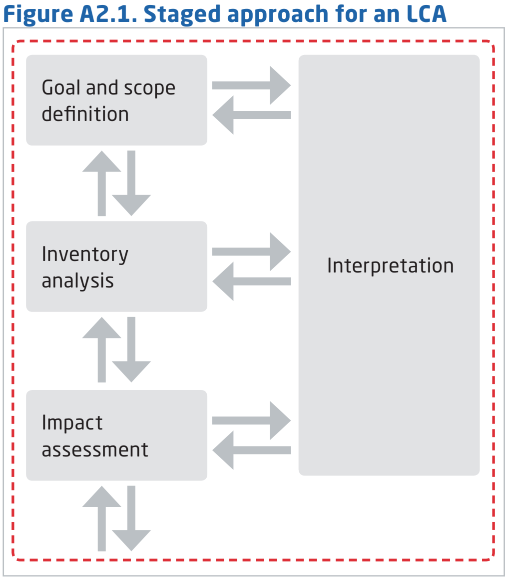


Table A2.3 Staged approach

STAGE	REQUIREMENTS OF THE STANDARDS
Stage 1: Goal and scope definition	The goal states: • the intended application; • the reasons for carrying out the study; • the intended audience, i.e. to whom the results of the study are intended to be communicated; and • whether the results are intended to be used in comparative assertions intended to be disclosed to the public; • The scope includes the following items: • the product system to be studied; • the functions of the product system or, in the case of comparative studies, the systems; • the functional unit; • the system boundary; • allocation procedures; • impact categories selected and methodology of impact assessment, and subsequent interpretation to be used; • data requirements; • assumptions; • limitations; • initial data quality requirements; • type of critical review, if any; • type and format of the report required for the study.
Stage 2: Life cycle inventory (LCI) analysis	Life cycle inventory (LCI) analysis involves data collection and calculation procedures to quantify relevant inputs and outputs of a product system.
Stage 3: Life cycle impact assessment	The impact assessment phase of LCA is aimed at evaluating the significance of potential environmental impacts, specifically using the LCI results. The LCIA phase also provides information for the life cycle interpretation phase.
Stage 4: Interpretation of results	The results are analysed to identify significant impacts and differences, especially impact ' hot spots'.

ATTACHMENT 3
GHG ACCOUNTING REQUIREMENTS

1. General requirements

Principles and requirements for accounting and reporting greenhouse gas emissions are stated in the Greenhouse Gas Protocol (the Protocol) (World Business Council for Sustainable Development and the World Resource Institute 2004) and various supporting documents and guidelines. The Protocol is an internationally accepted accounting and reporting standard for facility or organisational GHG emissions. The methodology in the Greenhouse Gas Protocol is consistent with the methodology in the National Greenhouse Accounts (NGA) Factors (Australian Government 2009).

2. Greenhouse gases

A greenhouse gas (GHG) is a gas in the atmosphere that absorbs and emits radiation within the thermal infrared range. This process is the fundamental cause of the greenhouse effect, a natural phenomenon which maintains the Earth's temperature at habitable levels. The enhanced greenhouse effect is additional trapping of solar energy and warming as a result of increasing emissions, mainly anthropogenic i.e. as a result of human activities (IPCC, 2007).

There are various naturally occurring greenhouse gases. Anthropogenic greenhouse gases included within the Kyoto Protocol, on which the Greenhouse Gas Protocol is based, are carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O) and three groups of fluorinated gases, (sulphur hexafluoride, hydrofluorocarbons and perfluorocarbons). Only the first three are relevant to this study. To account for these emissions they are converted to carbon dioxide equivalents (CO2-e) as specified under the Kyoto Protocol to produce comparable measures of global warming potential (GWP). The GWP is a measure of the amount of infrared radiation captured by a gas in comparison to an equivalent mass of CO2 over a fixed lifetime. The GWP factors used are those specified in the NGA Factors i.e. carbon dioxide 1, methane 21 and nitrous oxide 310 (NGA Factors, 2010, Table 27). It should be noted that GWPs relative to carbon dioxide change with time horizon as gases decay. The GWP for methane is 21 over 100 years but higher over 20 years. Estimates vary according to the source but UNFCCC 1995 estimated the short term GWP of methane as 56.

Emission factors for calculating direct emissions are generally expressed in the form of a quantity of a given GHG emitted per unit of energy (kg CO2-e /GJ), fuel (t CH4/t coal) or a similar measure. Emission factors are used to calculate GHG emissions by multiplying the emission factor (e.g. kg CO2-e/GJ energy in diesel) with activity data (e.g. kilolitres x energy density of diesel used). The document NGA Factors 2010 and National Greenhouse and Energy Reporting (Measurement) Technical Guidelines 2008 provide examples of calculations and further information.

3. Scope 1, 2 and 3 emissions

The Protocol separates GHG-producing activities according to the relevant scope.

- Scope 1 GHG emissions are produced directly from combustion, fugitive and vented sources that are within the boundary of an operation or organisation.
- Scope 2 GHG emissions arise from the generation of purchased electricity, heat and steam. These emissions are generated outside of the operation's or organisation's boundary.
- Scope 3 GHG emissions are related to the activities of the reporting entity but arising from sources beyond the boundary of the operation or organisation – for example production and transport of materials and equipment onto a facility site. Scope 3 GHG emissions are also associated with the extraction, production and transportation of purchased fuels consumed.

4. Guiding principles

Table A2.4 states the guiding principles of the Protocol for compiling an inventory of GHG emissions

Table A3.1 WBCSD GHG Protocol Principles

PRINCIPLE	REQUIREMENTS
Relevance	The inventory must contain the data that information that both internal and external users need for their decision-making.
Completeness	All relevant emissions sources within the inventory boundary need to be accounted for so that a complete and meaningful inventory is compiled.
Consistency	The consistent application of accounting approaches, inventory boundary and calculation methodologies is essential to produce comparable GHG methodologies over time.
Transparency	All relevant issues must be addressed in a factual and coherent manner, based on a clear audit trail. Disclose any relevant assumptions and make appropriate references to the accounting and calculation methodologies and data sources used.
Accuracy	Data should be sufficiently precise to enable intended users to make decisions with reasonable assurance that the reported information is credible.

5. Materiality

A further principle used in accounting which applies to GHG accounting is materiality. In accounting, materiality is a concept used in to minimise time spent calculating or verifying amounts and figures that do not impact a company's accounts or inventory in a material way. The exact materiality threshold used is subjective and dependent on the context and the features of the inventory. All items that are found within the boundary are included in the inventory unless they are excluded on materiality grounds. Information is considered to be material if, by its inclusion or exclusion it can be seen to influence any decisions or actions taken by users. Normally, emissions are assumed to be immaterial if they are likely to account for less than 5% of the overall emissions profile.

The LCA presented in this report focuses on those GHG life cycle emissions from Australian CSG or coal projects which are material. From experience, these are especially Scope 1 GHG emissions (direct GHG emissions from operations e.g. from burning fuel or from fugitive emissions) and Scope 2 (indirect, from electricity use where the emissions are generated elsewhere in power generation). Scope 3 GHG emissions are the indirect GHG emissions produced outside of operational boundaries (e.g. embedded energy in materials, transport of employees and materials, production and transport of fuels). Scope 3 GHG emissions are identified and quantified for Australian operations for completeness but in practice tend to be insignificant compared to Scope l and 2 GHGs.

6. Uncertainty

A measure of uncertainty is a standard part of a GHG inventory established under the WBCSD GHG Protocol and related guidelines. Uncertainties associated with a GHG inventory are either related to scientific uncertainty or estimation uncertainty. Scientific uncertainty includes uncertainties in the global warming potential values. Estimation uncertainty includes model uncertainty (in the mathematical equations used to calculate the emissions and parameter uncertainties relating to activity data and to emission factors in the conversion of measured activities to GHG emissions. Scientific and model uncertainties are outside of the scope of this study. Therefore only activity and emission factor uncertainties are considered here.

National Greenhouse and Energy Reporting (Measurement) Determination 2008 provides a method for aggregating uncertainty levels for emission factors, energy content of fuels and quantity of fuel combusted. It also provides aggregated uncertainty levels for certain parameters including ± 50% for fugitive emissions from open cut mines. Overall uncertainty and the contribution of any activity to overall uncertainty are considered against the contribution of an activity to overall uncertainty i.e. a high level of uncertainty in a low contribution activity will not materially affect overall uncertainty.

The technique used for aggregating the uncertainty is known as the first order error propagation. There are four key assumptions that are made when this technique is used and should be considered.

- The error in each parameter is normally distributed;
- There are no biases in the estimator function (i.e. the estimated value is the mean value);
- The estimated parameters are uncorrelated; and
- Individual uncertainties in each parameter must be less than 60% of the mean.

7. GHG emissions factors

A GHG emission factor is a factor expressed as the amount of GHG emissions per unit of activity and is a way of estimating emissions where direct measurement is not possible. Emissions can be estimated using the WBCSD GHG Protocol methodology and the Australian Government's National Greenhouse Accounting (NGA) Factors Workbook which is revised annually, for example to account for changes in the power generation mix on Scope 2 emissions.

Default emissions factors are used where there is no technical basis for estimation, for example stoichiometric calculation for combustion emissions.

The following tables illustrate some emissions factors relevant to the present LCA. It should be noted that individual EISs used various editions of NGA Factors (typically the 2008 version) depending on when the EIS was produced.

These generic emissions factors apply to all relevant activities and underly all of the emissions estimates drawn from the EIS. They have also been used in back-calculating the energy values in Tables 3.6 and 3.7.

Emissions factors for land clearing were used for the CSG/LNG EIS since cleared areas are significant for the 450 km pipeline and gas field. Land clearing was not included in the coal base case (see Inclusions/exclusions Table 3.4) since emissions were not considered to be material for the reasons stated.

Table A3.2 Emissions factors

EMISSION SOURCE	EMISSION FACTOR	UNITS	SOURCE
SCOPE 1 EMISSIONS			
Combustion emission factor - diesel	2.7	t CO_2-e/KL	NGA Factors 2010, Table 3: Liquid fuel combustion, stationary sources.
Consumption of natural gas (or CSG) - Queensland	51.3	t CO_2-e/GJ	NGA Factors, 2010, Table 2: Fuel combustion, gas.
Fugitive emissions Queensland open cut NSW open cut Gassy underground Non gassy underground	 0.017 0.045 0.305 0.008	t CO_2-e/t ROM	NGA Factors, 2010 Table 6: emission factors for the production of coal (fugitive) – underground. NGA Factors, 2010 Table 8: emission factors for the production of coal (fugitive) – open cut. Section 3.2 of Technical Guidance.
Explosives – ANFO and emulsion	0.17	t CO_2-e/t product	NGA Factors: explosive use.
SCOPE 2 EMISSIONS			
Electricity consumption - Queensland NSW	 0.91 0.89	kg CO_2-e/kWh	NGA Factors, 2010 Table 5: Indirect (scope 2) for consumption of purchased electricity from the grid. Note: These change annually depending on the fuel and other energy mix of grid electricity for a State.
SCOPE 3 EMISSIONS			
Land clearing	Av 36.7	tC/ha	National Carbon Accounting Toolbox (DCCEE, 2005). Depends on type of vegetation.

Table A3.3 GHG emission factors used to estimate scope 3 emissions

Scope 1 emissions –transport - NGA factors, 2010, Table 4.
Scope 1 emissions –stationary energy - NGA factors, 2010, Table 3.
Scope 3 emission - NGA factors, 2010, Table 39.

FUEL COMBUSTED	SCOPE 1 EMISSION FACTOR KG CO_2-E/GJ	SCOPE 3 EMISSION FACTOR KG CO_2-E/GJ	ENERGY CONTENT GJ/KL
Diesel emissions (transport)	69.9	5.3	38.6
Petrol emissions (transport)	67.4	5.3	34.2
Fuel oil emissions (transport)	73.6	5.3	39.7
Diesel emissions (stationary)	69.5	5.3	38.6

ATTACHMENT 4
LIFE CYCLE GHG INVENTORY: COAL SEAM GAS

1. CSG industry overview

Various major new projects are being planned in Queensland for exporting LNG and these are at various stages of government approval. The Queensland coal seam gas reserves are mainly located in the Surat and Bowen Basins, in the Western Downs Region, approximately 450 km from the coast. The proposed projects plan to extract the CSG and deliver it via pipeline to coastal processing facilities for treatment and export by ship. The main location for process facilities is Curtis Island, near Gladstone, approximately 1 km offshore and presently only accessible by barge.

If all current projects go ahead and operate to full capacity, exports are projected to be 43Mtpa (Queensland Government, 2010.

The existing CSG industry in Queensland and NSW is small scale for domestic markets. Operational conditions and GHG emissions are not representative of the level of operations planned for the emerging industry.

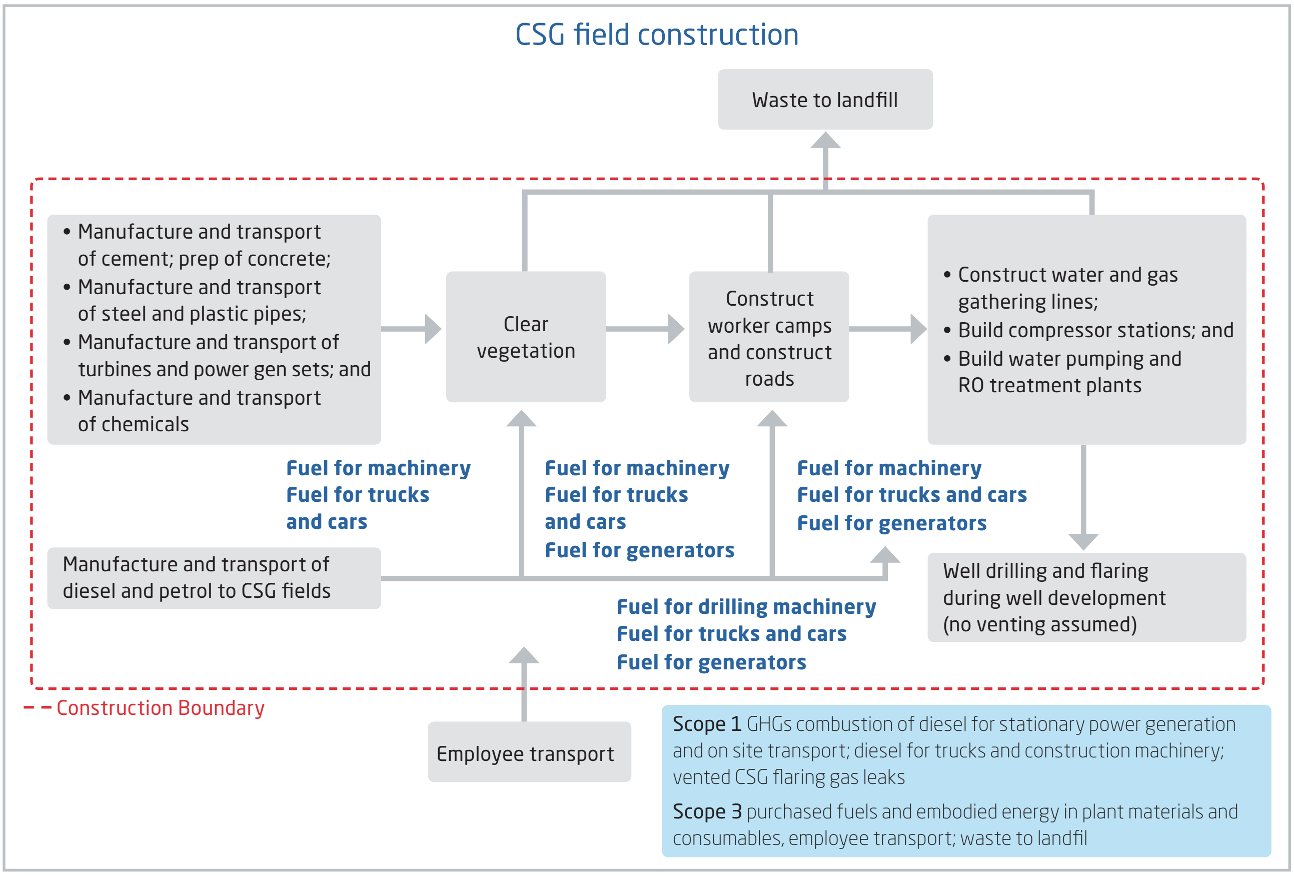
In making comparisons with the CSG/LNG industry in North America, it should be noted that although the latter industry is large and well established, geological, hydrological operating and other conditions are different and varied and so, even if data were available, it could not be readily compared to the Queensland situation.

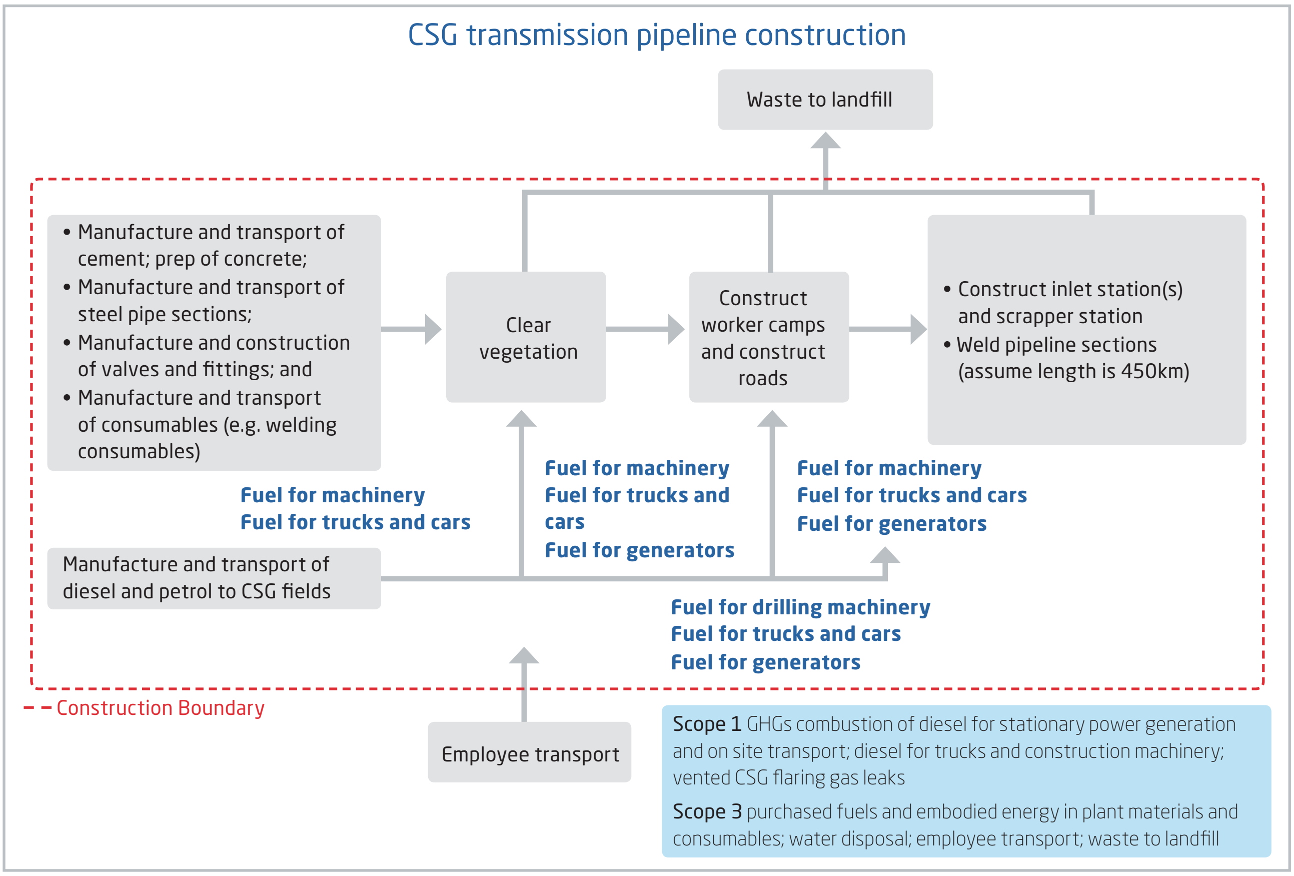
2. Description of csg life cycle processes and operations

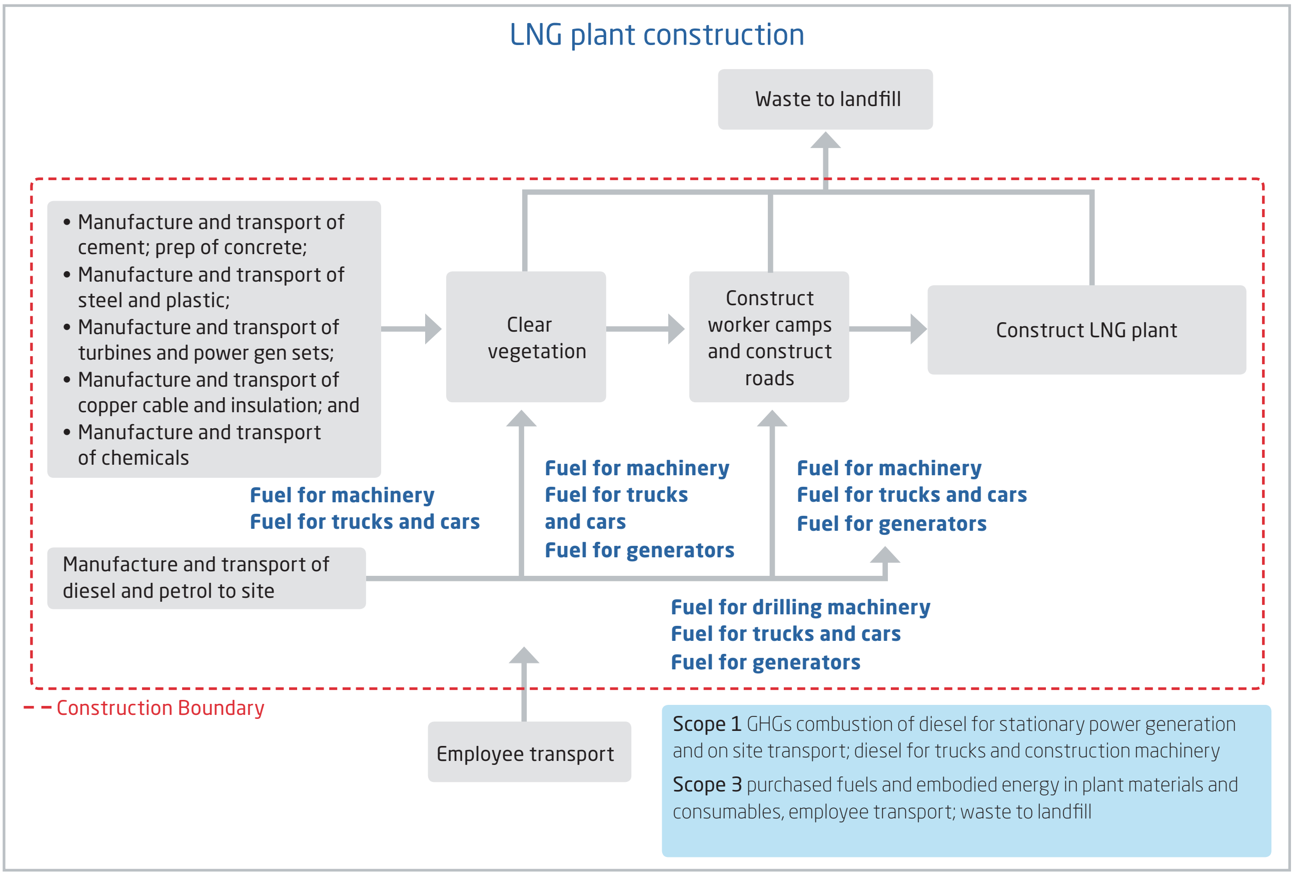
A typical project consists of a gas field and a transmission pipeline to an LNG facility. In the gas fields a large number of wells (e.g. for the Santos Gladstone LNG ('GLNG') project up to 10,000 are proposed over a 30-year project lifespan) will be constructed and gas and water gathering systems will be developed to send the gas and water extracted from the wells to gas processing facilities and water treatment facilities respectively. Well drilling for exploration and construction in low permeability, harder rock includes a process termed hydraulic fracturing ('fraccing') using water under high hydraulic pressure. Before transmission to the LNG plant the CSG is dehydrated and compressed.

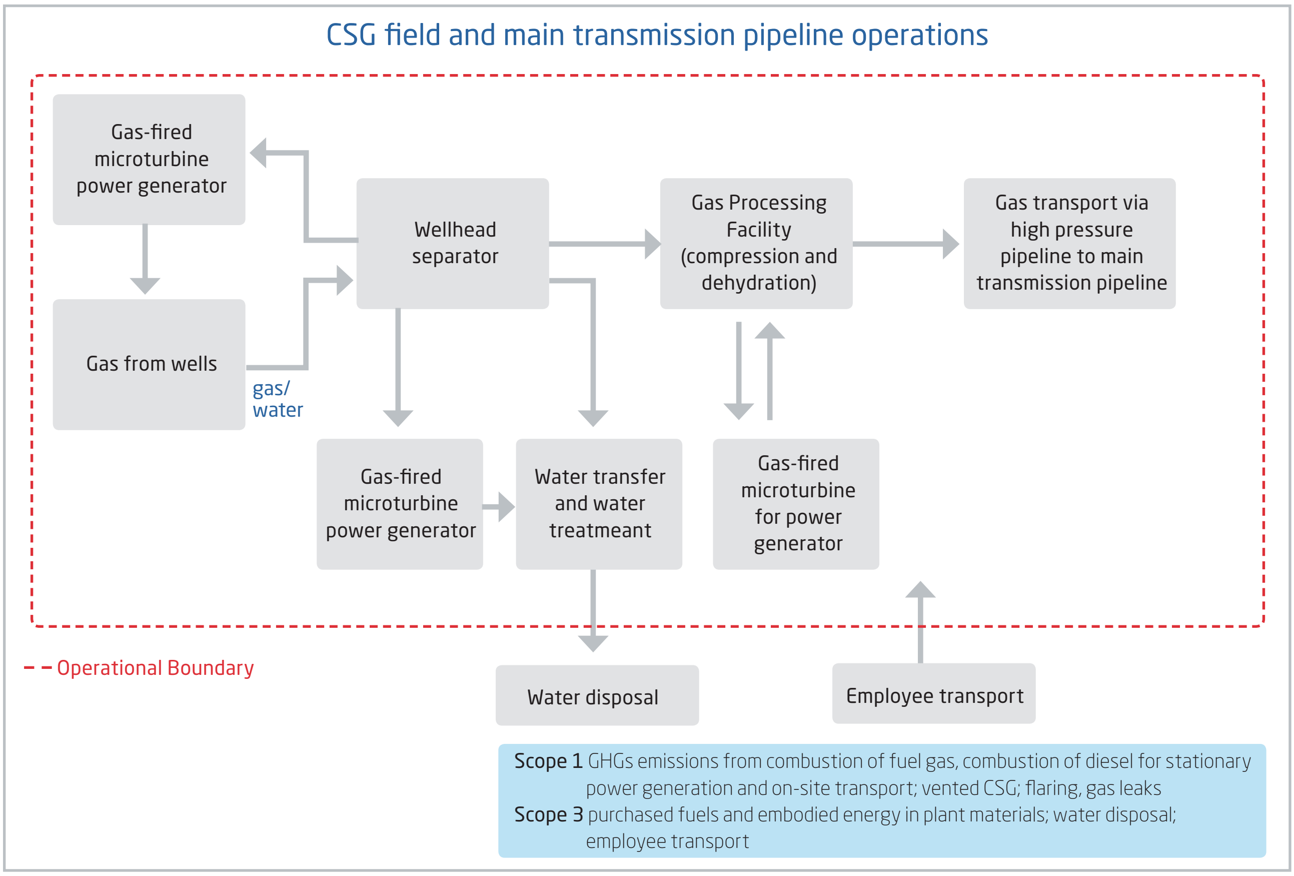
An underground high pressure gas pipeline of around 450 km will connect the gas fields with the LNG facility. The pipeline will be typically approximately 1.1 metres diameter and will be co-located with other high pressure gas transmission pipelines, where practicable. LNG facilities may consist of a single or multiple trains, each with capacity of approximately 4 million tonnes per annum (Mtpa) and an associated wharf and materials offloading facility (MOF). The LNG will be shipped in LNG-fuelled bulk carriers to a port where it is re-gasified and transferred by pipeline to the end user, in this case power plant.

The following flow diagrams show the life cycle activities and boundaries, recognising that emissions from construction will be small as a proportion of the total.


CSG field construction
Waste to landfill
• Manufacture and transport of cement; prep of concrete;
• Manufacture and transport of steel and plastic pipes;
• Manufacture and transport of turbines and power gen sets; and
• Manufacture and transport of chemicals
Clear vegetation
Construct worker camps and construct roads
• Construct water and gas gathering lines;
• Build compressor stations; and
• Build water pumping and RO treatment plants
Fuel for machinery
Fuel for trucks and cars
Fuel for machinery
Fuel for trucks and cars
Fuel for generators
Fuel for machinery
Fuel for trucks and cars
Fuel for generators
Manufacture and transport of diesel and petrol to CSG fields
Well drilling and flaring during well development (no venting assumed)
Fuel for drilling machinery
Fuel for trucks and cars
Fuel for generators
Construction Boundary
Employee transport
Scope 1 GHGs combustion of diesel for stationary power generation and on site transport; diesel for trucks and construction machinery; vented CSG flaring gas leaks
Scope 3 purchased fuels and embodied energy in plant materials and consumables, employee transport; waste to landfil


CSG transmission pipeline construction
Waste to landfill
• Manufacture and transport of cement; prep of concrete;
• Manufacture and transport of steel pipe sections;
• Manufacture and construction of valves and fittings; and
• Manufacture and transport of consumables (e.g. welding consumables)
Clear vegetation
Construct worker camps and construct roads
• Construct inlet station(s) and scrapper station
• Weld pipeline sections (assume length is 450km)
Fuel for machinery
Fuel for trucks and cars
Fuel for machinery
Fuel for trucks and cars
Fuel for generators
Fuel for machinery
Fuel for trucks and cars
Fuel for generators
Manufacture and transport of diesel and petrol to CSG fields
Fuel for drilling machinery
Fuel for trucks and cars
Fuel for generators
Construction Boundary
Employee transport
Scope 1 GHGs combustion of diesel for stationary power generation and on site transport; diesel for trucks and construction machinery; vented CSG flaring gas leaks
Scope 3 purchased fuels and embodied energy in plant materials and consumables; water disposal; employee transport; waste to landfill


LNG plant construction
Waste to landfill
• Manufacture and transport of cement; prep of concrete;
• Manufacture and transport of steel and plastic;
• Manufacture and transport of turbines and power gen sets;
• Manufacture and transport of copper cable and insulation; and
• Manufacture and transport of chemicals
Clear vegetation
Construct worker camps and construct roads
Construct LNG plant
Fuel for machinery
Fuel for trucks and cars
Fuel for machinery
Fuel for trucks and cars
Fuel for generators
Fuel for machinery
Fuel for trucks and cars
Fuel for generators
Manufacture and transport of diesel and petrol to site
Fuel for drilling machinery
Fuel for trucks and cars
Fuel for generators
Construction Boundary
Employee transport
Scope 1 GHGs combustion of diesel for stationary power generation and on site transport; diesel for trucks and construction machinery
Scope 3 purchased fuels and embodied energy in plant materials and consumables, employee transport; waste to landfill


CSG field and main transmission pipeline operations
Gas-fired microturbine power generator
Wellhead separator
Gas Processing Facility (compression and dehydration)
Gas transport via high pressure pipeline to main transmission pipeline
Gas from wells
gas/ water
Gas-fired microturbine power generator
Water transfer and water treatmeant
Gas-fired microturbine for power generator
Operational Boundary
Water disposal
Employee transport
Scope 1 GHGs emissions from combustion of fuel gas, combustion of diesel for stationary power generation and on-site transport; vented CSG; flaring, gas leaks
Scope 3 purchased fuels and embodied energy in plant materials; water disposal; employee transport

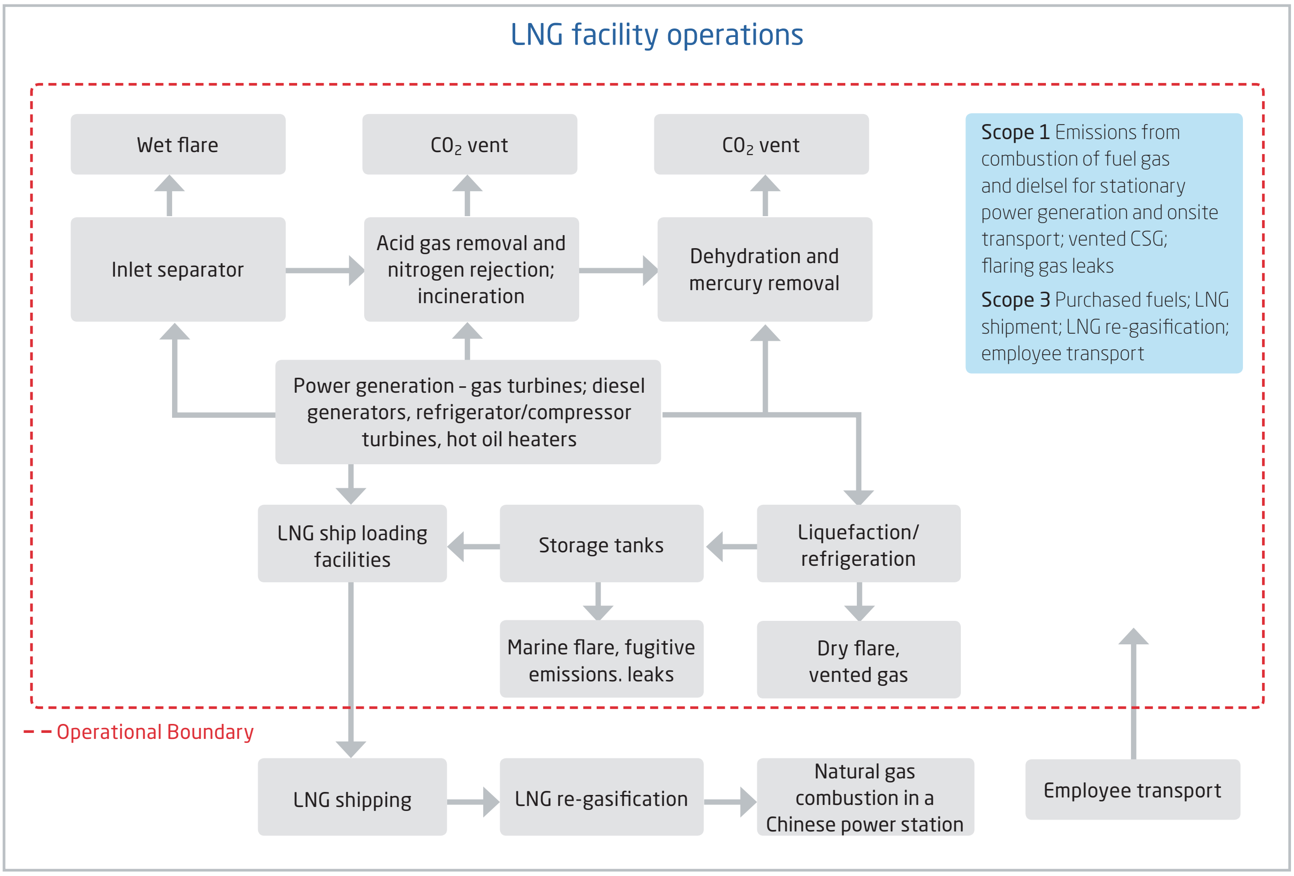

LNG facility operations
Wet flare
CO_2 vent
CO_2 vent
Scope 1 Emissions from combustion of fuel gas and dielsel for stationary power generation and onsite transport; vented CSG; flaring gas leaks
Scope 3 Purchased fuels; LNG shipment; LNG re-gasification; employee transport
Inlet separator
Acid gas removal and nitrogen rejection; incineration
Dehydration and mercury removal
Power generation - gas turbines; diesel generators, refrigerator/compressor turbines, hot oil heaters
LNG ship loading facilities
Storage tanks
Liquefaction/ refrigeration
Marine flare, fugitive emissions. leaks
Dry flare, vented gas
Operational Boundary
LNG shipping
LNG re-gasification
Natural gas combustion in a Chinese power station
Employee transport

Table A4.1: Summary of CSG life cycle

STAGE	PROCESS/OPERATION
UPSTREAM	
Exploration	Various testing methods are used including seismic surveys and drilling of trial and pilot wells to test reservoir characteristics and suitability. Initial flows from wells are typically mainly water and the gas flows are monitored and, if sufficiently productive, independently certified. In Queensland, pilots must be flared and it is illegal to vent gas unless necessary for safety or other reasons.
Construction, commissioning and decommissioning	Upstream construction includes clearing and earthworks and construction of wells and well heads. Wells are constructed by drilling, with hydraulic fracturing as required, and lining to contain the gas. Dehydration plant, compression plant and pipelines are constructed, together with access roads, temporary camps and other infrastructure. As noted above, pipeline routes may be shared between projects. Power is supplied by diesel generators (preferred option for Qld CSG projects) or by connection to the grid. During commissioning, systems are hooked up and tested for functionality and integrity. A typical construction period will be 2-4 years. Decommissioning includes closure and sealing of individual wells, and when a gas field is exhausted, parts of or the entire system.
Operation	CSG is drawn to the surface under natural pressure, dehydrated and compressed for pipeline transmission to the processing plant. Pumping and compression may be powered from direct drive, CSG power generation or grid power. Maintenance includes routine inspection of systems and equipment, and repair or replacement of equipment. Considerable quantities of water will be released with the CSG and this will be subjected to treatment according to quality and the approvals conditions, using dams, chemical treatment and reverse osmosis. Clean and treated water may be suitable for irrigation and other purposes such as dust suppression.
LNG FACILITY	
Construction, commissioning and decommissioning	Construction activities cover land clearing, excavation, equipment hauling, and civil works. Other activities include temporary camps, worker transport (local or from Brisbane), shipment of materials and equipment to the project site. The plant constructed includes treatment and liquefaction plant, associated equipment such as pumps, compressors, oil heaters and effluent treatment plant, and power plant (for projects based on Curtis Island, Qld, this is the preferred option to grid connection) – gas turbine and standby diesel. In practice much of the processing plant will be prefabricated in yards in Asia and shipped to the site as modular units. Various types of construction equipment will be used from the inception of site works until start-up and commissioning of the LNG facility. Construction periods will vary according to the number of trains and be in the range 2-5 years. There is a concentration of proposed plants in Gladstone and Curtis island for direct access to sea transport. Transport the site includes barges and shore facilities, shared or specific to a project. Commissioning includes hook-up to gas supplies and plant testing. Decommissioning involves plant run down and closure at end of life (typical design life 30 years).

<table>
<tr><th>STAGE</th><th>PROCESS/OPERATION</th></tr>
<tr><td>Operation</td><td>The LNG facility will utilise proprietary technologies to process the coal seam gas e.g. Optimized Cascade® technology. The various technologies have some differences in efficiencies and GHG emissions but are similar in their functions of acid gas and nitrogen removal, and gas liquefaction.
Process trains may be single or multiple depending on required capacity.
Other processes include oil heating for various operations. Plants may generate power on site or use grid electricity, but, because of the island location and other factors, on-site generation is the generally preferred option. Power is generated for all site processes, but especially liquefaction, which is energy intensive.
CO_2 removal is normally carried out by amine adsorption. Nitrogen removal entails venting which carries over some methane.
As noted above, there are various proprietary plant design types performing the same functions but with some differences in characteristics.</td></tr>
<tr><td>DOWNSTREAM</td><td></td></tr>
<tr><td>Transport</td><td>LNG from the process plant is transferred to bulk transport ships usually powered by LNG. Some gas may be released in the transfer process (boil off gas) but this can be captured for use by the transport vessel. The destination for most of the gas will be China, Japan, South Korea or other Asian countries.</td></tr>
<tr><td>Regasification</td><td>LNG is transferred to a re-gasification facility for piping to end users.</td></tr>
<tr><td>Combustion</td><td>The gas may be used directly for power generation (the main use), converted to DomGas as a domestic or industrial fuel, or used in chemical processes such as fertiliser production.
Gas is burnt for power generation in two types of gas turbine plant: Open-Cycle (OCGT) and Combined Cycle (CCGT). CGT plants are generally not used for large scale baseload generation but generally for small scale or peak shaving power plants. The range of efficiencies of the two types are shown here (source WorleyParsons 2008)
<table>
<tr><th>TECHNOLOGY</th><th colspan="3">EFFICIENCY %</th></tr>
<tr><th></th><th>HIGH</th><th>MID</th><th>LOW</th></tr>
<tr><td>OCGT</td><td>36</td><td>39</td><td>46</td></tr>
<tr><td>CCGT</td><td>46</td><td>53</td><td>60</td></tr>
</table></td></tr>
</table>

3. ASSUMPTIONS FOR CSG GHG INVENTORY

The following assumptions are made in assembling the greenhouse inventory.

Table A4.2 Assumptions

Product stream

a) For the LCA comparison, it s assumed that all gas is exported, although in future a relatively small proportion may be supplied for domestic use in Australia. This assumption facilitates a like for like comparison with black coal.

b) For the comparison it is also assumed that all the gas goes to combustion in power plants although in practice some goes to domestic and industrial use. Again this facilitates a like for like comparison with black coal.

Location of power plant

c) For simplicity, China is assumed to be the destination for comparison although in practice both CSG and black coal have multiple destinations. For simplicity and comparability, it is assumed that power stations are at or near the receiving port. In the case of coal this is generally the case, for economic reasons, to minimize rail haulage and because of the location of the main industrial regions. Inland power stations are mainly supplied by the domestic coal industry. There is some piping of gas to individual power stations but, for comparability, power stations are assumed to be at or near the port and pumping energy use not material.

Technologies applied

d) Emissions from existing technologies are assumed to apply for the comparison, including best practice for GHG mitigation.

e) A normal range of combustion technologies for gas combustion and power generation. These technologies are internationally similar for power generation although the mix of types and relative efficiency (and greenhouse emissions) will vary from country to country.

Life of projects

f) LNG plant and GSG field compressor stations are assumed to have a life of 30 years.

g) Emissions from exploration, construction and embedded energy in materials are amortised over the life of the operations.

Venting from transmission pipelines

h) No venting is assumed from gas transmission pipelines in Australia during operation. Pipelines are underground and entirely welded pipe without release points, such as pumps or compressor stations along the gas pipeline corridor. Pipeline length assumed to be approximately 435 km.

Use of grid power

i) Grid power use during construction is assumed to be negligible.

Land clearance

j) Emissions from land clearance are included but carbon sequestration due to rehabilitation of cleared areas is not included.

Scope 3 emissions

k) Scope 3 emissions for Australian operations, though relatively small compared to Scope 1 and 2, are included for completeness as being within the operational boundaries for the Australian industries.

l) Scope 3 emissions include embodied energy related emissions in construction materials, extraction, processing and transport of imported fuels such as diesel, employee transport and transport of consumables and construction materials by third parties.

m) Scope 3 emissions relating to capital equipment and supply chain material for shipping transport and combustion in China are not included as material.

4. GHG INVENTORY BY SCOPE

Sources of GHG emissions by Scope are shown in Table A3.2. Scope I accounts for most emissions and, from experience, all of the significant emissions.

Table A.3: Summary of CSG GHG sources

	POSSIBLE EMISSIONS SOURCES		
STAGE	**SCOPE 1**	**SCOPE 2**	**SCOPE 3**
UPSTREAM			
Exploration	Fuel use – direct use of vehicles and drilling rigs. Flaring, venting, potential leaks. Land clearing.		Embedded energy in fuel and materials. Auxiliary transport.
Construction Well heads, processing, compression plants, other infrastructure, temporary camps	Fuel use in generators, vehicles and plant, and Flaring, venting, leaks from temporary works. Land clearing.		Embedded emissions relating to pipeline, concrete, fuel and other materials in infrastructure and capital equipment.
Operation	Direct drive pumps, compressors, Generators. Flaring from pressure relief. Venting from maintenance; potential leaks.		Transport of workers Embedded energy in consumables (including drilling materials), fuel.
LNG PROCESS PLANT			
Construction	Fuel use in power generator sets, vehicles and plant for main construction and camp. Construction barges to island located plant. Flaring, venting from commissioning.		Embedded emissions relate to pipeline, concrete and other materials in infrastructure and capital equipment.
Operation	Use of gas in Power generation, Liquefaction. Acid gas removal. Nitrogen venting. Flaring.	Use of grid power is an option in Queensland, but is not considered in this study.	Transport
DOWNSTREAM			
Transport			LNG or marine fuel to power the bulk carrier. Any release of boil-off gas.
Regasification			Energy use in regasification.
Combustion			Use in power generation.

5. CSG LCA DATA SOURCES AND BASES FOR ESTIMATION

The main data sources for the upstream and LNG plant Scope 1, 2 and 3 emissions is the publicly available Environmental Impact Statements (EIS) for the GLNG and APLNG projects, with supporting data supplied by Santos. These are the most detailed EISs produced to date with respect to forecast GHG emissions, and are representative of large projects geared to exporting LNG. A range of industry and other sources was used in estimating emissions from transport, regasification and combustion, and GHG emissions not within the scope of the EISs examined. The detailed inventory in Attachment 6 shows the sources and assumptions.

Table A4.4 Data sources and bases for estimates

Note: See Attachment 3, Section 7 for an explanation on how emissions factors are used.

ACTIVITY	BASIS FOR ESTIMATE	SOURCES
UPSTREAM		
Diesel use for vehicles, generators and drilling rigs	Estimated in EISs.	Operational forecasts and NGA factors.
Use of gas for generators or direct drive	Estimated in EISs.	Operational forecasts and NGA factors.
Use of grid power	Estimated in EISs.	Operational forecasts and NGA factors.
Water treatment	Estimated in APLNG EIS Further estimates for treatment of produced water. Worst case 100% RO, mean 50%.	Estimates of produced water and energy use of RO plant.
Flaring, venting, potential leaks	Compressor stations typically include flares which are used in the event of emergency shutdown or maintenance. Systems may also include cold vents which vent the gas stream directly to the atmosphere in emergencies. Provision is made for made for such fugitive emissions based on experience and NGA Factors, noting that vented greenhouse emissions are methane and flared greenhouse emissions mostly carbon dioxide. Estimated in EISs where an average flaring rate is assumed. A conservative estimate is made for a worst case.	A estimate of 0.1% gas lost is industry accepted practice. Santos estimated 1 MMscf of gas flared per well during construction. Uncertainty factor of 50%.
Land clearing	Estimated in EISs.	National Carbon Accounting Toolbox (DCCEE, 2005).
Embedded energy in fuel and materials	Estimated in APLNG EIS.	Hammond and Jones (2008).
Auxiliary transport	Estimated in EISs.	Operational forecasts and NGA factors.
LNG PROCESS PLANT		
Construction	Estimated in EISs from use of diesel etc. Emissions from subsequent trains are assumed to be 50% of train 1 based on established infrastructure and less site and other work. Bases for and clearing, embedded materials and worker transport as for Upstream.	Operational forecasts and NGA factors.

ACTIVITY	BASIS FOR ESTIMATE	SOURCES
Plant operation	Estimated in EISs.	Estimates supplied by Bechtel for GLNG, APLNG. Also estimates for Foster Wheeler plant. Based on design, number and type of gas turbines for liquefaction and power generation, acid gas and nitrogen removal, flaring rates, fugitives from leaks and other emissions estimates times emissions factors.
SHIPPING		
LNG to power the bulk carrier	Estimated in APLNG EIS.	From R Heede Report (2006).
USE IN CHINA		
Energy use in regasification	Estimated in APLNG EIS.	Industry experience 3% of product.
Use in power generation	Estimated in APLNG EIS.	Combustion calculations and NGA factors.

6. CSG BASE CASES AND SCENARIOS

A base case scenario and a range of cases is presented in Table A4.5.

The following should be noted:

- The base case is a typical case for comparison and not a statistical average (the total number and sample of CSG projects is small) or a particular project; also that the minima and maxima illustrate the broad range based on EISs examined and other estimates rather than every possible situation. They are based on current technologies employed or proposed.
- The figures are mainly based on annual averages for specific projects, recognising that some emission types will vary from year to year depending on stage of process development, gas supply for production and other factors.

The variations relate to scenarios not to uncertainties and accuracies in estimates which are considered separately.

Table A4.5 Base case and scenarios for emissions per tonne of product

FACTOR	BASE CASE	MINIMUM	MAXIMUM
CONSTRUCTION			
Construction - fuel use	Typical estimate from EIS.	Lower than average estimate – less infrastructure per tonne of production. Construction emissions for LNG plant spread over more trains, less excavation; shared infrastructure.	Higher than average estimate – more infrastructure per tonne of production. Single train; more excavation; dedicated infrastructure.
Exploration and construction - diesel fuel consumption	Typical number of wells and strike rate. Typical venting, flaring.	Higher than average strike rate in exploration. Low venting, flaring.	Lower than average strike rate in exploration. Higher venting, flaring.
Construction - clearing emissions	Typical number of wells. Typical emission factor values for agricultural land.	Fewer, more productive wells and less clearing. Shared routes for pipelines. Low factor vegetation, net offset from rehabilitation.	More, less productive wells and more clearing. Dedicated routes and easements for pipelines. High factor vegetation, no net of sets from rehabilitation.
Construction - embedded emissions in materials, fuels	Typical estimate from EIS.	Lower than average estimate.	Higher than average estimate.
Operations - power	Typical estimate from EIS.	All gas, high efficiency.	Significant grid power
Operations - venting leaks and flaring	Typical estimate from EIS.	Lower than average.	Higher than average
OPERATIONS			
Gas fields	Estimate from APLNG EIS for venting, flaring, RO water treatment.	Low estimate for flaring, venting. Low estimate for RO energy use.	Conservative estimate for flaring, venting. Conservative estimate for RO.
Pipeline	Typical estimate from EIS.	Lower than average estimate.	Higher than average estimate.
LNG plant	Typical estimate from EIS.	Lower than average estimate.	Higher than average estimate.
SHIPPING			
Shipping	Single estimate. No significant basis for a range.		
END USE			
Regasification	Single estimate. No significant basis for a range.		
Combustion	Average efficiency for a particular type of power plant. Typical material composition for LNG from CSG. Single estimate. No significant basis for a range of gas compositions since non-methane elements are small.	Below average efficiency for a particular type of power plant.	Above average efficiency for a particular type of power plant.

7. CSG LIFE CYCLE EMISSIONS AND IMPACTS

Life cycle emissions and impacts are detailed in the tables in Attachment 6.

8. UNCERTAINTY ANALYSIS

Uncertainties in the CSG analysis is shown in Table A4.6 (see Attachment 3, Section 6 for explanation).

Table A4.6 Uncertainty analysis: CSG

Method follows National Greenhouse and Energy Reporting (Measurement) Determination 2008.

SCOPE	SOURCE OF EMISSIONS	CONTRIBUTION TO EMISSIONS (%)	ACTIVITY UNCERTAINTY (±%)	EMISSION FACTOR UNCERTAINTY (±%)	CONTRIBUTION TO OVERALL UNCERTAINTY (±%)
1	CSG fields – construction	0.6	30	2	0.18
1	CSG pipeline construction	0.1	30	2	0.04
1	LNG plant construction	0.4	30	2	0.12
1	CSG fields – operations	12.9	10	4	1.39
1	CSG pipeline – operations	0.0	10	30	0.004
1	LNG plant operations	8.3	10	4	0.89
3	LNG shipment	2.2	10	5	0.25
3	LNG re-gasification	1.8	10	5	0.20
3	Combustion of LNG	73.6	10	5	8.23

ATTACHMENT 5
LIFE CYCLE GHG INVENTORY – BLACK COAL

1. BLACK COAL INDUSTRY OVERVIEW

Mainly centred in Queensland and New South Wales, the Australian black coal industry is large, well established and the world's largest exporter of black coal. It is also diverse with respect to mine numbers, types (surface, open cut and high wall), sizes, ownership (major and independents), location (coalfield), operational conditions and product types (*Nicholls, 2001*). The black coal industry is distinct from the brown coal industry, located in Victoria and producing coal for domestic power generation.

In addition to the existing industry, a large number of new and mine expansion projects are proposed in both NSW and Queensland in response to rising prices and world demand for coal, especially from China.

Table A5.1 summarises some statistics for the NSW and Queensland black coal industry.

Table A5.1 NSW and Queensland black coal industry

		NSW	QLD	TOTAL
Existing mines (approx)	Open cut (OC)	31	41	72
	Underground (UG)	29	13	42
	Total	60	54	114
	Saleable product Mtpa (2008-9)	131	190	449 Mtpa
New projects (2010)	New	11	25	36
	Expansion	16	16	32
	Total	27	41	68
	Saleable product Mtpa projected	Up to 100	Up to 300	Up to 400 Mtpa

Sources: Queensland Government, NSW Government

Australia produces a variety of black coal types a, including thermal (for steam and power generation) and metallurgical (for minerals processing and including hard and soft coking coals and other grades). Around 75% of production is exported. The export percentage mix of thermal and metallurgical coal is roughly 50:50. Over 75% of exports go to Asian countries, especially Japan and China.

In NSW there are six main coalfields in the Sydney-Gunnedah Basin, mostly fairly near to the shipping ports coalfields of Newcastle and Port Kembla via an extensive rail system. The Queensland industry is mainly located in the Bowen Basin in Central Queensland, approximately 450 km from the main shipping ports of Gladstone, Hay Point, Dalrymple Bay, Abbott Point and Brisbane. In NSW new projects are in existing coalfields. In Queensland the main potential area for expansion of the industry is likely to be the Surat-Dawson and Northern Bowen coal fields.

2. DESCRIPTION OF COAL LIFE CYCLE PROCESSES AND OPERATIONS

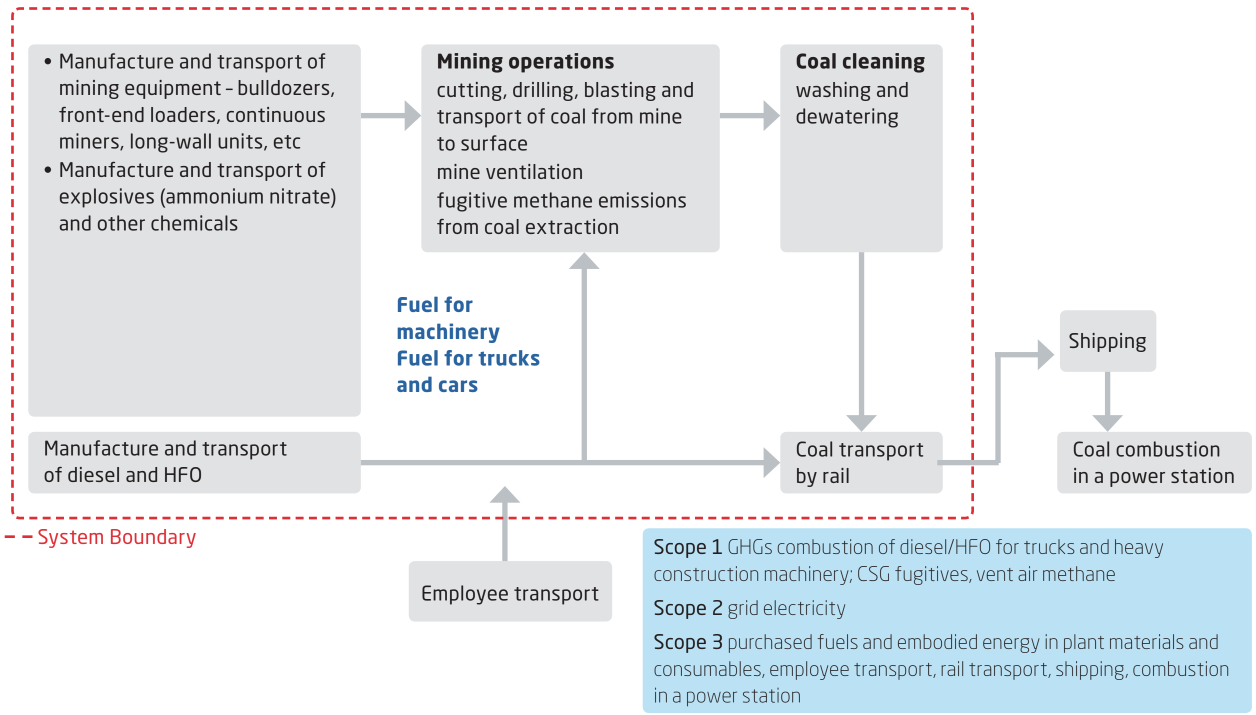
Open cut mining operations include removal of overburden and excavation by shovel, bucketwheel or dragline. Deep mining operations include two main types. In bord and pillar operations, coal is extracted from seams by cutting and roofs are supported. In longwall operations the seam is cut mechanically and the roof collapses behind the advancing cutting machinery.

Preparation plant for all mines includes crushing, screening, sizing, washing, blending and loading onto trucks and conveyors and then rail to port for shipment in bulk carriers.

The most common modern type of power plant is pulverised coal power plant where the coal is pulverised in the receiving power station. Various combustion technologies are commonly employed, including sub-, super and ultra super critical of various efficiencies in electricity sent out.

The following flow diagrams show the life cycle activities and boundaries, while table A5.2 describes them.

Underground coal mine



Open-cut coal mine

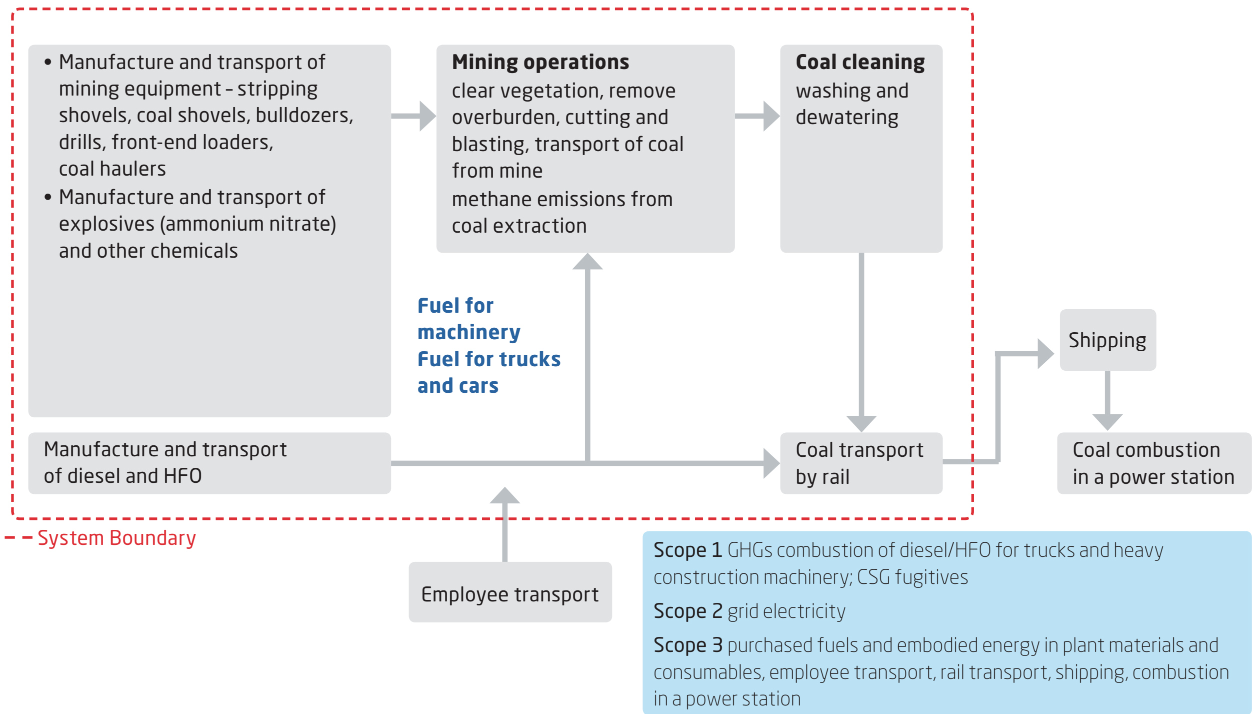


Table A5.2: Summary of black coal life cycle

STAGE	PROCESS/OPERATION
OPEN CUT	
Exploration	Drilling using drill rig.
Construction and decommissioning	Blasting, excavation and removal of overburden. Construction of infrastructure, including access roads. Installation of processing facilities. Decommissioning includes removal of equipment and infrastructure.
Operation	Excavation of coal using truck and shovel, bucketwheel or dragline plus conveyor. Operation of coal preparation plant: Crushing, washing, blending. Loading onto transport. Ancillary services.
DEEP	
Construction, commissioning and decommissioning	Excavation of shafts and galleries. Construction of infrastructure, including access roads. Installation of mining equipment and coal processing plant.
Operation	Excavation of coal using bord and pillar or longwall plus conveyor. Operation of coal preparation plant: Crushing, washing, blending. Loading onto transport. Ancillary services.
DOWNSTREAM	
Transport	Coal transportation to port in Australia is handled by a network of rail, road and conveyor systems, with most being transported by State owned or private rail systems. Road transport is used for some mines, especially in NSW, but is not significant compared to rail. At the ports the coal is transhipped to bulk sea transporters.
Pulverisation	At the receiving power station the coal is pulverised to the required size for the plant.
Combustion from power generation	Various types of combustion technologies are commonly employed in existing projects, with various levels of efficiency in power generation (source WorleyParsons 2008) and IEA, 2006. Sub critical 33% ±4. Super critical 41%±4. Ultra supercritical 43%±2. The average efficiency of power plant in China is currently around 35% (source IEA, 2006) and dominant technology subcritical, but supercritical is now the minimum standard for approval of new stations. It has been widely claimed that technology improvements could achieve up to 55% but this is not demonstrated.

3. COAL LIFE CYCLE INVENTORY BY SCOPE

Table A5.3: Sources of GHG emissions

	EMISSIONS SOURCES		
STAGE	**SCOPE 1**	**SCOPE 2**	**SCOPE 3**
OPEN CUT			
Exploration	Fuel use – direct use of vehicles and drilling rigs. Land clearing. Fugitives emissions.		Embedded energy in fuel and materials. Auxiliary transport.
Construction	Fuel use in generators, vehicles and plant in excavation and removal of overburden construction of infrastructure and processing plant. Use of explosives. Land clearing. Fugitives emissions.	Direct power from any grid connection.	Embedded emissions relating, concrete, fuel and other materials in infrastructure and capital equipment.
Operation	Use of fuel in plant and vehicles, Generators (diesel or gas). Fugitives emissions. Spontaneous combustion of coal and carbonaceous wastes.	Grid power for draglines, conveyors, pumps, compressors etc.	Transport of workers. Embedded emissions relating to fuel and other consumables use.
DEEP MINE			
Exploration	Fuel use – direct use of vehicles and drilling rigs. Land clearing.		Embedded energy in fuel and materials. Auxiliary transport.
Construction	Fuel use in generators, vehicles and plant in excavation and removal of spoil, construction of infrastructure and processing plant. Use of explosives. Land clearing. Fugitives emissions.	Direct power from any grid connection.	Embedded emissions relating, concrete, fuel and other materials in infrastructure and capital equipment.
Operation	Use of fuel in plant and vehicles. Generators. Fugitives emissions. Spontaneous combustion of coal and carbonaceous wastes.	Grid power.	Transport of workers. Embedded emissions relating to fuel and other consumables use.
DOWNSTREAM			
Transport			Rail to port. Port handling.
Pulverisation			Included in power plant.
Combustion			Use in power generation.

4. ASSUMPTIONS FOR COAL GHG INVENTORY

The following assumptions are made in assembling the greenhouse inventory.

Table A5.4 Assumptions

Product stream and boundaries

a) As noted above the study only considered black coal exported to Asia to facilitate a like for like comparison with CSG.
b) Also as noted, the study only assesses only that component that goes to combustion in power plants in China. It is recognised that large quantities of coal go to metallurgical use and to multiple destinations. Again this facilitates a like for like comparison with black coal.
c) For simplicity, China is assumed to be the destination for comparison although in practice both CSG and black coal have multiple destinations. The range of combustion technologies is internationally similar for power generation although the mix of types and relative efficiency (and greenhouse emissions) will vary from country to country.

Location of power plant

d) For simplicity and comparability, it is assumed that power stations are at or near the receiving port. In the case of coal this is generally the case, for economic reasons, to minimise rail haulage and because of the location of the main industrial regions. Inland power stations are mainly supplied by the domestic coal industry.

Technologies applied

e) Emissions from existing technologies are assumed to apply for the comparison.
f) A normal range of modern combustion technologies for coal combustion and power generation. These technologies are internationally similar for power generation although the mix of types and relative efficiency (and greenhouse emissions) will vary from country to country

Project life

g) Mine lives for expansion and new projects are considered on an individual bases when amortising construction or other short term emissions over the project life..
h) Emissions from exploration, construction and embedded energy in materials are amortised over the life of the operations.

Use of grid power

i) Grid power use during construction is assumed to be negligible. A mix of on-site generation (mainly gas but some diesel) and grid power may be used for operations.

Fugitives, spontaneous combustion and slow oxidation

j) It is assumed that 100% of the gas content of fugitives released is methane. This is conservative for coal mind at less than 45m where nitrogen and CO_2 are likely to be present. Thereafter proportions rapidly increase to pure methane at 60m bgl (Wandoan EIS)
k) Spontaneous combustion may occur in stockpiles and release greenhouse emissions and estimates are made based those EIS which have estimated them:
   - there is no accepted methodology at international or Australian level for estimating them.
   - there is wide variability in the occurrence of spontaneous combustion and it can generally be avoided by good management practice.
l) Slow oxidation is the release of carbon dioxide from exposed coal surfaces without combustion. It is rarely included in EIS statements but considered here for completeness.

Land clearance

m) Emissions from land clearance and rehabilitation offsets were considered but deemed immaterial.

Venting from decommissioned underground mines

n) Gassy underground mines continue to vent methane for many years after closure and the NGA Technical Guidelines include methods for estimation depending on mine gassiness and the number of years the mine has been closed. Since the typical case for this study is an open cut mine, continued venting does not apply and is not included in the assessment. The factor is nevertheless noted in considering the sensitivity of the overall results to fugitives from the industry.

Gas flaring

o) Gas flaring occurs in a few underground mines where methane is captured but is not typical. Emissions were found to be not significant and, though accounted for, are not noted in the main report.

Combustion for power generation

p) For pulverised fuel combustion, the shipped coal is pulverised to the required specification. Power use in crushing mills is part of the internal power use of a power station and is reflected in overall efficiency figures. Pulverisation takes up to 2% of output and feed pumps and other systems another 2% (WorleyParsons estimate based on experience)

Consideration of Scope 3 emissions

q) Scope 3 emissions for Australian operations, though relatively small compared to Scope 1 and 2, are included as being within the operational boundaries for the Australian industries.

r) Scope 3 emissions relating to capital equipment and supply chain materials for shipping transport and combustion in China are not included as immaterial.

5. COAL LIFE CYCLE DATA SOURCES AND BASES FOR ESTIMATES

The main data source for the upstream and LNG plant Scope 1, 2 and 3 emissions is the publicly available Environmental Impact Statement (EIS) for various black coal projects.

Fifteen mines, one rail and one port EIS were examined in detail to generate the core relevant data for Australian extraction, processing and transport operations and emissions. They were selected on the basis of

- As far as was possible, providing a range of examples of mine types, by underground or surface (and gassiness) and location (with varying distances to port) and an operating as well as expansion and new mine projects
- Availability: Data based on measurement is not readily available for operational mines (the Dendrobium example is an exception); the EIS data are forecasts for new mines and expansions, although there are many projects awaiting approval; the EIS is not always prepared or available beyond the consultation period. The sample of rail and port EISs is limited.
- Quality: While verifying accuracy of the EIS forecasts selected was outside the scope of this study, they appeared to have been thoroughly and professionally prepared and transparent in their calculations and assumptions. Around six other EIS estimates were examined but rejected on the grounds of unstated or inconsistent bases for estimates.

Around 20 mine EISs were examined for comparative data. The mines selected for more detailed analysis were as follows (Table A5.5):

Table A5.5: Mines included in the analysis

MINE	MINE TYPE OPEN CUT OR UNDERGROUND	PROJECT TYPE NEW, EXPANSION EIS FORECAST OR OPERATIONAL DATA	MAIN PRODUCT	ESTIMATED RAIL DISTANCE TO PORT (KM)
QUEENSLAND				
Alpha	OC	New	Thermal	450
Caval Ridge	OC	Expansion	Coking	300
Clermont	OC	Expansion	Thermal	400
Daunia	OC	New	Coking	300
Ellensfield	UG	New	Thermal/coking	400
Ensham OC	OC	Expansion	Thermal	400
Ensham UG	UG	Expansion	Thermal	400
New Acland	OC	Expansion	Thermal	150
Wandoan	OC	New	Thermal	350
NSW				
Abel Hill	UG	New	Thermal, coking	25

MINE	MINE TYPE OPEN CUT OR UNDERGROUND	PROJECT TYPE NEW, EXPANSION EIS FORECAST OR OPERATIONAL DATA	MAIN PRODUCT	ESTIMATED RAIL DISTANCE TO PORT (KM)
Austar	UG	Expansion	Coking	50
Cumnock	OC	Operating	Thermal, coking	100
Dendrobium	UG	Operating	Coking	15
Wallarah	UG	New	Thermal	60
Ulan	OC	Expansion	Thermal	250

Table A5.6 Data sources and bases for estimates

See Attachment 3 Section 7 for emissions factors used.

ACTIVITY	BASIS FOR ESTIMATE	SOURCES
Diesel use for haul trucks vehicles, plant and machinery rigs	Estimated in EISs.	Operational forecasts and NGA factors.
Production and consumption of power	Estimated in EISs. Significant quantities of power are used for operating preparation and other plant, lighting, draglines and other equipment. Some mines use 100% grid power (accounted for as Scope 2), some generate all of their own power from gas or diesel generators and some use a mix.	Operational forecasts and NGA factors. Power –related emissions are included in all EIS statements using power estimates and NGA factors. These EIS illustrate the diversity of situations and proposals depending on availability and economics e.g. where methane is captured for safety reasons, some deep mines have installed or propose gas power plant. A base case has been derived from these recognising that emissions are higher where grid power is used.
Use of grid power	Estimated in EISs.	Operational forecasts and NGA factors.
Fugitives	Estimated in EISs. Fugitive emissions of methane from coal mines occur when coal and rock layers are broken and disturbed as part of the mining process. There is a high level of variation in methane fugitives across the industry depending on the characteristics of individual mines.	Default NGA factors quote single figures for all Queensland and all NSW deep mines. Emissions vary with location, depth and other factors and even from year to year. The methane is mostly vented but there are a few cases of the gas being captured for power generation (e.g. BHP Illawarra Coal's West Cliff Mine). Based on CSIRO research, NGA emissions factors per ROM tonne are specified for Queensland and NSW and these are used for the base case. Some EIS statements (e.g. Wandoan) estimate much lower figures based on exploration and measurement (Report by GeoGas).
Use of explosives	Commonly used to open overburden and break coal seams. Small quantities of greenhouse emissions arise from use of ANFO and emulsion explosives.	Operational forecasts and NGA factors.
Land clearing	Some but limited consideration in EISs.	National Carbon Accounting Toolbox (DCCEE, 2005).
Spontaneous combustion	Some but limited consideration in EISs.	
Slow oxidation	Consideration in one EIS.	

ACTIVITY	BASIS FOR ESTIMATE	SOURCES
Embedded energy in fuel and materials	No consideration in EISs. Nominal estimate in the absence of data.	Hammond and Jones (2008).
Auxiliary transport	Estimated in some EISs.	Operational forecasts and NGA factors.
TRANSPORT		
Use of fuel for rail	Estimated in some mine EISs and Alpha Rail.	QR (2002). Emissions from rail transport are estimated in some EISs as Scope 3 using Queensland Rail and other figures for diesel consumed per tonne-km. These are used to develop a base case of emissions per tonne of product for a typical haul distance which ranges from an average of around 30Km for the Newcastle Coalfield to 450km for the Surat Basin.
Construction and embedded emissions in rail	Alpha Coal rail project.	LCA model data.
Port handling	Hay Point EIS.	Port handling emissions are a small part of life cycle emissions but have been estimated. Power is consumed in handling plant and equipment, including conveyors. Limited EIS or other specific information is available but an estimate was derived from the EIS for Hay Point.
Marine diesel or HFO to power the bulk carrier	Estimated in some mine EISs.	Emissions from fuel oil use in bulk carriers is derived from 2006 IPCC guidance factors. Emissions depend on size of vessel and distance. The average carrying capacity of Panamax and capsize vessels is assumed in various EIS to be 75000 and 165000 tones of product coal respectively.
COMBUSTION		
Use in power generation	Estimated in some mine EISs. Note that the efficiency factor determines the electricity sent out in MWh per tonne of coal, The GHG emissions are determined from the calorific value, moisture content and ash content of the coal, and application of low NOx burners. NGA emission factors are available for typical thermal coals from Queensland and NSW and many of the coal EIS examined have estimated combustion emissions as Scope 3 for the specific project. Scope 3 emissions from power station construction and from pulverisation, and power station operation, and any residual emissions from ash are not included within the boundary.	From combustion calculations and/or NGA factors.

Notes on accounting for coal mine construction and Scope 3 emissions

1. Accounting for mine exploration and construction emissions presents an issue for like for like comparison.
   a) For comparison of CSG and new coal projects construction emissions should be considered since they have been included in the CSG assessment. However, it could be argued that a large proportion of existing and future coal is from existing mines or expansion of existing mines and that there is no significant additional construction element. Furthermore, apart from access roads, coal preparation plant, water treatment and other plant, some construction activities are similar to ongoing mining activities.
   b) Data was not readily available on construction emissions. None of the coal mine EIS examined, even though mostly new mines, accounted for construction emissions although Alpha Rail did so and estimated 100,000 CO_2-e pa or 4% of mine emissions and 0.4% of total life cycle emissions.
   c) Scope 3 emissions for worker transport during construction, for similar reasons, have not been included in most EIS, and embedded emissions in fuel and materials, and for waste have not been included in any except Alpha rail.
   d) Land clearing takes place mostly during construction and operations and gives rise to emissions depending on the vegetation and location as specified in the NGA Workbook Most EIS do not make an estimate on the grounds that it is not material and offset by sequestration during rehabilitation but some have done so.
   e) Even where major construction is undertaken, amortised emissions for shared infrastructure is typically spread across multiple mines (railways, in Queensland and NSW are rarely dedicated to single mines) and not material in relation to the overall life cycle emissions.
   f) For the above reasons, for a typical open cut expansion project the emissions are included in operational estimates.
2. Accounting for rail construction emissions, including embedded emissions in materials presents an issue for like for like comparison. For comparison of CSG and new coal projects it should be considered. However, it could be argued that a large proportion of existing and future coal is or will be carried on existing routes and that there is no additional construction element. Furthermore, most routes are shared rather than dedicated and that when emissions are allocated and amortised they will be immaterial. Therefore the base case below assumes no rail construction emissions. A higher emissions scenario considers the detailed Scope 3 analysis for Alpha Rail, a dedicated railway for Alpha Coal. With exploitation of the Surat Basin, the construction element will increase although remain relatively small as a proportion of the total.

   The focus has been on a typical scenario and range recognising the diversity of distances and situations from dedicated rail links to common carrier systems. Diesel haulage is assumed for simplicity in the base case recognising that some routes are electrified. Any allowance for the latter would tend to increase emissions as Scope 2 energy use tends to increase GHG emissions.

6. COAL BASE CASES AND SCENARIOS

A base case scenario and a range of cases for GHG emissions is presented in Table A5.7.

The following should be noted:

- The base case is a typical case for comparison and not a statistical average or a particular project; also that the minima and maxima illustrate the broad range based on EISs examined rather than every case, and current technologies employed or proposed.
- The figures are mainly based on annual averages for specific mines, recognising that some emission types vary from year to year depending on production and stage of mine development.
- The variations relate to scenarios not to uncertainties and accuracies in estimates which are considered below.

The various sources include some for completeness which are clearly not material and within the range of uncertainty of the more important sources. In accordance with the principles of conducting LCAs, the research effort for data has been commensurate with its importance. For 'immaterial' emissions where data has not been readily available, estimates are based on reasonable assumptions.

Table A5.7 Base case and scenarios for emissions per tonne of product

FACTOR	BASE CASE	MINIMUM	MAXIMUM
CONSTRUCTION	No additional emissions.	No additional emissions.	Estimate from fuel use for major new mine.
OPERATIONS			
Fugitives	New, open cut, NSW.	Expansion, shallow QLD.	Deep, NSW, not captured.
Diesel	New, open cut.	Expansion, open cut, shallow.	New deep.
Power	Mix of sources.	On site gas.	Full grid source.
Explosives	Typical use from EIS.	Shallow, softer overburden and coal.	Harder overburden and coal.
Spontaneous combustion	Some for waste but controlled. None from product in transport as if happened there would be no additional emissions.	None for waste – fully controlled.	Higher estimate for waste based on industry research.
TRANSPORT			
Rail to port	200 km haul.	30 km haul.	450km haul.
Port handling	Single estimate. No significant basis for a range.		
Shipping	Single estimate. No significant basis for a range.		
Pulverisation	No additional emissions – coal burnt for power and reflected in plant efficiencies.		
Combustion	Typical carbon content for thermal coal.	Higher carbon content.	Lower carbon content.

7. BLACK COAL LIFE CYCLE EMISSIONS AND IMPACTS

Life cycle emissions and impacts are detailed in the tables in Attachment 6.

8. UNCERTAINTY ANALYSIS

Some of the coal GHG forecasts in EISs have included estimates of uncertainty and a good example is that for Wandoan which estimates and overall uncertainty of ±17%. In this case activity uncertainties are 10-15%, fuel and power emissions factor uncertainties 10% except for fugitives, which is 40%. Since fugitive emissions are estimated to be low and their contribution to overall uncertainty is only 3% for this mine's Scope 1 and 2 emissions. Uncertainties in the coal life cycle analysis are shown in Table A5.6 (see Attachment 2, Section 6 for explanation). Uncertainties in the CSG analysis are shown in Table A5.8 (see Attachment 2, Section 6 for explanation).

Table A5.8 Uncertainty analysis: Coal

Method follows National Greenhouse and Energy Reporting (Measurement) Determination (2008).

SCOPE	SOURCE OF EMISSIONS	CONTRIBUTION TO EMISSIONS (%)	ACTIVITY UNCERTAINTY (±%)	EMISSION FACTOR UNCERTAINTY (±%)	CONTRIBUTION TO OVERALL UNCERTAINTY (±%)
1	Mine fugitives	4.0	15	40	1.70
1	Mine diesel use	1.2	15	2	0.18
1	Mine explosives	0.0	10	20	0.01
1	Slow oxidation	0.0	15	40	0.01
1	Spontaneous combustion	0.2	15	40	0.08
2	Mine electricity (grid)	1.7	10	10	0.24
1	Rail transport	0.2	15	2	0.03
3	Shipping	8.4	10	5	0.94
3	Port facilities	0.2	10	10	0.02
3	End-use electricity Consumption	0.3	10	10	0.04
3	End-use diesel Consumption	0.0	15	2	0.00
3	End use coal combustion	83.8	10	5	9.37

ATTACHMENT 6 - EMISSIONS TABLES - COAL SEAM GAS

1. CSG FIELDS - CONSTRUCTION - BASE CASE

Note: for the following tables exported means produced for export; sent out means sent out from a power station after generation efficiency losses. The annual tonnes/MWh in Tables 1 to 6 are for the OCGT case.

Activity - CSG fields - construction	Annual tonnes CO_2-E/GJ exported	Annual tonnes CO_2-E/MWH sent out (OCGT)	Comments
Camp construction – diesel for transport	3.71E-07	3.43E-06	Based on APLNG EIS data: construction period is 90 days; fuel consumption for construction was 4.20 kL/day; 1 day=24 h. GHG emissions from diesel consumed for earth moving and equipment hauling. Construction will take place over a 4.75 year period, so emissions were averaged over this period.
Camp construction – diesel for power generation	3.69E-07	3.41E-06	Diesel consumption same as above same as above. .Construction will take place over a 4.75 year period, so emissions were averaged over this period.
Water and gas gathering line and well drilling construction – diesel for transport	1.23E-05	1.14E-04	Based on the GLNG EIS where 9.25 kL of diesel is consumed per well by vehicles during construction period – which is assumed to be 14 days. Number of gas wells from GLNG EIS • Fairview = 53.1 wells/years for 16 years = 850 wells • Roma = 56.4 wells/year for 25 years = 1410 • Arcadia = 32.6 wells/year for 12 years = 391 Total = 2650 wells. For 10 Mtpa LNG, 8800 wells required; therefore scale number of wells by 3.33. As construction will be staggered over a 30 year period, the GHG emissions were amortised over 30 years.
Water and gas gathering line – diesel for power generation	1.89E-05	1.75E-04	Based on APLNG EIS – pipe length required per well is 1000 m; construction rate is 2-300 m/day; construction period per well is 5 days; fuel consumed is 4.20 kL/day; number of wells = 2650; approx 9000 days required for construction of the pipeline over 25 years. For 10 Mtpa LNG, 8800 wells required; scale by 3.33. As construction will be staggered over a 30 year period, the GHG emissions were amortised over 30 years.
Gas well drilling – diesel for power generation	5.57E-05	5.14E-04	Based on APLNG EIS: drilling and workover period per well is 14 days; approx 3 kL/d diesel consumed per well. For GLNG, there are 2650 wells. For 10 Mtpa LNG, 8800 wells required; scale by 3.33.
Gas processing stations construction – diesel for transport	2.18E-05	2.02E-04	From the APLNG EIS, the daily average consumption of diesel for transportation (i.e. earth moving) during construction was 1.10 kL/day. Average construction time for a GPS is 27 months, but this varies depending on the expected output in TJ/d of the GPS. For GLNG, there are 12 GPSs. As construction will be staggered over a 30 year period, the GHG emissions were amortised over 30 years.
Construction of water treatment facility – diesel for transport	5.88E-06	5.43E-05	From the APLNG EIS – construction fuel consumption (for earth moving) was estimated to be 6.70 kL/day; construction period is 365 days. From the GLNG EIS, assume 16 water treatment facilities as per APLNG. As construction will be staggered over a 30 year period, the GHG emissions were amortised over 30 years.

Activity - CSG fields - construction	Annual tonnes CO_2-E/GJ exported	Annual tonnes CO_2-E/MWH sent out (OCGT)	Comments
High pressure gas and water pipelines construction – diesel for transport	3.26E-05	3.01E-04	Based on APLNG EIS: approx 600 km of pipe is required for the GLNG project; construction length per site assumed to be 50 km per GPS; fuel consumption is about 12 kL/km; construction period is 12 months. For GLNG there are 12 GPSs.
High pressure gas and water pipelines construction – diesel for power generation	3.26E-05	3.01E-04	Assumes same as above (APLNG EIS).
Embedded GHGs – cement and other materials need for concrete	8.37E-07	7.72E-06	Based on data from the APLNG EIS for 4 trains: 83,000 tonnes concrete for the construction camp and 83,000 tonnes for the operations camps. Data scaled for 3 LNG trains for the GLNG project. Concrete embodied emissions factor is 0.12 t CO_2/t concrete (source: Sima Pro v 7.24). Amortized emissions over 30 years.
Embedded GHGs – concrete for wells	3.59E-06	3.31E-05	Based on data from the APLNG EIS. Amortized emissions over 30 years.
Embedded GHGs – steel casing and tubing	2.17E-05	2.00E-04	Based on APLNG EIS: 24,000 tonnes of steel tubing and 97,000 tonnes steel casing. Steel casing embodied energy factor is 3.2 t CO_2/t (source: Hammond and Jones, 2008). Amortized emissions over 30 years.
Embedded GHGs – steel pipe (HP and water network)	4.75E-05	4.38E-04	Based on APLNG EIS: 138,000 tonnes for the gas network and 176,000 tonnes for the water network. Steel pipe embodied energy factor is 2.7 t CO_2/t (source: Hammond and Jones, 2008). Amortized emissions over 30 years.
Embedded GHGs – HDPE pipes	3.36E-05	3.10E-04	Based on APLNG EIS – HDPE required for water and gas gathering network. HDPE embodied emissions factor is 2.00 t CO_2/t concrete (Hammond and Jones, 2008). Amortized emissions over 30 years.
Extraction, production and transport of diesel	6.92E-06	6.39E-05	Scope 3 GHG factor = 5.3 GJ/kg CO_2-e from NGA Factors, July 2010. As construction is staggered over a 30 year period, GHG emissions were amortized over 30 years.
Road transport for fuels, concrete ingredients, imported water, gravel and pipe sections	5.87E-05	5.42E-04	Based on data for the APLNG EIS – this will be a conservative estimate for GLNG given its relatively smaller scale of development. Amortized emissions over 30 years.
Clear vegetation	8.11E-05	7.49E-04	GLNG – total land clearance for Roma (5640 ha; 155 t CO_2/ha), Arcadia Valley (1564 ha; 159 tCO_2/ha), Fairview (3396 ha; 96 tCO_2/ha). Amortized emissions over 30 years.
Total	4.35E-04	4.01E-03	

2. PIPELINE CONSTRUCTION - BASE CASE

Activity - main transmission pipeline - construction	Annual tonnes CO_2-e/GJ exported	Annual tonnes CO_2-e/MWh sent out (OCGT)	Comments
Diesel used in heavy truck transport	3.77E-06	3.48E-05	From the GLNG EIS – heavy truck diesel fuel efficiency 0.542 L/km; average trip distance 218 km/trip; number of trips = 12,333. GHG factors for diesel consumption for transport from the NGA Factors July 2010.
Diesel used in transmissions pipeline construction – earth moving vehicles etc	2.85E-06	2.63E-05	From the GLNG EIS, a weighted average of 5.4 kg CO_2/hr for all pipeline construction vehicles assumed; vehicles operate over 10 hrs/day; 7 days per week. 100 vehicles operate for 15 months; 50 vehicles for 6 months. Total vehicle hours = 549,000.
Diesel used in transmissions pipeline construction – power generation for camps	3.16E-06	2.92E-05	From the GLNG EIS – total MWh assuming 3 MWh per person in Qld is 4500 MWh – assume diesel gen set provides power. From AP42 guidelines, diesel engine GHG emission data (<600 hp): 0.7 kg CO_2/kWh; 0.0015 kg CH_4/kWh; N_2O – negligible.
Extraction, production and transport of diesel	5.01E-07	4.62E-06	Scope 3 GHG factor = 5.3 GJ/kg CO_2-e from NGA Factors, July 2010.
Embedded GHGs – steel pipe	8.21E-05	7.58E-04	Based on the APLNG EIS: approx 550,000 tonnes steel pipe required for the main high pressure pipeline, gas and water network piping. Steel pipe embedded energy factor 2.70 t CO_2/t steel pipe (Hammond & Jones, 2008).
Clear vegetation	9.64E-06	8.90E-05	From the GLNG EIS – based on ~450 km pipeline with 30 m clearance; assumed GHG loss factor is 135 t CO_2/ha.
Employee transport	9.84E-07	9.08E-06	From the GLNG EIS – bus diesel fuel efficiency 0.276 L/km; average trip distance 50 km/day; number of trips = 43; duration of 21 months or 640 days. GHG factors for diesel consumption for transport from the NGA Factors July 2010.
Total	1.03E-04	9.51E-04	

3. LNG PROCESSING FACILITY - CONSTRUCTION - BASE CASE

Activity - LNG processing plant - construction	Annual tonnes CO_2-e/GJ exported	Annual tonnes CO_2-e/MWh sent out (OCGT)	Comments
Diesel used in power generation for camp	2.72E-05	2.51E-04	Based on GLNG EIS; 10 Mtpa case. GHG emissions amortized over the construction period.
Diesel used in on-site transport	1.77E-05	1.63E-04	Based on APLNG EIS. GHG emissions amortized over the construction period.
Diesel used in constructing LNG plant	7.51E-05	6.93E-04	Based on GLNG EIS; 10 Mtpa case; inclusive of road and camp construction emissions. GHG emissions amortized over the construction period.
Extraction, production and transport of diesel	9.12E-06	8.42E-05	Scope 3 GHG factor = 5.3 GJ/kg CO_2-e from NGA Factors, July 2010. GHG emissions amortized over the construction period.
Embedded GHGs - concrete	1.51E-06	1.40E-05	APLNG EIS - based on 4 train construction - very conservative for GLNG; reduce by 25% to give a 3 train estimate. Concrete embodied emissions factor is 0.12 t CO_2/t concrete; Sima Pro v 7.24. GHG emissions were amortized over the assumed 30 lifetime for the LNG plant.
Embedded GHGs - structural steel	5.82E-06	5.37E-05	APLNG EIS - based on 4 train construction - very conservative estimate for GLNG; reduce by 25% to give a 3 train estimate. Structural steel embodied emissions factor is 2.31 t CO_2/t concrete; Sima Pro v 7.24. GHG emissions were amortized over the assumed 30 lifetime for the LNG plant.
Embedded GHGs - copper cable	1.61E-05	1.48E-04	APLNG EIS - based on 4 train construction - very conservative for GLNG; reduce by 25% to give a 3 train estimate. Copper cable embodied energy factor is 3.83 t CO_2/t copper cable; Hammond & Jones (2008). GHG emissions were amortized over the assumed 30 lifetime for the LNG plant.
Embedded GHGs - insulation	8.79E-06	8.11E-05	APLNG EIS - based on 4 train construction - very conservative for GLNG; reduce by 25% to give a 3 train estimate. Insulation embodied energy factor is 1.35 t CO_2/t insulation; Hammond & Jones (2008). GHG emissions were amortized over the assumed 30 lifetime for the LNG plant.
Employee transport - transport by ferry	1.06E-05	9.79E-05	Based on GLNG EIS estimate: 1.5 trips per day; 2.25 hours travel/day; 3 tonnes fuel oil consumed per day; 40 month construction period; density of fuel oil is 0.98 tonnes/kL. GHG emissions amortized over the construction period.
Employee transport - transport by car	1.06E-05	9.79E-05	Based on the APLNG EIS. GHG emissions amortized over the construction period.
Employee transport - transport by plane	5.30E-05	4.90E-04	Based on the APLNG EIS. GHG emissions amortized over the construction period.
Shipping of LNG plant sections	8.84E-06	8.16E-05	Based on the APLNG EIS. GHG emissions amortized over the construction period.

Activity - LNG processing plant - construction	Annual tonnes CO_2-e/GJ exported	Annual tonnes CO_2-e/MWh sent out (OCGT)	Comments
Materials and equipment transport – by barge	1.26E-05	1.16E-04	Based on the GLNG EIS: 2500 trips, 3.5 trips per day; travel time is 5.2 hours per day; 7 tonnes fuel consumed per day; delivery occurs over 24 months.
Materials and equipment transport – by ship	2.12E-05	1.96E-04	Based on the APLNG EIS. GHG emissions amortized over the construction period.
Materials and equipment transport – by truck	7.43E-06	6.86E-05	Based on the APLNG EIS. GHG emissions amortized over the construction period.
Clear vegetation	1.69E-06	1.56E-05	Based on GLNG EIS; 10 Mtpa case. GHG emissions were amortized over the assumed 30 lifetime for the LNG plant.
Waste to landfill	3.54E-06	3.26E-05	Based on the APLNG EIS. GHG emissions amortized over the construction period.
Total	2.91E-04	2.68E-03	

4. CSG FIELDS – OPERATIONS – BASE CASE

Activity - CSG Fields - operations	Annual tonnes CO_2-e/GJ exported	Annual tonnes CO_2-e/MWh sent out (OCGT)	Comments
Combustion of CSG – operation of compressor and power generation turbines at gas compressor stations	7.80E-03	7.20E-02	Based on the GLNG EIS: 8 compressors per stations; 12 stations in total. Estimated 1.4 million tonnes CO_2-e/yr for the 12 compressor stations. Assume this figure is based on output from 2650 wells; multiply by 3.33 to scale for output from 8800 wells for 10 Mtpa LNG.
Combustion of CSG – operation of water transfer stations	4.04E-05	3.73E-04	Based on the APLNG EIS – over 30 years it is assumed that there will be approx 10,000 wells, requiring 33 water transfer stations (which consists of a lined pond, a pump powered by a small gas-fired generator of 125 kWe capacity). The engine consumes 30 kg gas/hr or 43 m^3/hr. This estimate assumes GHG emissions from the 33 water transfer stations occur simultaneously as a worst case scenario. Emissions are calculated using the energy content for coal seam methane of 0.0377 GJ/m^3 (from NGA factors July 2010) and the NGA GHG factors.
Combustion of CSG – operation of Reverse Osmosis plants	7.84E-04	7.23E-03	Based on the APLNG EIS – over 30 years it is assumed that there will be approx 10,000 wells, requiring 16 RO water treatment stations (which consists of a water feed pond, lined storage ponds and an RO unit powered by 4 gas-fired generators of 1.6 MWe capacity each). Each engine consumes 300 kg gas/hr or 430 m^3/hr of gas. This estimate assumes emissions from the 16 water treatment stations occurs simultaneously as a worst case scenario. Emissions are calculated using the energy content for coal seam methane of 0.0377 GJ/m^3 (from NGA factors July 2010) and the NGA GHG factors.

Activity - CSG Fields - operations	Annual tonnes CO_2-e/GJ exported	Annual tonnes CO_2-e/MWh sent out (OCGT)	Comments
CSG flaring – Gas Processing Stations	5.54E-04	5.12E-03	From the GLNG EIS – there are 12 compressor stations in total; flaring occurs at 10. From data supplied by Santos, CSG released at CS1 and CS2 combined = 2044 Mscf per month = 57,880 m^3/month = 39,185 kg/month. Assumptions were based on flows from 2 plants combined, so multiply by 5 to give GHGs for 10 plants. This gives 6650 t CO_2-e/yr. However, this is appears to be an under-estimate. For 10 Mtpa, estimate 705 PJpa of CSG based on data in the GLNG EIS; this is similar to APLNG which assumes 633 PJpa. Approx 330,000 t CO_2-e/yr is released from flaring (ops & maintenance) in APLNG EIS. Therefore, to be conservative, use APLNG EIS data for the 10 Mtpa case.
CSG fugitive emissions – Gas Processing Stations	1.66E-05	1.53E-04	Based on GLNG EIS – 12 compressor stations in total – venting occurs at 2. From data supplied by Santos, CSG released at CS1 and CS2 combined = 2044 Mscf per month = 57,880 m3/month = 39,185 kg/month. In this calculation, assume that CSG is released as a fugitive emission from equipment leaks; no CSG is vented. The emissions reported are consistent with the APLNG EIS.
CSG flaring – gas wells	1.34E-05	1.24E-04	From the APLNG EIS, flaring during well development, on average over 30 years, amounted to 8000 t CO_2-e/yr, which is consistent with the GLNG EIS. We further assume that no venting or fugitive releases of CSG occur during well development.
CSG venting from workover of wells	8.64E-05	7.97E-04	Assume that venting is 1% of total GHG emissions from combustion of gaseous fuel and from flaring – estimate is consistent with APLNG EIS.
CSG leaks – high pressure pipelines	1.68E-05	1.55E-04	Based on APLNG EIS data; assume no leaks from low pressure gathering lines.
CSG leaks – main transmission pipeline	8.40E-06	7.75E-05	Based on the APLNG EIS and default NGA factors for natural gas leaks from pipelines.
Diesel combustion – power gen sets	1.34E-05	1.24E-04	APLNG EIS – power for camps, backup for gas processing facilities etc.
Diesel combustion – on-site transport	1.51E-05	1.40E-04	Based on the GLNG EIS – 10 Mtpa case.
Total	9.34E-03	8.62E-02	

5. LNG PROCESSING FACILTY - OPERATIONS - BASE CASE

Activity - LNG processing facility - operations	Annual tonnes CO_2-e/GJ exported	Annual tonnes CO_2-e/MWh sent out (OCGT)	Comments
Oil heating	4.66E-04	4.30E-03	GLNG EIS – Bechtel data; 10 Mtpa case; 6 x hot oil heaters.
Refrigeration compressor turbines	3.55E-03	3.28E-02	GLNG EIS – Bechtel data; 10 Mtpa case; 18 x refrigerator/compressor turbines.
LNG facility power	5.36E-04	4.95E-03	GLNG EIS – Bechtel data; 10 Mtpa case; 11 x power generation turbines.
Regenerative gas heaters	1.33E-04	1.23E-03	GLNG EIS – Bechtel data, 10 Mtpa case.
Acid gas vent	6.11E-04	5.64E-03	GLNG EIS – Bechtel data; 10 Mtpa case; 3 x CO_2 vents.
Nitrogen rejection unit	2.67E-04	2.46E-03	GLNG EIS – Bechtel data; 10 Mtpa case; 3 x N_2 vents.
Wet flare	8.85E-05	8.17E-04	GLNG EIS – Bechtel data; 10 Mtpa case.
Dry flare	1.30E-04	1.20E-03	GLNG EIS – Bechtel data; 10 Mtpa case.
Marine flare	2.20E-05	2.03E-04	
Flare pilots and purge	2.36E-05	2.18E-04	GLNG EIS – Bechtel data; 10 Mtpa case; 2 x (flare pilots + purge).
Fugitive methane from plant processing equipment	2.02E-05	1.86E-04	APLNG EIS – LNG facility, 3 train case.
Diesel for backup power generation	5.04E-07	4.65E-06	APLNG EIS – LNG facility, 3 train case.
employee transport by car and ferry	5.88E-05	5.43E-04	APLNG EIS – LNG facility.
transport of consumables by truck	1.68E-05	1.55E-04	APLNG EIS – LNG facility.
transport of consumables by barge	8.40E-06	7.75E-05	APLNG EIS – LNG facility.
Total	5.93E-03	5.48E-02	

6. SHIPMENT, RE-GASIFICATION AND COMBUSTION

Activity - LNG shipment, re-gasification and combustion	Annual tonnes CO_2-e/GJ exported	Annual tonnes CO_2-e/MWh sent out (OCGT)	Comments
LNG shipment to China	1.57E-03	1.45E-02	Engine power = 44,742 kW; Ship speed = 20 knots; Trip Distance = 4,250 naut. Miles; Trip time, one way = 218 hours; Energy use per roundtrip = 19,502,923 kWh; Emission factor = 529 g CO_2/kWh; Emissions per roundtrip = 10,317 tonnes CO_2. Number of round trips = 120 per year Reference: R Heede (2006).
LNG re-gasification	1.29E-03	1.19E-02	Calculation assumes 3% of LNG used in re-gasification process.
End-user LNG combustion	6.26E-02	5.78E-01	Plant efficiency = 39%; Operating hours = 8410 hours; fuel usage by the plant = 501.26 PJ; fuel usage = 16,556,423 kW, which generates 54,303,413 MWh.
Total	9.12-03	6.04E-01	

7. TOTALS - BASE CASE

Rounded

Activity	Annual tonnes CO2-e/tonne LNG	Annual tonnes CO_2-e/GJ exported	Annual tonnes CO_2-e/MWh sent out (OCGT)	Annual tonnes CO_2-e/MWh sent out (OCGT)
CSG fields construction	0.026	0.0004	0.004	0.003
Pipeline construction	0.006	0.0001	0.0009	0.001
LNG facility construction	0.017	0.0003	0.003	0.002
CSG fields/pipeline operation	0.551	0.0093	0.086	0.063
LNG facility operation	0.353	0.0059	0.055	0.040
LNG shipment to China	0.094	0.0016	0.015	0.011
LNG re-gasification	0.077	0.0013	0.012	0.009
End-user LNG combustion	3.138	0.0626	0.578	0.425
Total	4.27	0.081	0.75	0.55

8. SENSITIVITY TO POWER GENERATION EFFICIENCY AND TECHNOLOGY

Units: tonnes CO2-e/MWh

Activity	Base case OCGT (39% efficiency)	Low OCGT (36% efficiency)	High OCGT (46% efficiency)	Base case CCGT (53% efficiency)	Low CCGT (46% efficiency)	High CCGT (60% efficiency)
CSG fields – construction	0.004	0.004	0.003	0.003	0.003	0.003
CSG pipeline construction	0.001	0.001	0.001	0.001	0.001	0.001
LNG plant construction	0.003	0.003	0.002	0.002	0.002	0.002
CSG fields – operations	0.085	0.093	0.072	0.063	0.072	0.056
CSG pipeline – operations	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
LNG plant operations	0.055	0.059	0.046	0.040	0.046	0.036
LNG shipment	0.015	0.016	0.012	0.011	0.012	0.009
LNG re-gasification	0.012	0.013	0.010	0.009	0.010	0.010
Combustion of LNG	0.578	0.626	0.490	0.425	0.490	0.376
CSG fields – construction	0.004	0.004	0.003	0.003	0.003	0.003
Total	0.75	0.81	0.64	0.55	0.64	0.49

9. SENSITIVITY OF THE BASE OCGT RESULTS TO VARIATIONS IN OPERATING PARAMETERS

units: tonnes CO_2-e/MWh

ACTIVITY	GHGS FROM COMPRESSOR TURBINES IN CSG FIELDS (50% HIGHER THAN BASE CASE)	GHGS FROM COMPRESSOR TURBINES IN CSG FIELDS (50% LOWER THAN BASE CASE)	GHGS FROM RO AND WATER TRANSPORT IN CSG FIELDS (50% HIGHER THAN BASE CASE)	GHGS FROM RO AND WATER TRANSPORT IN CSG FIELDS (50% LOWER THAN BASE CASE)	GHGS FROM VENTING AND FLARING IN CSG FIELDS (50% HIGHER THAN BASE CASE)	GHGS FROM VENTING AND FLARING IN CSG FIELDS (50% LOWER THAN BASE CASE)	SENSITIVITY TO LNG PLANT DESIGN (FOSTER-WHEELER ALTERNATIVE)
CSG fields – construction	0.004	0.004	0.004	0.004	0.004	0.004	0.004
CSG pipeline construction	0.001	0.001	0.001	0.001	0.001	0.001	0.001
LNG Plant construction	0.003	0.003	0.003	0.003	0.003	0.003	0.003
CSG Fields – operations	0.121	0.049	0.089	0.082	0.088	0.083	0.085
CSG pipeline – operations	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
LNG Plant operations	0.055	0.055	0.055	0.055	0.055	0.055	0.059
LNG Shipment	0.015	0.015	0.015	0.015	0.015	0.015	0.015
LNG re-gasification	0.012	0.012	0.012	0.012	0.012	0.012	0.012
Combustion of LNG	0.578	0.578	0.578	0.578	0.578	0.578	0.578
Total	0.79	0.72	0.76	0.75	0.76	0.75	0.76

ATTACHMENT 7 - EMISSIONS TABLES - BLACK COAL

1. EMISSIONS FACTORS

Emissions were estimated as described in Attachment 5, Section 5. In most cases. emissions for the coal mines examined were collated from EIS greenhouse emissions documents and divided by the annual quantity of product coal for each mine. This gave an emission value per tonnes of product coal for several sites, which were then collated and averaged. Where yield (saleable product/ROM) was not stated and only ROM was stated, saleable product was estimated from State averages. Where factors were mine-specific NGA factors were used for the base value.

EMISSION SOURCE	EMISSION FACTOR T CO_2-E/T PRODUCT COAL			COMMENT
	BASE VALUE	LOW VALUE	HIGH VALUE	
Mine fugitives	0.03752	0.00183	0.396	NGA Tables 6 to 8. Base is NGA average. Low is for Wandoan Mine based on site testing. High is for a gassy underground mine.
Mine diesel use	0.01153	0.00046	0.048	Range from EIS statements.
Explosives	0.00025	0	0.00061	Some mines do not require explosives.
Slow oxidation	0.00018	0	0.00070	Most EIS examined did not include this emission.
Spontaneous combustion	0.00185	0.00027	0.00422	
Electricity consumption (grid)	0.01571	0.00187	0.0337	
Scope 3 electricity consumption	0.00010	0.00080	0.00423	
Scope 3 diesel	0.00278	0.00006	0.00013	
Rail	0.00205	0.00032	0.00602	From EISs based on Queensland Rail factors. Check done using NGA factors and distances to port.
Port handling	0.00161	0.00161	0.00161	
Shipping	0.07908	0.01073	0.25725	
End use combustion	2.3876	1.8435	3.1097	Base is NGA factor. Min/max from EISs.
Total	**2.54009**	**1.86141**	**3.86263**	
Calorific value effect on GHG intensity (tCO_2-e/MWh)	1.0263	0.7521	1.5607	Base is NGA factor of 27.0 GJ/t for thermal coal. Range from ABARE 24-32 J/t.

2. LIFE CYCLE EMISSIONS - BASE CASE

EMISSION SOURCE	SUB-CRITICAL BASE CASE			SUPER-CRITICAL BASE CASE			ULTRA SUPER-CRITICAL BASE CASE		
	T CO_2E/T PRODUCT COAL	T CO_2E/MWH	T CO_2E/GJ COAL	T CO_2E/T PRODUCT COAL	T CO_2E/MWH COAL	T CO_2E/GJ COAL	T CO_2E/T PRODUCT COAL	T CO_2E/MWH	T CO_2E/GJ COAL
Mine fugitives	0.03752	0.0152	0.0014	0.03752	0.0122	0.0014	0.03752	0.0116	0.0014
Mine diesel Use	0.01135	0.0046	0.0004	0.01135	0.0037	0.0004	0.01135	0.0035	0.0004
Mine explosives	0.00025	0.0001	0.0000	0.00025	0.0001	0.0000	0.00025	0.0001	0.0000
Slow oxidation	0.00018	0.0001	0.0000	0.00018	0.0001	0.0000	0.00018	0.0001	0.0000
Spontaneous combustion	0.00185	0.0007	0.0001	0.00185	0.0006	0.0001	0.00185	0.0006	0.0001
Mine electricity consumption (grid)	0.01571	0.0063	0.0006	0.01571	0.0051	0.0006	0.01571	0.0049	0.0006
Scope 3 electricity consumption	0.00278	0.0011	0.0001	0.00278	0.0007	0.0001	0.00278	0.0006	0.0001
Scope 3 diesel Consumption	0.00010	0.0000	0.0000	0.00010	0.0257	0.0000	0.00010	0.0245	0.0000
Rail transport	0.00205	0.0008	0.0001	0.00205	0.0005	0.0001	0.00205	0.0005	0.0001
Port facilities	0.00161	0.0007	0.0001	0.00161	0.0009	0.0001	0.00161	0.0009	0.0001
Shipping	0.07908	0.0320	0.0029	0.07908	0.0000	0.0029	0.07908	0.0000	0.0029
End Use coal combustion	2.38761	0.9647	0.0884	2.38761	0.7765	0.0884	2.38761	0.7403	0.0884
Total	**2.540**	**1.026**	**0.0941**	**2.540**	**0.826**	**0.0941**	**2.540**	**0.788**	**0.0941**

3. RANGES OF EMISSIONS INTENSITIES

This table shows the life cycle emissions intensity with the rows reflecting ranges due to effects of thermal efficiency alone and the columns reflecting ranges due to site-to-site variations in all contributing emmissions sources.

COMBUSTION TECHNOLOGY	ELECTRICITY SENT OUT	EMISSIONS INTENSITY		
		BASE	LOW	HIGH
	MWh/t product coal	T CO_2e/MWh	T CO_2e/MWh	T CO_2e/MWh
Subcritical pulverised coal power station				
LOW end of efficiency range	2.100	1.2096	0.8864	1.8393
BASE case efficiency	2.475	1.0263	0.7521	1.5607
HIGH end of efficiency range	2.850	0.8913	0.6531	1.3553
Supercritical pulverised coal power station				
LOW end of efficiency range	2.850	0.8913	0.6531	1.3553
BASE case efficiency	3.075	0.8260	0.6053	1.2561
HIGH end of efficiency range	3.150	0.8064	0.5909	1.2262
Ultra supercritical pulverised coal power station				
LOW end of efficiency range	3.150	0.8064	0.5909	1.2262
BASE case efficiency	3.225	0.7876	0.5772	1.1977
HIGH end of efficiency range	3.975	0.6390	0.4683	0.9717

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