FINAL REPORT

SURAT GAS IMPACT ASSESSMENT REPORT
GREENHOUSE GAS ASSESSMENT

Coffey Environments Pty Ltd

Job No: 3568a2

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A PEL Company

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PREPARED FOR:	Jessica Wiltshire **COFFEY ENVIRONMENTS AUSTRALIA PTY LTD**
PREPARED BY:	S Colson
QA PROCEDURES CHECKED BY:	M Goodfellow
APPROVED FOR RELEASE BY:	C Kolominskas
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Queensland Environment Pty Ltd trading as
PAEHolmes ABN 86 127 101 642

BRISBANE:
Level 1, La Melba, 59 Melbourne Street, South Brisbane QLD 4101
PO Box 3306, South Brisbane QLD 4101
Ph: +61 7 3004 6400
Fax: +61 7 3844 5858

SYDNEY:
Suite 203, Level 2, Building D, 240 Beecroft Road
Epping NSW 2121
Ph: +61 2 9870 0900
Fax: +61 2 9870 0999

ADELAIDE:
72 North Terrace, Littlehampton SA 5250
PO Box 1230, Littlehampton SA 5250
Ph: +61 8 8391 4032
Fax: +61 7 3844 5858

MELBOURNE:
Suite 62, 63 Turner Street, Port Melbourne VIC 3207
PO Box 23293, Docklands VIC 8012
Ph: +61 3 9681 8551
Fax: +61 3 9681 3408

PERTH:
Level 18, Central Park Building,
152-158 St Georges Terrace, Perth WA 6000
Ph: +61 8 9288 4522
Fax: +61 8 9288 4400

GLADSTONE:
Suite 2, 36 Herbert Street, Gladstone QLD 4680
Ph: +61 7 4972 7313
Fax: +61 7 3844 5858

Email: info@paeholmes.com
Website: www.paeholmes.com

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ES1 EXECUTIVE SUMMARY

The conceptual Surat Gas Project design presented in the environmental impact statement (EIS) is premised upon peak gas production from Arrow Energy Pty Ltd's (Arrow's) Surat Basin gas fields of approximately 1,050 TJ/d. The peak gas production comprises 970 TJ/d for LNG production (including a 10% fuel gas requirement for facility operation) and a further 80 TJ/d for supply to the domestic gas market.

The Arrow Surat Gas Project has a project life of 35 years. In line with requirements of the EIS, the greenhouse gas emissions associated with Arrow's Surat Gas Project have been estimated.

The primary objectives of this study are to estimate the greenhouse gas emissions resulting from the development and operation of the Arrow Surat Gas Project, identify methods to reduce or mitigate those emissions and comment on the potential impact of these emissions with respect to climate change. Impacts have been assessed in line with the Terms of Reference.

Direct (scope 1) and indirect (scope 2) greenhouse gas emissions from the operation of the Arrow Surat Gas Project have been estimated to be 3.5 Mt CO_2-e/annum for year 2030 at peak operation (i.e., worst-case for emissions), with the majority of emissions associated with gas combustion. The worst-case scenario represents approximately 0.85% of Australia's 2007 greenhouse gas emission inventory.

The scope 1 and scope 2 greenhouse gas emissions associated with the peak operation scenario from the Arrow Surat Gas Project are minor (approximately 13.1% of the total emissions) in comparison with scope 3 emissions, which are primarily associated with the end use of the product fuel. In comparison with other fossil fuels, particularly coal, combusting gas or liquefied natural gas (LNG) for heating purposes emits less greenhouse gas emissions per unit of thermal energy produced. If gas or LNG is combusted to produce electricity, the greenhouse gas reductions, when compared to other fossil fuels, are even greater, per MWh of electricity generated.

The impacts associated with the Arrow Surat Gas Project's greenhouse gas emissions, with respect to climate change, will be in proportion with the project's contribution to global greenhouse gas emissions. As such, the impacts are expected to be negligible.

ES2 GLOSSARY

Abbreviation	Meaning
ACCUs	Australian Carbon Credit Units
AGO	Australian Greenhouse Office
API	American Petroleum Institute
BAT	Best Available Technology
CDM	Clean Development Mechanism
CFI	Carbon Farming Initiative
CGPF	Central Gas Processing Facility
COP	Conference of Parties
CPRS	Carbon Pollution Reduction Scheme
CSG	Coal Seam Gas
DCC	Department of Climate Change
DCCEE	Department of Climate Change and Energy Efficiency
EEO	Energy Efficiency Opportunities
EIT	Economies In Transition
EITE	Emission Intensive Trade Exposed
ETS	Emission Trading Scheme
EPA	Environmental Protection Agency
FCF	Field Compression Facility
GEC	Gas Electricity Certificate
GHG	Greenhouse Gas
GT	Gas Turbine
GWP	Global Warming Potential
HSEMS	Health, Safety and Environmental Management System
IPCC	Intergovernmental Panel on Climate Change
IPF	Integrated Processing Facility
JI	Joint Implementation
LNG	Liquefied Natural Gas
LULUCF	Land Use, Land Use Change and Forestry
NCOS	National Carbon Offset Standard
NGA	Australia's National Greenhouse Accounts
NGERs	National Greenhouse and Energy Reporting System
OECD	Organisation for Economic Co-operation and Development
OTN	Obligation Transfer Number
QGS	Queensland Gas Scheme
SESP	Smart Energy Savings Program
SOP	Standard Operating Procedure
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
WMO	World Meteorological Organisation
USC	Ultra Super Critical

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1 INTRODUCTION

1.1 Proponent

Arrow Energy Pty Ltd (Arrow) is an integrated energy company with interests in gas field developments, pipeline infrastructure, electricity generation and a proposed liquefied natural gas (LNG) project.

Arrow has interests in more than 65,000 km^2 of petroleum tenures, mostly within Queensland's Surat and Bowen basins. Elsewhere in Queensland, the company has interests in the Clarence-Moreton, Coastal Tertiary, Ipswich, Styx and Nagoorin Graben basins.

Arrow's petroleum tenures are located close to Queensland's three key energy markets; Townsville, Gladstone and Brisbane. The Moranbah Gas Project in the Bowen Basin and the Tipton West, Daandine, Kogan North and Stratheden projects in the Surat Basin near Dalby comprise Arrow's existing coal seam gas production operations. These existing operations currently account for approximately 20% of Queensland's overall domestic gas production.

Arrow supplies gas to the Daandine, Braemar 1 and 2, Townsville and Swanbank E power stations which participate in the National Electricity Market. With Arrow's owernship of Braemar 2 and the commercial arrangements in placed for Daandine and Townsville power stations, Arrow has access to up to 600 MW of power generation capacity.

Arrow and its equity partner AGL Energy have access rights to the North Queensland Pipeline which supplies gas to Townsville from the Moranbah Gas Project. They also hold the pipeline licence for the proposed Central Queensland Gas Pipeline between Moranbah and Gladstone.

Arrow is currently proposing to develop the Arrow LNG Project, which is made up of the following aspects:

- Arrow LNG Plant – The proposed development of an LNG Plant on Curtis Island near Gladstone, and associated infrastructure, including the gas pipeline crossing of Port Curtis.
- Surat Gas Project – The upstream gas field development in the Surat Basin, the subject of this assessment.
- Arrow Surat Pipeline Project – (Formerly the Surat Gladstone Pipeline), the 450 km transmission pipeline connects Arrow's Surat Basin gas developments to Gladstone.
- Bowen Gas Project – The upstream gas field development in the Bowen Basin.
- Arrow Bowen Pipeline – The transmission pipeline which connects Arrow's Bowen Basin gas developments to Gladstone.

1.2 Arrow Surat Gas Project

Arrow proposes expansion of its gas operations in the Surat Basin through the Surat Gas Project. The need for the project arises from the growing demand for gas in the domestic market and global demand and the associated expansion of LNG export markets.

The project development area covers approximately 8,600 km^2 and is located approximately 160 km west of Brisbane in Queensland's Surat Basin. The project development area extends from the township of Wandoan in the north towards Goondiwindi in the south, in an arc adjacent Dalby. Townships within or in close proximity to the project development area include (but are not limited to) Wandoan, Chinchilla, Kogan, Dalby, Cecil Plains, Millmerran, Miles and

Goondiwindi. Project infrastructure including gas production wells and production facilities (including both water treatment and power generation facilities where applicable) will be located throughout the project development area but not in towns. Facilities supporting the petroleum development activities such as depots, stores and offices may be located in or adjacent to towns.

The conceptual Surat Gas Project design presented in the environmental impact statement (EIS) is premised upon peak gas production from Arrow's Surat Basin gas fields of approximately 1,050 TJ/d. The peak gas production comprises 970 TJ/d for LNG production (including a 10% fuel gas requirement for facility operation) and a further 80 TJ/d for supply to the domestic gas market.

A project life of 35 years has been adopted for EIS purposes. Ramp-up to peak production is estimated to take between 4 and 5 years, and is planned to commence in 2014. Following ramp-up, gas production will be sustained at approximately 1,050 TJ/d for at least 20 years, after which production is expected to decline.

Infrastructure for the project is expected to comprise:

- Approximately 7,500 production wells drilled over the life of the project at a rate of approximately 400 wells drilled per year.
- Low pressure gas gathering lines to transport gas from the production wells to production facilities.
- Medium pressure gas pipelines to transport gas between field compression facilities and central gas processing and integrated processing facilities.
- High pressure gas pipelines to transport gas from central gas processing and integrated processing facilities to the sales gas pipeline.
- Water gathering lines (located in a common trench with the gas gathering lines) to transport produced water from production wells to transfer, treatment and storage facilities.
- Approximately 18 production facilities across the project development area expected to comprise of six of each of the following:
    - Field compression facilities.
    - Central gas processing facilities.
    - Integrated processing facilities.
- A combination of gas powered electricity generation equipment that will be co-located with production facilities and/or electricity transmission infrastructure that may draw electricity from the grid (via third party substations).

Further detail regarding the function of each type of production facility is detailed below.

1.2.1 Field compression facilities

Field compression facilities will receive gas from production wells and are expected to provide 30 to 60 TJ/d of first stage gas compression. Compressed gas will be transported from field compression facilities in medium pressure gas pipelines to multi-stage compressors at central gas processing facilities and integrated processing facilities where the gas will be further compressed to transmission gas pipeline operating pressure and dehydrated to transmission gas pipeline quality. Produced water will bypass field compression facilities.

1.2.2 Central gas processing facilities

Central gas processing facilities will receive gas both directly from production wells and field compression facilities. Central gas processing facilities are expected to provide between 30 and 150 TJ/d of gas compression and dehydration. Produced water will bypass central gas processing facilities and be pumped to an integrated processing facility for treatment.

1.2.3 Integrated processing facilities

Integrated processing facilities will receive gas from production wells and field compression facilities. Integrated processing facilities are expected to provide between 30 and 150 TJ/d of gas compression and dehydration. Produced water received at integrated processing facilities is expected to be predominantly treated using reverse osmosis and then balanced to ensure that it is suitable for the intended beneficial use. Produced water received from the field, treated water and brine will be stored in dams adjacent to integrated processing facilities.

It is envisaged that development of the Surat Gas Project will occur in five development regions: Wandoan, Chinchilla, Dalby, Kogan/Millmerran and Goondiwindi. Development of these regions will be staged to optimise production over the life of the project.

Arrow has established a framework to guide the selection of sites for production wells and production facilities and routes for gathering lines and pipelines. The framework will also be used to select sites for associated infrastructure such as access roads and construction camps. Environmental and social constraints to development that have been identified through the EIS process coupled with the application of appropriate environmental management controls will ensure that protection of environmental values (resources) is considered in project planning. This approach will maximise the opportunity to select appropriate site locations that minimise potential environmental and social impacts.

Arrow has identified 18 areas that are nominated for potential facility development to facilitate environmental impact assessment (and modelling). These are based on circles of approximately 12 km radius that signify areas where development of production facilities could potentially occur.

Arrow intends to pursue opportunities in the selection of equipment (including reverse osmosis units, gas powered engines, electrical generators and compressors) and the design of facilities that facilitates the cost effective and efficient scaling of facilities to meet field conditions. This flexibility will enable Arrow to better match infrastructure to gas production. It will also enable Arrow to investigate the merits of using template design principles for facility development, which may in turn generate further efficiencies as the gas reserves are better understood, design is finalised, or as field development progresses.

1.3 Objectives of Study

The primary objectives of this study are to estimate the greenhouse gas emissions resulting from the development and operation of the Arrow Surat Gas Project and identify methods to reduce or mitigate those emissions and comment on the potential impact of these emissions. Impacts have been assessed in line with the Terms of Reference.

The following assessment considered exploration and appraisal, construction, operational, decommissioning and rehabilitation project activities.

The following tasks formed the scope of work of the study and the outcomes of each task are included in this report:

- Fulfil the requirements of the Terms of Reference for the Arrow Energy Surat Gas Project EIS (see Appendix C), as issued by the Coordinator General, December 2010.
- Review and identify relevant international, federal and state greenhouse gas and climate change related policies.
- Collate anticipated emissions of greenhouse gases from project activities (exploration and appraisal, construction activities, operation and maintenance, and decommissioning and rehabilitation) in an inventory of projected annual emissions for each relevant greenhouse gas, with total emissions expressed in "CO_2 equivalent".
- Compare emissions to global, national and state totals.
- Identify potential impacts of the proposed project.
- Identify and describe measures to avoid, reduce, mitigate and manage greenhouse gas emissions for project activities, and describe how these measures would be implemented, monitored and audited.
- Assess residual and cumulative impacts of greenhouse gases arising from project activities, taking into account implemented mitigation measures and relevant assessment frameworks.
- Assess potential impacts of changing climate patterns on the viability and environmental management of the project.
- Describe intended audit and critical review procedures.

2 LEGISLATIVE AND POLICY CONTEXT OF THE ASSESSMENT

This section identifies the key international, federal and state government policies and laws regulating greenhouse gas emissions, and the prescribed methods and factors for estimating greenhouse gas emissions.

2.1 International Framework

2.1.1 Intergovernmental Panel on Climate Change

The Intergovernmental Panel on Climate Change (IPCC) is a panel established in 1988 by the World Meteorological Organisation (WMO) and the United Nations Environment Programme (UNEP), to provide independent scientific advice on climate change. The panel was asked to prepare, based on available scientific information, a report on all aspects relevant to climate change and its impacts and to formulate realistic response strategies. This first assessment report of the IPCC served as the basis for negotiating the United Nations Framework Convention on Climate Change (UNFCCC) (IPCC, 2004).

The IPCC also produce a variety of guidance documents and recommended methodologies for greenhouse gas emissions inventories, including:

- 2006 IPCC Guidelines for National Greenhouse Gas Inventories; and
- Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (2000).

Since the UNFCCC entered into force in 1994, the IPCC remains the pivotal source for scientific and technical information relevant to climate change and greenhouse gas emissions.

The IPCC operates under the following mandate: *"to provide the decision-makers and others interested in climate change with an objective source of information about climate change. The IPCC does not conduct any research nor does it monitor climate-related data or parameters. Its role is to assess on a comprehensive, objective, open and transparent basis the latest scientific, technical and socio-economic literature produced worldwide, relevant to the understanding of the risk of human-induced climate change, its observed and projected impacts and options for adaptation and mitigation. IPCC reports should be neutral with respect to policy, although they need to deal objectively with policy relevant scientific, technical and socio economic factors. They should be of high scientific and technical standards, and aim to reflect a range of views, expertise and wide geographical coverage"* (CCC, 2011).

The stated aims of the IPCC are to assess scientific information relevant to:

- human-induced climate change;
- the impacts of human-induced climate change; and
- options for adaptation and mitigation.

The IPCC released its fourth assessment report in 2007. The fifth assessment report is now underway and is expected to be completed in 2013/2014. IPCC reports are widely cited in climate change debates and policies, and are generally regarded as authoritative.

2.1.2 United Nations Framework Convention on Climate Change (UNFCCC)

The UNFCCC sets an overall framework for intergovernmental efforts to tackle the challenge posed by climate change. It recognises that the climate system is a shared resource, the stability of which can be affected by industrial and other emissions of carbon dioxide and other greenhouse gases. The convention enjoys near-universal membership, with 172 countries (parties) having ratified the contained treaty, the Kyoto Protocol – refer to section 2.1.3 below. Australia ratified the Kyoto Protocol in December 2007.

Under the UNFCCC, governments:

- gather and share information on greenhouse gas emissions, national policies and best practices;
- launch national strategies for addressing greenhouse gas emissions and adapting to expected impacts, including the provision of financial and technological support to developing countries; and
- cooperate in preparing for adaptation to the impacts of climate change.

2.1.3 Kyoto Protocol

The Kyoto Protocol entered into force on 16 February 2005. The Kyoto Protocol builds upon the UNFCCC by committing to individual, legally binding targets to limit or reduce greenhouse gas emissions. Annex I Parties are countries that were members of the Organisation for Economic Co-operation and Development (OECD) in 1992, plus countries with economies in transition (the EIT Parties), such as Russia. The greenhouse gases included in the Kyoto Protocol are:

- carbon dioxide (CO_2);
- methane (CH_4);
- nitrous oxide (N_2O);
- hydrofluorocarbons (HFCs);
- perfluorocarbons (PFCs); and
- sulfur hexafluoride (SF_6).

The emission reduction targets are calculated based on a party's domestic emission greenhouse gas inventories (which include the land use change and forestry clearing, transportation and stationary energy sectors). Domestic inventories require approval by the Kyoto Enforcement Branch. The Kyoto Protocol requires developed countries to meet national targets for greenhouse gas emissions over a five year period between 2008 and 2012.

To achieve their targets, Annex I Parties must put in place *domestic policies and measures.* The Kyoto Protocol provides an indicative list of policies and measures that might help mitigate climate change and promote sustainable development.

Under the Kyoto Protocol, developed countries can use a number of flexible mechanisms to assist in meeting their targets. These market mechanisms include:

- Joint Implementation (JI) – where developed countries invest in greenhouse gas emission reduction projects in other developed countries; and
- Clean Development Mechanism (CDM) – where developed countries invest in greenhouse gas emission reduction projects in developing countries.

Annex I countries that fail to meet their emissions reduction targets during the 2008-2012 period may be liable for a 30% penalty (additional to the level of exceedence). Countries would have to make up the exceedence plus penalty in the post-2012 commitment period.

2.1.4 International Agreement Post-Kyoto

An international framework for mitigating the impacts of climate change past the Kyoto period was discussed at the 15th United Nations Conference of Parties (COP), Copenhagen, in December 2009. It concluded with an agreement that the global temperature rise should be capped through significant emission reductions by all countries; however no legally binding agreement was ratified. The *Copenhagen Accord* was drafted and supported by the majority countries, and outlined the following (UNFCCC, 2009):

- The global temperature increase should be held below 2°C.
- Emissions targets for developed countries and actions to reduce emissions by developing countries should be specified.
- An international framework for measurement, reporting and verification of greenhouse gas emissions will be developed.
- Financial assistance will be provided for developing countries to reduce emissions and adapt to climate change.

Nations went to Copenhagen with national emission reduction targets, both unconditional and dependent on global emission reduction commitments. On 27 January 2010, Australia officially presented its full target range to the *Copenhagen Accord.* The *Accord* is not legally binding to the extent of the Kyoto Protocol and the specification of national emissions reduction commitments for the period 2012-2020 will be subject to further negotiation.

At the 16th United Nations COP in Cancún, November - December 2010, the *Cancún Agreements* were developed. While not legally binding, the *Agreements* anchor the mitigation pledges made by both developed and developing countries in the *Copenhagen Accord* under the UNFCCC. This is seen as an important step in securing a new global treaty to replace the Kyoto Protocol after 2012. Other outcomes from the conference include the establishment of a new Green Climate Fund to support developing countries with climate change adaption, as well as technology sharing mechanism.

2.2 Australian Context

2.2.1 Australia's Greenhouse Gas Inventory

According to the Department of Climate Change and Energy Efficiency[a] (DCCEE), Australia's greenhouse gas emissions increased by 9.3% between 1990 and 2007 (refer to Table 1). The largest increase was in the energy sector, with emissions increasing by 42.5% between 1990 and 2007. In particular, the sub-sector "stationary energy", which includes emissions associated with non-transport fuel combustion, increased by 49.5% (96.6 Mt CO_2-e) between 1990 and 2007 (DCCEE, 2009a). The largest contribution to "stationary energy" comes from electricity generation (68.4%) (DCCEE, 2009a). Emissions from the Arrow Surat Gas Project will be categorised as part of the energy sector.

The relatively small change in total emissions from 1990 to 2007 is largely due to a significant reduction in greenhouse gas emissions associated with land use change, which has decreased by over 57% between 1990 and 2007 (DCCEE, 2009a). Under current Kyoto accounting provisions, these emissions include:

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[a] The Department of Climate Change and Energy Efficiency (DCCEE), was previously known as the Department of Climate Change (DCC), established on 3 December 2007.

- afforestation and reforestation (establishment or re-establishment of forests) since 1990; and
- deforestation – the deliberate human induced removal of forest cover and replacement with other uses.

Since 1990, there has been a significant reduction in deforestation within Australia and annual associated release of stored carbon combined with an increase in forestry projects. In addition there has been an increase in forest planting, increasing the amount of carbon dioxide sequestered from the atmosphere.

Table 1: Australian Greenhouse Gas Emissions 1990 and 2007 Kyoto Baseline by Sector

Sector	Emissions (Mt CO_2-e)		Percentage Change
	1990	2007	1990 to 2007
Energy	**286.4**	**408.2**	**42.5%**
Stationary Energy	*195.1*	*291.7*	49.5%
Transport	*62.1*	*78.8*	26.9%
Fugitive Emissions from Fuel	*29.2*	*37.7*	28.9%
Industrial Processes	**24.1**	**30.3**	**25.7%**
Agriculture	**86.8**	**88.1**	**1.5%**
Waste	**18.8**	**14.6**	**-22.5%**
Land Use, Land Use Change and Forestry (LULUCF) [a]	**130.1**	**56.0**	**-57.0%**
Australia's Net Emissions	**546.3**	**597.2**	**9.3%**

Source: Table reproduced (DCCEE, 2009a).

a. Strictly speaking, the net credits from land use change and forestry should only enter the account during the first commitment period (2008 to 2012). However, the 1990 and 2007 values are indicated for reference, and included in totals.

2.2.2 Australia and the Kyoto Protocol

Australia submitted its "instrument of ratification" on 12 December 2007. Ratification came into force for Australia on 11 March 2008 following a mandatory 90 day waiting period.

Under the protocol, developed countries are legally required to take domestic action to reduce greenhouse gas emissions. Each developed country's target was negotiated and agreed. Australia's national target is to achieve an average of 108% of 1990 emissions for the five years of the first commitment period (2008-2012). Any new sources that begin emitting during this period will contribute to Australia's Kyoto target.

The National Greenhouse Gas Inventory 2007 from the Australian Government Department of Climate Change and Energy Efficiency (DCCEE), shows that 2007 emissions were 109.3% of the 1990 baseline (refer to Table 1). The DCCEE is projecting that emissions will reduce to an average of 583 Mt CO_2-e per annum over 2008-12. This is 107 per cent of 1990 levels, meaning that Australia is expected to meet its Kyoto obligations (DCCEE, 2009a).

The Kyoto Protocol requires Australia to implement a range of monitoring and reporting commitments. Specifically, Australia is required to report its annual greenhouse gas emissions every year during the 2008 to 2012 commitment period.

2.2.3 The National Greenhouse and Energy Reporting Act (NGER Act)

Federal parliament passed the *National Greenhouse and Energy Reporting Act 2007* (the NGER Act) in September 2007 (DCCEE, 2007). The NGER Act establishes a mandatory corporate reporting system for greenhouse gas emissions, energy consumption and production.

The NGER Act is one of a number of legislative instruments related to greenhouse reporting, which together form the National Greenhouse and Energy Reporting System (NGERs), as follows:

- The *National Greenhouse and Energy Reporting Regulations 2008* (DCCEE, 2008c) and the *National Greenhouse and Energy Reporting Amendment Regulations 2008* (DCCEE, 2009d) which provide the necessary details that allow compliance with, and administration of, the *NGER Act*.
- The *National Greenhouse and Energy Reporting (Measurement) Determination 2008* (DCCEE, 2008d) and *National Greenhouse and Energy Reporting (Measurement) Amendment Determination – Reporting Year 2010-2011* (DCCEE, 2010d) which provides methods and criteria for calculating greenhouse gas emissions and energy data under the *NGER Act*.
- The *National Greenhouse and Energy Reporting (Audit) Determination 2009* (DCCEE, 2009e) which sets out the requirements for preparing, conducting and reporting on greenhouse and energy audits.

The NGER Act is seen as an important first step in the establishment of a domestic emissions trading scheme. This intention is explicitly stated in the objectives for the NGER Act, as follows:

- establish a baseline of emissions for participants in a future Australian emissions trading scheme;
- inform the Australian public;
- meet international reporting obligations; and
- assist policy formulation of all Australian governments while avoiding duplication of similar reporting requirements.

Corporate and facility reporting thresholds for greenhouse gas emissions and energy consumption or energy production are provided in Table 2. Based on the findings of this study, annual greenhouse gas emissions from the Arrow Surat Gas Project will exceed the NGERs facility threshold (refer to Section 4 for emission estimates). Existing Arrow Energy Limited facilities exceeded the corporate thresholds in 2009-2010. Therefore Arrow will be required to report greenhouse gas emissions and energy consumption/production from the Arrow Surat Gas Project.

Table 2: NGER Reporting Thresholds

Year	Corporate Threshold		Facility Threshold	
	Greenhouse Gas Emissions (kt CO_2-e)	Energy Usage (TJ)	Greenhouse Gas Emissions (kt CO_2-e)	Energy Usage (TJ)
2008-2009	125	500	25	100
2009-2010	87.5	350		
2010-2011	50	200		

Source: DCCEE (2007)

2.2.4 Energy Efficiency Opportunities Program

The Energy Efficiency Opportunities (EEO) Program is designed to improve the energy efficiency of large businesses (DRET, 2010). Participation is mandatory for corporations that use more than 0.5 PJ of energy. Participating corporations must assess their energy efficiency, and energy efficiency opportunities with a payback period less than four years, and publicly report the results. This means that if the resulting efficiencies of an identified improvement measure can recover the costs of implementing the program within four years, the initiative must be assessed in detail.

Arrow Energy will trigger the 0.5 PJ energy consumption threshold and will thus be required to report under the EEO program.

2.2.5 Proposed Legislation - The Carbon Price Mechanism

On 10 July 2011, the Australian Government released its *Clean Energy Plan*, which incorporates a Carbon Pricing Mechanism. Under this proposed policy, from 1 July 2012, the eligible industries in Australia will be required to pay for every tonne of carbon pollution released to the atmosphere (Australian Government, 2011a). This mechanism is expected to replace the Carbon Pollution Reduction Scheme (CPRS) put forward by the Australian Government in 2008.

The CPRS was intended to be the principal mechanism used to reduce Australia's greenhouse gas emissions for the Kyoto period, and beyond. The centrepiece of the CPRS was a "cap and trade" emissions trading scheme to constrain greenhouse gas emissions and establish a price for greenhouse gas emissions in Australia. On 27 April 2010 the Australian Government announced the deferral of the CPRS implementation date.

Although the framework of the proposed carbon mechanism resembles that proposed in the Green and White Papers (DCCEE, 2008a and DCCEE, 2008b) for the CPRS, the carbon price mechanism involves the following distinguishing features:

- The carbon price mechanism will consist of two distinct stages. For the first three years, a fixed price stage will operate with the price of all carbon permits set by the government. The carbon price will start at $AUD 23 per tonne and rise by 2.5 % a year, resulting in a carbon price of $AUD 24.15 per tonne in 2013-14 and $AUD 25.40 per tonne in 2014-15 (Australian Government, 2011a). During this fixed price period, businesses will be able to acquire as many permits at the set price as required to meet their obligations.
- Subsequent to this three year period, a flexible cap and trade emissions trading scheme will commence (refer to Section 2.2.5.1).
- During the fixed price stage, *eligible* Australian carbon credit units (ACCUs) produced from Australian projects under the Carbon Farming Initiative (CFI), will be accepted as currency as an alternative of purchasing Australian Permits. CFI will produce carbon credits eligible

for local and international compliance (e.g., Emission Trading Scheme - ETS) and voluntary markets (e.g., National Carbon Offset Standard - NCOS) (Carbon Neutral, 2011). Only 5 % of liable entities' obligation may be met by surrendering eligible ACCUs during the fixed price stage. However, Australia's carbon price will not be linked to international carbon markets during the fixed price period.

- The *Clean Energy Plan* is expected to cut pollution by a minimum of 5% below 2000 levels *by 2020 and by 80% below 2000 lev*els *by 2050.*
- Before the flexible price period, the Government will set annual caps on pollution for the first *five years which w*ill be extended each year to assist businesses planning their strategy for compliance.

As proposed in the CPRS, the threshold for facilities will be identical to that employed for NGER reporting (i.e., 25,000 kt CO_2-e/year or more - excluding emissions from transport fuels and some synthetic greenhouse gases) and will be used to identify whether a facility will be covered by the carbon pricing mechanism.

2.2.5.1 Emissions Trading

Subsequent to the fixed price stage, a variable price as part of a "cap and trade" system will be implemented where the carbon price will be set by the market. The number of permits issued by the Government each year will be capped. In cap and trade schemes, an aggregate cap is enforced. Organisations within the cap are able to trade emission permits to meet their permitting liabilities. International carbon markets and land abatement programs will also be available to acquire permits for compliance. During the flexible price period, an unlimited amount of eligible ACCUs can be surrendered for compliance, as opposed to the 5% limit set for the fixed price period.

Carbon permits can enter the market either by auction or by administrative allocation. Companies will have an economic incentive to pay for permits if their internal costs of abatement are higher than the price of permits, and to directly reduce their emissions if their internal costs of abatement are lower than the price of permits. In theory, companies that own permits would be willing to sell them if the revenue received from selling permits exceeds the profits from using them.

These market incentives are designed to encourage the cheapest abatement to occur first.

The carbon price mechanism will cover the same emissions as proposed under the CPRS, with the exception of the definite exclusion of agricultural carbon emissions. Approximately 60 % of Australia's carbon pollution is expected to be covered by the carbon price, which encompasses the following emission sources:

- stationary energy production (e.g., natural gas, coal, petroleum fuels, electricity);
- some business transport;
- industrial processes (e.g., cement or aluminium production);
- fugitive emissions (other than from decommissioned coal mines); and
- emissions from non-legacy waste.

The scheme will have broad economic ramifications beyond large emitters with direct obligations. Households are likely to experience increased costs associated with carbon intensive goods and services such as electricity, gas and food. However, a significant portion of the scheme is devoted to measures to ease the transition to carbon-constrained economy and assistance from the Australian Government will be provided to approximately 8 million households.

2.2.5.2 Support Measures

Assistance will be provided through allocation of permits early in each compliance period to new and existing entities undertaking an eligible emissions-intensive trade-exposed (EITE) activity prescribed in regulations. The most emissions-intensive trade-exposed activities will receive assistance to cover 94.5% of industry average carbon costs in the first year of the carbon price. Less emissions-intensive trade-exposed activities will also receive assistance to cover 66% of industry average carbon costs. Assistance will be reduced by 1.3% each year to encourage industry to cut pollution (Australian Government, 2011a).

2.2.5.3 The Arrow Surat Gas Project and the Carbon Price Mechanism

Arrow will be a direct participant in the carbon price mechanism as it is currently proposed, since Arrow is part of the stationary energy sector, is a large supplier of gas and currently reports to NGERs (Australian Government, 2011b). This means that Arrow must report their emissions and hold emission permits at the end of each period. As the cost of permits fluctuates, it may be more economically viable to pursue emission mitigation and avoidance measures than to obtain permits for all emissions. The extent of emissions reductions will largely be determined by market forces.

There will also be flexibility for large facilities that purchase natural gas from a retailer to assume responsibility for emissions from their use of natural gas. In this case, an obligation transfer number (OTN) mechanism will provide for the voluntary transfer of carbon price liability from natural gas retailers to large natural gas users in prescribed circumstances (Australian Government, 2011a).

The objective of the carbon price is to change Australia's electricity generation by encouraging investment in renewable energy like wind and solar power but by also encouraging the use of cleaner fuels like natural gas. A *Clean Technology Investment Program* of $AUD 800 million over seven years from 2011-12 will also be implemented and will include funds to support the conversion of facilities from coal to natural gas.

2.2.6 Proposed Legislation - The Coalition's Direct Action Plan

On December 1 2009, a new Opposition Leader was elected by the Liberal Party. Under the new leadership, the Opposition is seeking to defeat the proposed emissions trading scheme. The policy currently put forward by the Opposition is the *Direct Action Plan* (LPA, 2010). This policy remains in force after the announcement made by the Australian Government in regards to the carbon tax on 10 July 2011 (LPA, 2011).

The centrepiece of this policy is the replenishment of soil carbons – a large CO_2 abatement through bio-sequestration (currently soil carbons are not recognised under the Kyoto Protocol; however future global agreements on CO_2 reductions may include them).

The policy will also introduce an Emissions Reduction Fund to facilitate 140 million tonnes of CO_2 abatement per annum by 2020. The fund is intended to aid projects that would:

- reduce CO_2 emissions;
- not result in price increases for consumers;
- deliver additional practical environmental benefits;
- protect Australian jobs; and

- not proceed without fund assistance.

A particular target of the policy is the nation's oldest and most inefficient power generation facilities, which will have the ability to use the fund to introduce programs to increase efficiency, or switch to less carbon intensive fuels, such as natural gas.

The *Direct Action Plan* is essentially a "baseline and credit" approach, where:

- if businesses reduce their emissions below their baseline they have the opportunity to offer the abatement for sale to the government; and
- while no penalties are proposed for businesses that remain at their baseline levels of emissions, financial penalties are proposed for those businesses that emit more than their baseline levels.

The Coalition claimed that the *Direct Action Plan* would match the 5% emission reductions outlined in the governments draft CPRS legislation (LPA, 2010) (now deferred); however no emission reduction target was specified.

2.2.6.1 The Arrow Surat Gas Project and the Direct Action Plan

While the nature of the Arrow Surat Gas Project will lead to an increase in greenhouse gas emissions over the life of the project, and hence an increase from the baseline "historic average", the proposed policy should not impose penalties on Arrow. The policy states that, "provision will be made to ensure penalties will not apply to new entrants or business expansion at "best practice" ". While the policy does not go into further detail on how the expansion at best practice would be assessed, it is expected that this will involve consideration of the emission intensity of the business.

The Direct Action Plan may therefore provide options for Arrow to further reduce the emission intensity of their operation, if significant abatement opportunities arise which Arrow would not pursue without the fund's contribution. The policy as it is currently proposed should not place a financial burden on Arrow, or any further effort on top of the current NGER system.

2.2.7 Australian Context Post-Kyoto

Currently an unconditional emission reduction target of 5% below 2000 levels by 2020 is supported by both major political parties. This was part of Australia's submission to the United Nations COP in Copenhagen. Other conditional targets included in the submission are 15% below 2000 levels and 25% below 2000 levels. These targets would require a global agreement that has developed countries contributing comparably to Australia. However, at present, Australia has no legally binding emission reduction target after the Kyoto period, which ends in 2012. The targets pledged in the *Copenhagen Accord* and anchored with the *Cancún Agreements* will nonetheless be treated as serious political commitments, and will likely form the basis of targets agreed to under a replacement of the Kyoto Protocol.

2.3 Queensland Greenhouse Gas Policy

The Queensland Government's climate change mitigation strategy is presented in *ClimateQ: toward a greener Queensland* (Queensland Government, 2009). It is a consolidation and update to previous Qld Government strategies - *ClimateSmart 2050* and the *ClimateSmart Adaptation Plan 2007-12*.

ClimateQ outlines a commitment to reduce Queensland's greenhouse gas emissions by 60% by 2050, in line with the Australian Government's long-term target. This is proposed to be achieved through a variety of short, medium and long-term strategies, such as:

- improving energy efficiency;
- reducing the emissions intensity of the Queensland energy sector;
- mode switching and fuel efficiency in the transport sector;
- reduction of land clearing; and
- carbon sequestration.

2.3.1 Smart Energy Savings Program

Improving energy efficiency in the residential, commercial and industrial sectors has been identified by *ClimateQ* as a key strategy, as reductions in greenhouse gas emissions can be achieved with little or no cost. For small to medium sized businesses that use 100 to 500 TJ of energy, energy auditing and reporting will be mandatory under the Smart Energy Savings Program (SESP), introduced through the *Clean Energy Act 2008*.

For larger businesses, using more than 500 TJ, energy auditing and reporting is mandatory under the national EEO Program. As detailed in Section 2.2.4 it is expected that the Arrow Surat Gas Project will be a participant in the EEO Program, and as such will not have to report under the SESP.

2.3.2 Queensland Gas Scheme

Greenhouse gas emissions from the stationary energy sector will be reduced through the *Queensland Gas Scheme* (QGS). Under the QGS, Queensland electricity retailers and large electricity users will be required to source a portion of their electricity from gas-fired generation at rates of:

- 15% by 2010; and
- 18% by 2020.

The QGS has been in effect since 2005. In the period 2005 to 2009, the QGS required 13% of electricity in Queensland to be generated from gas.

The Government administers targets through tradeable gas electricity certificates (GECs). Accredited gas fired power stations earn tradeable gas electricity certificates for each MWh of electricity produced. Electricity retailers and large consumers must purchase and surrender GECs equivalent to the proportion of electricity that must be generated by gas under the QGS. Since 2005, the average price of GECs has been $16, and the scheme has generated $158 million through GECs sales, making gas fired power generation economically competitive with coal (DME, 2008).

The Queensland Government's rationale for increasing electricity sourced from natural gas is that in comparison to coal-fired generation, natural gas produces approximately half the emissions per unit of electricity generated. Therefore, natural gas has been identified as a key transitional fuel source while renewable energy and clean coal technologies are developed.

As the Arrow Surat Gas Project is not generating electricity for retail use, it will not be a direct participant in the QGS, and will not be required to trade GECs.

2.4 Summary of Relevant Policies

A summary of the relevant policies relating to emissions of greenhouse gases and electricity consumption/generation from the Arrow Surat Gas Project is presented in Table 3.

Table 3: Summary of Greenhouse Gas Emissions Policies Relevant to the Arrow Surat Gas Project

Level	Policy	Arrow Surat Gas Project Participation	Section in Report
International	Kyoto Protocol	INDIRECT As the Arrow Surat Gas Project is planned to be commissioned after 2013, emissions will not count towards Australia's Kyoto target for the 2008-2012 period.	Section 2.1.3
Australia	NGERs	MANDATORY Arrow already participates in NGERs and will have to annually report greenhouse gas emissions and energy consumption/production associated with the Arrow Surat Gas Project.	Section 2.2.3
	EEO Program	MANDATORY (expected) It is expected that Arrow will report energy usage and energy efficiency opportunities associated with the Arrow Surat Gas Project.	Section 2.2.4
	Carbon Price Mechanism (proposed)	MANDATORY Arrow is expected to be a participant in the proposed Carbon Price Mechanism and will have to annually report emissions from the Arrow Surat Gas Project and hold emission permits at the end of each period. Assistance from the government will potentially be given if gas production qualifies as an EITE industry.	Section 2.2.5
	Direct Action Plan (proposed)	VOLUNTARY It is expected that the Direct Action Plan will place no demand on the Arrow Surat Gas Project. Opportunities may exist for the Arrow Surat Gas Project to receive funding to further reduce its emissions intensity.	Section 2.2.6
Queensland	SESP	NONE (expected) Arrow will only have to report energy efficiency data from the Arrow Surat Gas Project if it does not do so under the EEO Program.	Section 2.3.1
	QGS	INDIRECT The Arrow Surat Gas Project is not a direct participant in trading of GECs.	Section 2.3.2

3 GREENHOUSE GAS EMISSIONS ESTIMATION METHODOLOGY

3.1.1 Introduction

Greenhouse gas emission calculations are generally of the form:

$$Emission_i = Activity\ data \times EF_i$$

where:

$Emission_i$	=	Estimated emissions of greenhouse gas i	(t CO_2-e)
$Activity\ data$	=	Basis of emission estimate (for example, amount of fuel combusted for energy generation)	(generally in the units of GJ for fuel combustion)
EF_i	=	Emission factor for greenhouse gas i	(t CO_2-e/Activity)

The activity data used to determine greenhouse gas emissions for this assessment were provided by Coffey Environments.

PAEHolmes has estimated greenhouse gas emissions based upon the methods outlined in the following documents:

- The World Resources Institute/World Business Council for Sustainable Development Greenhouse Gas Protocol (WRI & WBCSD, 2004).
- The National Greenhouse and Energy Reporting (Measurement) Determination 2008 as amended – Reporting Year 2010-11 (DCCEE, 2010d) and National Greenhouse and Energy Reporting (Measurement) Determination 2008 (DCCEE, 2008d).
- The National Greenhouse and Energy Reporting System Measurement Technical Guidelines 2010 (*Technical Guidelines*) (DCCEE, 2010e).
- The Australian Government Department of Climate Change National Greenhouse Accounts Factors 2010 (DCCEE, 2010f).

3.1.2 The Greenhouse Gas Protocol

The Greenhouse Gas Protocol (WRI & WBCSD, 2004) establishes an international standard for accounting and reporting of greenhouse gas emissions. The Greenhouse Gas Protocol has been adopted by the International Organization for Standardization, endorsed by greenhouse gas initiatives (such as the Carbon Disclosure Project) and is compatible with existing greenhouse gas trading schemes.

Under this protocol, three "scopes" of emissions (scope 1, scope 2 and scope 3) are defined for greenhouse gas accounting and reporting purposes. This terminology has been adopted in Australian greenhouse reporting and measurement methods and has been employed in this assessment. The definitions for scope 1, scope 2 and scope 3 emissions are provided in the following sections.

3.1.2.1 Scope 1: Direct Greenhouse Gas Emissions

Direct greenhouse gas emissions are defined as emissions that occur from sources owned or controlled by the reporting entity. For Arrow, direct greenhouse gas emissions principally result from the following types of project activities:

- Direct generation of electricity, heat or steam. These emissions result from combustion of fuels in stationary sources.
- Physical or chemical processing. Most of these emissions result from processing of gas.
- Transportation of materials, products, waste and employees. These emissions result from the combustion of fuels in Arrow owned/controlled mobile combustion sources; e.g., buses, cars, etc.
- Construction activities. These emissions result from the combustion of fuels in Arrow owned/controlled industrial vehicles and equipment; e.g., excavators, graders, truck-mounted drilling rig etc., as well as clearing of land.
- Fugitive emissions. These emissions result from intentional or unintentional releases; e.g., equipment leaks from joints, seals (pump and compressor), valves, flanges, methane and carbon dioxide emissions from equipment, venting and flaring.

Table 4 summarises the scope 1 greenhouse gas emission sources considered for the assessment, how these sources have been grouped, and the key variables used to estimate emissions.

Table 4: Scope 1 Greenhouse Gas Emission Sources

Project Phase	Project Activity	Source of Greenhouse Gas Emissions	Key Variables which Influence Total Greenhouse Gas Emissions
Construction, Operation and Decommissioning	Power generation.	Reciprocating gas powered generation sets which provide power to: - Construction activities. - Gas processing and compression, water storage and treatment and field development. - Decommissioning activities.	Amount of gas combusted in stationary engines and associated time period.
Exploration	Seismic data collection. Exploration well installation. Core sampling. Pilot well installation.	- Earthmoving and construction equipment (fuel usage). - Diesel consumption in light and heavy vehicles. - Industrial vehicles fuel usage.	- Fuel consumption in vehicles in kL/annum or - Number of kilometres travelled by vehicles and fuel consumption rate in kL/km for each type of vehicle selected.
Construction	Land clearing.	Clearing of vegetation.	Total area cleared (ha).
	Production well installation.	- Ramp-up flaring associated with wells installation. - Industrial vehicles fuel usage.	- Amount of gas flared and associated time period. - Fuel consumption of industrial vehicles associated with each well.
	Gas and water gathering infrastructure installation. Water transmission infrastructure. High pressure pipeline construction. Road construction to production facilities . Dam construction associated with each integrated processing facility. Facility construction. Accommodation camp construction.	Earthmoving and construction equipment (fuel usage).	- Fuel consumption in vehicles in kL/annum or - Number of kilometres travelled by vehicles and fuel consumption rate in kL/km for each type of vehicle selected.
Operation and maintenance	Well site operation and maintenance including well workovers.	Diesel consumption in light and heavy vehicles.	- Fuel consumption in vehicles in kL/annum or - Number of kilometres travelled by vehicles to operate and maintain infrastructure and fuel consumption rate in kL/km for each type of vehicle selected.

Project Phase	Project Activity	Source of Greenhouse Gas Emissions	Key Variables which Influence Total Greenhouse Gas Emissions
	Gathering infrastructure operation and maintenance (water and gas)	- Diesel consumption in light and heavy vehicles. - Fugitive emissions through water gathering system (high point vents, associated water dams). - Fugitive emissions through gas gathering line (compressor blow downs, maintenance of pipelines, leakage, accidents).	- Fuel consumption in vehicles in kL/annum or - Number of kilometres travelled by vehicles to operate and maintain infrastructure and fuel consumption rate in kL/km for each type of vehicle selected. -Maximum amount of gas processed and efficiency of separation. - Length of gathering line.
	Facility operation and maintenance	- Diesel consumption in light and heavy vehicles. - Flaring is expected to occur at all the facilities, which includes: - Pilot light under normal operating conditions. - Flaring due to upset conditions. - Fugitive emissions associated with gas compression, dehydration and other type of equipments associated with each facilities.	- Fuel consumption in vehicles in kL/annum or - Number of kilometres travelled by vehicles and fuel consumption rate in kL/km for each type of vehicle selected. - Flare pilot light rate and duration of pilot light. - Maximum flaring rate, duration of the flaring event and maximum number of events due to upset conditions. - Maximum amount of gas processed.
Decommissioning and rehabilitation	Well site decommissioning and rehabilitation	Earthmoving equipment and industrial (fuel usage).	- Fuel consumption in vehicles in kL/annum or - Number of kilometres travelled by vehicles and fuel consumption rate in kL/km for each type of vehicle selected.
	Gathering infrastructure decommissioning and rehabilitation		
	Facility site decommissioning and rehabilitation		

3.1.2.2 Scope 2: Energy Product Use

Scope 2 emissions are indirect greenhouse gas emissions from the generation of purchased energy products by the entity. For Arrow, this will include purchased electricity.

Scope 2 emissions physically occur at the facility that generates the electricity, rather than the facility that uses the electricity. This is why they are often referred to as indirect greenhouse gas emissions.

Greenhouse gas emissions released from the production of electricity in the proposed infrastructure are classified as scope 1 emissions in this assessment since the power generation is under the control of Arrow. However, electricity purchased from the grid during construction or operation will have associated scope 2 emissions.

3.1.2.3 Scope 3: Other Indirect Greenhouse Gas Emissions

Scope 3 emissions are defined as those emissions that are a consequence of the activities of an entity, but which arise from sources not owned or controlled by that entity. Some examples of scope 3 activities provided in the Greenhouse Gas Protocol are extraction and production of purchased materials, transportation of purchased fuels, and use of sold products and services.

In line with the Terms of Reference, scope 3 emissions quantified in this assessment included emissions associated with:

- fuel cycles (diesel and electricity consumption from the grid);
- the end-use of produced gas and;
- third party infrastructure required to export the gas as LNG, which includes gas losses through transmission to Arrow LNG Plant and downstream gas processing.

The scope 3 emissions included in this assessment do not encompass emissions associated with LNG product shipping, waste products management and construction material embedded energy. It is difficult to quantify these emissions with the number of unknown variables involved (e.g. the destination of the ships or the origin of the construction material). Therefore in order to be conservative in estimating the scope 3 emissions associated with the third party infrastructure, the scope 1 and scope 2 emissions associated with the worst-case scenario ("all electrical") for the currently proposed Arrow LNG Plant were used and scaled according to the currently expected fraction of gas supplied by the Project.

The Greenhouse Gas Protocol allows optional reporting of scope 3 emissions. If an organisation believes that scope 3 emissions are a significant component of the total emissions inventory, these can be reported along with scope 1 and scope 2 emissions. However, the Greenhouse Gas Protocol notes that reporting scope 3 emissions can result in double counting of emissions and can also make comparisons between organisations and/or products difficult (because reporting is voluntary). Double counting needs to be avoided when compiling national (country) inventories under the Kyoto Protocol. The Greenhouse Gas Protocol also recognises that compliance regimes are more likely to focus on the "point of release" of emissions (i.e., direct emissions) and/or indirect emissions from the purchase of electricity.

Table 5 presents the scope 3 emission sources considered for the Arrow Surat Gas Project.

Table 5: Scope 3 Greenhouse Gas Emission Sources

Greenhouse Gas Emission Source	Key Variables which Influence Total Greenhouse Gas Emissions
Fuel cycles of diesel (indirect emissions due to extraction, production and transport of fuel consumed)	Amount of fuel used
Electricity consumption from the grid (fuel transport, distribution losses)	Amount of electricity consumed
Gas end use (domestic or export)	Amount of gas produced
Third party infrastructure to export the gas as LNG	Length of transmission pipeline to transport coal seam gas to Arrow LNG Plant. Amount of gas to be processed at Arrow LNG.

3.1.2.4 Audit and Review Procedures of the Methodology

Arrow Energy will annually review the emissions associated with the Arrow Surat Gas Project by using real production data and the latest NGER methodologies. In this way, the project's greenhouse gas emissions performance can be determined on an annual basis.

3.1.2.5 Summary of Activities

The activities associated with the project during the construction, operation and decommissioning of all of Arrow's facilities and infrastructure are summarised in Table 6. These activities are associated with the base case scenario which corresponds to integrated power generation. However, power requirement is expected to be met through a combination of local power generation and electricity from the main grid. Only the base case was considered in this assessment except where assumptions were provided for the grid power supply option (worst-case scenario); i.e., electricity supplied to the well heads.

Table 6: Activities Associated with the Project

Category	Activity [a]	Construction	Operation	Decommissioning
Fuel combustion	Power generation (gas)	Construction power	Power to production wells, and compression and water treatment facilities.	Power to production wells, and compression and water treatment facilities until full decommissioning. Decommissioning power.
	Light and heavy vehicles (diesel)	Installation of production wells, facilities and infrastructure.	Operation and maintenance of production wells, production facilities and gathering infrastructure.	Decommissioning of production wells, facilities and infrastructure.
Fugitive emissions	Transmission	-	All production facilities	All facilities until decommissioning.
	Facility-level fugitive emissions	-	All production facilities	All facilities until decommissioning.
	Flaring	Ramp-up flaring	Pilot flaring and flaring due to upset conditions.	Pilot flaring and flaring due to upset conditions until full decommissioning.
Energy consumption	Electricity consumption	-	Power to wellheads on-line (worst-case scenario)	Power to wellheads on-line (worst-case scenario)
Land clearing	Clearing of vegetation	Site preparation	-	-

a. Refer to Table 4 for more details on scope 1 emissions sources.

3.1.3 National Greenhouse and Energy Reporting (Measurement) Determination 2008 (and Amendment)

The National Greenhouse and Energy Reporting Determination 2008 (*Determination*) (DCCEE 2008d) provides for the measurement of:

- greenhouse gas emissions;
- the production of energy; and
- the consumption of energy.

The Determination provides guidance for the estimation of scope 1 and scope 2 emissions. In the Determination there are four categories of scope 1 emissions:

- fuel combustion;
- fugitive emissions from fuels, which deals with emissions released from the extraction, production, flaring of fuel, processing and distribution of fossil fuels;
- industrial processes emissions; and
- waste emissions.

Where possible, PAEHolmes has employed methods consistent with those described in the Determination related to scope 1 and scope 2 emissions. Refer to Appendix A for further information.

3.1.4 National Greenhouse Accounts Factors

The National Greenhouse Accounts (NGA) Factors (DCCEE, 2010f) provides emission factors for use in a variety of emission reporting frameworks. This document replaces the Australian Greenhouse Office Factors and Methods Workbook. The Department of Climate Change, using the Australian Greenhouse Emissions Information System, has derived default emission factors.

The NGA Factors are relevant for the purposes of estimating scope 3 emissions, since it provides emission factors for grid supplied electricity by state and emissions associated with fuel cycles.

4 FORECASTED GREENHOUSE GAS EMISSION ESTIMATES FOR THE ARROW SURAT GAS PROJECT

The project development will include:

- A ramp-up period of 6 years from 2014 to 2019.
- An operational period of approximately 20 years (i.e., 2020 – 2039 period) where a maximum production plateau is expected to be sustained to supply the Arrow LNG Plant and the domestic market.
- A ramp-down period of 5 to 10 years (i.e., 2040 – 2047 period selected) which will involve gas tail off and decommissioning of the facilities, the production wells and their associated infrastructure.

Figure 1 shows the total scope 1 and scope 2 greenhouse gas emissions associated with each period of the life of the project. A worst case year, which is the year that generates the highest greenhouse emission estimates, was selected for each period in order to present the most conservative estimates. Year 2019, Year 2030 and Year 2040 were selected for the respective periods. The associated greenhouse emission estimates are summarised in section 4.1, section 4.2 and section 4.3, respectively. Emissions estimates for each emissions source for individual years of the three phases of the project are presented in Appendix A.

Identifiable scope 3 emissions are also considered in this assessment and include fuel cycles (i.e., diesel and electricity usage associated with the worst-case scenario), product end-usage and third party infrastructure required to export gas as LNG. However, scope 3 emissions are not included in the estimation of the emissions intensity associated with the project as they do not provide useful comparisons with other projects (due to differing project boundaries). In the context of a life cycle assessment, all the coal seam gas produced that is not lost through transmission to Arrow LNG Plant (i.e., product end-use) is assumed to be combusted. The scope 3 emissions associated with the third party infrastructure encompass any emissions involved in the transport and processing of the gas for export as LNG (refer to scope 1 and 2 emissions associated with the "all electrical" scenario in Arrow's LNG EIS Greenhouse Gas chapter (PAEHolmes, 2011).

Figure 1: Total Greenhouse Gas Emissions (GHG) in t CO_2-e for each Year from 2014 until 2047

4.1 Ramp-Up Period Emissions

The total (scope 1 and scope 2) greenhouse gas emissions associated with the ramp-up period (i.e., 2014 – 2019) of the Arrow Surat Gas Project have been estimated to be approximately 2.6 Mt CO_2-e/annum for “worst-case” ramp-up year (i.e., 2019), as shown in Table 7.

Scope 1 “ramp-up” emissions are associated with fuel combustion (to run construction activities and construction camp, and for transport) and fugitive emissions from land clearing, gas processing, maintenance of the production wells and flaring (i.e., pilot flaring and flaring due to upset conditions, for example, shut down of compressors for service or maintenance). The total annual scope 1 emissions were estimated to be approximately 2.4 Mt CO_2-e/annum (i.e., 91.6% of the total scope 1 and 2 emissions), as shown in Table 7, with the majority of scope 1 emissions from gas combustion.

Scope 2 “ramp-up” emissions are associated with the electricity consumed to meet wellhead power requirements. 20% of wellheads are assumed to be powered with grid power (Coffey Environments, 2011e). The total annual scope 2 emissions were estimated to be approximately 216 kt CO_2-e/annum, as shown in Table 7, which represents a minor contribution (i.e., 8.4%) to the total emissions during the “worst case” ramp-up year.

Scope 3 emissions during the “ramp-up” phase are associated with full fuel cycles of diesel and electricity, the end-use of produced gas and the third party infrastructure required to export gas as LNG. The total annual scope 3 emissions were estimated to be approximately 18.4 Mt CO_2-e/annum, as shown in Table 7, which represents over seven times the amount of scope 1 and 2 emissions during the “worst case” ramp-up year.

The majority of greenhouse emissions during the “ramp-up” phase are associated with scope 3 emissions from the end-use of gas which represent 88.1% of the total scope 3 emissions during the “worst case” ramp-up year.

Table 7: Forecast Greenhouse Gas Emissions during Ramp-Up Period (Worst-Case Year 2019)

Category	Activity	Emissions [tonnes CO_2-e / annum]			
		CO_2	CH_4	N_2O	Total
RAMP-UP - SCOPE 1 EMISSIONS					
Fuel Combustion	Stationary engines (gas engines + drilling)	1,818,619	7,108	1,130	**1,826,858**
	Vehicles	4,772	14	34	**4,820**
Fugitive Emissions	Land clearing	26,418	-	-	**26,418**
	Ramp-up flaring	No ramp-up flaring forecast for this specific year			
	Transmission	42	18,149	-	**18,191**
	Facility-level fugitive emissions	4	223,927	-	**223,931**
	Well workovers	-	610	-	**610**
	Pilot lights & flaring due to upset conditions	236,532	21,700	2,604	**260,836**
RAMP-UP - SCOPE 2 EMISSIONS					
Energy Consumption	Electricity consumption – wellheads [c]	216,467	-	-	**216,467**
RAMP-UP - SCOPE 3 EMISSIONS					
Energy Consumption/ Production	End-use (combustion of gas)	16,152,199	63,218	9,483	**16,224,900**
	Full fuel cycle (diesel) [c]	365	-	-	**365**
	Full fuel cycle (electricity) [c]	31,619	-	-	**31,619**
	Third party infrastructure - CSG transmission to Arrow LNG Plant	18	8,035	-	**8,054**
	Third party infrastructure - CSG downstream processing	1,928,212	220,288	1,026	**2,149,526**
TOTAL SCOPE 1 EMISSIONS		**2,086,386**	**271,508**	**3,769**	**2,361,663**
TOTAL SCOPE 2 EMISSIONS [c]		**216,467**	**-**	**-**	**216,467**
TOTAL SCOPE 3 EMISSIONS		**18,111,361**	**291,537**	**10,508**	**18,413,406**
OVERALL		**20,414,214**	**563,046**	**14,277**	**20,991,537**

Notes:

a. Calculated based on activity data and emission estimation techniques detailed in Appendix A.

b. Annual emissions estimates are also provided in Appendix A.

c. Scope 2 and scope 3 emissions are presented as CO_2 emissions while they are in fact a combination of CO_2, CH_4 and N_2O emissions (i.e. emission factors expressed as CO_2-e only).

4.2 Operational Emissions

The total (scope 1 and scope 2) greenhouse gas emissions associated with the operational period (i.e., 2020 – 2039) of the Arrow Surat Gas Project have been estimated to be approximately 3.5 Mt CO_2-e/annum for the “worst-case” operational plateau year (i.e., 2030), as shown in Table 8.

Scope 1 operational emissions are associated with fuel combustion (to run construction and operation activities, and for transport) and fugitive emissions from land clearing, gas processing, maintenance of the production wells and flaring (i.e., pilot flaring, ramp-up flaring and flaring due to upset conditions). The total annual scope 1 emissions were estimated to be approximately 2.8 Mt CO_2-e/ annum (i.e., 80.5% of the total scope 1 and scope 2 emissions), as shown in Table 8, with the majority of scope 1 emissions from gas combustion.

Scope 2 operational emissions are associated with electricity consumed to meet wellhead power requirements (i.e., 20% of wellheads are powered with grid power). The total annual scope 2 emissions were estimated to be approximately 678 kt CO_2-e/annum, as shown in Table 8, which represents a minor contribution (i.e., 19.5% of the total scope 1 and scope 2 emissions) to the total emissions during the “worst case” operational plateau year.

Scope 3 emissions are associated with the full fuel cycles of diesel and electricity, the end-use of produced gas and the third party infrastructure required to export gas as LNG. The total annual scope 3 emissions were estimated to be approximately 23.1 Mt CO_2-e/annum, as shown in Table 8, which represents over six times the amount of scope 1 and 2 emissions during the “worst case” operational plateau year.

The majority of greenhouse gas total emissions are associated with scope 3 emissions from the end-use of gas which represents 78.7% of the total scope 3 emissions and during the “worst case” operational plateau year.

Table 8: Forecast Greenhouse Gas Emissions during Plateau Operation Period (Worst-Case Year 2030)

Category	Activity	Emissions [tonnes CO_2-e / annum]			
		CO_2	CH_4	N_2O	Total
OPERATIONS - SCOPE 1 EMISSIONS					
Fuel Combustion	Stationary engines (gas engines + drilling)	1,844,438	7,183	1,317	**1,852,938**
	Vehicles	14,404	42	104	**14,549**
Fugitive Emissions	Land clearing	87,465			**87,465**
	Transmission	130	56,574		**56,704**
	Facility-level fugitive emissions	4	253,676		**253,680**
	Pilot lights & flaring due to upset conditions	444,854	48,825	4,883	**498,562**
	Well workovers		1,910		**1,910**
	Ramp-up flaring	32,708	8,177	350	**41,235**
OPERATIONS - SCOPE 2 EMISSIONS					
Energy Consumption	Electricity consumption – wellheads [c]	678,053			**678,053**
OPERATIONS - SCOPE 3 EMISSIONS					
Energy Consumption/ Production	End-use (gas)	18,091,955	70,810	10,622	**18,173,387**
	Full fuel cycle (diesel) [c]	1,103			**1,103**
	Full fuel cycle (electricity) [c]	99,041			**99,041**
	Third party infrastructure - CSG transmission to Arrow LNG Plant	18	8,035	-	**8,054**
	Third party infrastructure - CSG downstream processing	4,319,582	493,489	2,299	4,815,369
TOTAL SCOPE 1 EMISSIONS		**2,424,003**	**376,388**	**6,654**	**2,807,044**
TOTAL SCOPE 2 EMISSIONS [c]		**678,053**			**678,053**
TOTAL SCOPE 3 EMISSIONS		**22,510,647**	**572,331**	**12,919**	**23,095,897**
OVERALL		**25,612,702**	**948,718**	**19,573**	**26,580,994**

Notes:

a. Calculated based on activity data and emission estimation techniques detailed in Appendix A.

b. Annual emissions estimates are also provided in Appendix A.

c. Scope 2 and scope 3 emissions are presented as CO_2 emissions while they are in fact a combination of CO_2, CH_4 and N_2O emissions (i.e. emission factors expressed as CO_2-e only).

4.3 Ramp-Down Period Emissions

The total (scope 1 and scope 2) greenhouse gas emissions associated with the ramp-down period (i.e., 2040 – 2047) of the Arrow Surat Gas Project have been estimated to be approximately 2.9 Mt CO_2-e/annum for worst-case ramp-down year (i.e., 2040), as shown in Table 9.

Scope 1 "ramp-down" emissions are associated with fuel combustion (to run operation and decommissioning activities, and for transport) and fugitive emissions from gas processing, maintenance of the production wells and flaring (i.e., pilot flaring and flaring due to upset conditions). The total annual scope 1 emissions were estimated to be approximately 2.6 Mt CO_2-e/ annum (i.e., 89.6% of the total scope 1 and scope 2 emissions), as shown in Table 9, with the majority of scope 1 emissions from gas combustion.

Scope 2 "ramp-down" emissions are associated with electricity consumed to meet wellhead power requirements (i.e., 20% of the power required by each wellhead). The total annual scope 2 emissions were estimated to be approximately 305 kt CO_2-e/annum, as shown in Table 9, which represents a minor contribution (i.e., 10.4% of the total scope 1 and scope 2 emissions) to the total emissions during the "worst case" ramp-down year.

Scope 3 emissions are associated with the full fuel cycles of diesel and electricity, the end-use of produced gas and the third party infrastructure required to export gas as LNG. The total annual scope 3 emissions were estimated to be approximately 20.3 Mt CO_2-e/annum, as shown in Table 9, which represents approximately seven times the amount of scope 1 and 2 emissions during the "worst case" ramp-down year.

The majority of greenhouse gas total emissions are associated with scope 3 emissions from the end-use of coal seam gas which represent 78.8% of the total scope 3 emissions during the "worst case" ramp-down year.

Table 9: Forecast Greenhouse Gas Emissions during Ramp-Down Period (Worst-Case Year 2040)

Category	Activity	Emissions [tonnes CO_2-e / annum] CO_2	CH_4	N_2O	Total
RAMP-DOWN - SCOPE 1 EMISSIONS					
Fuel Combustion	Stationary engines (gas engines + drilling)	1,809,196	7,081	1,062	**1,817,339**
	Vehicles	13,150	38	95	**13,283**
Fugitive Emissions	Transmission	60	26,065	-	**26,125**
	Facility-level fugitive emissions	4	224,646	-	**224,649**
	Pilot lights & flaring due to upset conditions	-	860	-	**860**
	Well workovers	475,234	56,420	5,208	**536,862**
RAMP-DOWN - SCOPE 2 EMISSIONS					
Energy Consumption	Electricity consumption – wellheads [c]	305,229	-	-	**305,229**
RAMP-DOWN - SCOPE 3 EMISSIONS					
Energy Consumption/ Production	End-use (gas)	15,947,316	62,416	9,362	**16,019,094**
	Full fuel cycle (diesel) [c]	1,007	-	-	**1,007**
	Full fuel cycle (electricity) [c]	44,584	-	-	**44,584**
	Third party infrastructure - CSG transmission to Arrow LNG Plant	18	8,035	-	**8,054**
	Third party infrastructure - CSG downstream processing	3,807,504	434,987	2,026	4,244,517
TOTAL SCOPE 1 EMISSIONS		**2,297,643**	**315,110**	**6,365**	**2,619,118**
TOTAL SCOPE 2 EMISSIONS [c]		**305,229**			**305,229**
TOTAL SCOPE 3 EMISSIONS		**19,799,377**	**505,435**	**11,388**	**20,316,199**
OVERALL		**22,402,249**	**820,545**	**17,753**	**23,240,547**

Notes:

a. Calculated based on activity data and emission estimation techniques detailed in Appendix A.

b. Annual emissions estimates are also provided in Appendix A.

c. Scope 2 and scope 3 emissions are presented as CO_2 emissions while they are in fact a combination of CO_2, CH_4 and N_2O emissions (i.e. emission factors expressed as CO_2-e only).

4.4 Summary of Emissions

Table 10 summarises the greenhouse gas emission estimates that will be generated during each phase of the Arrow Surat Gas Project. The emission estimates are only provided for the worst-case year for each phase, which is the year that generates the highest emissions (refer to section 4). Year 2030 is estimated to generate the highest emissions during the life of the project and is therefore selected as the reference year when comparing greenhouse gas emission estimates from the Arrow Surat Gas Project to local or global greenhouse gas emissions (refer to section 5.1).

Table 10: Greenhouse Gas Emissions by Scope Associated with the Arrow Surat Gas Project

Project Phase	Worst-Case Year Selected	Greenhouse Gas Emissions [t CO_2-e / annum]			
		Scope 1	Scope 2	Scope 3	Total
Ramp-up period (2014 - 2019)	Year 2019	2,361,663	216,467	18,413,406	**20,991,537**
Operational period (2020 - 2039)	Year 2030	2,807,044	678,053	23,095,897	**26,580,994**
Ramp-down period (2040 - 2047)	Year 2040	2,619,118	305,229	20,316,199	**23,240,547**

4.5 Uncertainty Associated with the Arrow Surat Gas Project

The Terms of Reference for the Arrow Surat Gas Project EIS requires an assessment of uncertainty associated with:

- timing of future development; and
- nature and location of future infrastructure.

An assessment of information quality is also required to consider:

- how recent the information is;
- how any background studies were taken (i.e. intensity of field work);
- how the reliability of the information was tested; and
- what uncertainties are present in the information (if any).

The location of emission sources is not a critical aspect of greenhouse gas emission estimation, as the ultimate impacts are not dependant on the location of the emission sources. Therefore, uncertainty in source locations will not have an effect on the project's emissions, and will not be discussed further.

The nature of future infrastructure and operational practices will impact the potential greenhouse gas emissions. However, in the case of the Arrow Surat Gas Project, the intended infrastructure and operations are not expected to change significantly over time. The design of the integrated processing facilities and other infrastructure is largely complete with respect to greenhouse gas emissions sources, and large changes would be impractical. As such, uncertainty in the nature of future infrastructure and operational practices will not have a significant effect on the project's emissions, and will not be discussed further.

The timing of future development may impact upon the estimated emissions from the project, as temporal change in the activity data used for forecasting can be difficult to predict. Currently the estimates include the expected ramp-up of gas production over the resource areas Arrow intends to develop. However, the starting dates for developing each resource area are subject to change, and will be determined by the development and productivity of the previous resource areas.

Table 11 presents the uncertainty related to the key emission sources of the project.

Table 11: Uncertainty Related to Key Emission Sources

Source	Key Input Data Subject to Change	Uncertainty
End-use of gas	Forecast gas production	Unproven reserve forecasts have been used as the basis of these estimates. Production will be affected by numerous factors that are difficult to predict.
Wellhead surface facilities	Forecast gas production	Unproven reserve forecasts have been used as the basis of these estimates. Production will be affected by numerous factors that are difficult to predict.
Fugitive emissions from production and processing	Forecast gas production	Unproven reserve forecasts have been used as the basis of these estimates. Production will be affected by numerous factors that are difficult to predict.
Exploration and pilot wells	Number of wells drilled	The actual number of wells required by the project will be determined by the results of exploration programs and the performance of existing and future production wells.

Arrow will be required to report the project's greenhouse gas emissions from the facilities under the NGER Act. Through this reporting, Arrow must understand and estimate the uncertainties associated with the emission factors used to estimate emissions. From 2011, businesses that report to NGER will be required to report the uncertainty associated with emissions estimates in accordance with national reporting guidelines.

5 IMPACT OF GREENHOUSE GAS EMISSIONS FROM THE ARROW SURAT GAS PROJECT

5.1 Potential Impacts

According to the IPPC, global surface temperature has increased by 0.74 ± 0.18ºC during the 100 years ending 2005, and that: *"most of the observed increase in globally averaged temperatures since the mid-twentieth century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations"* (IPCC, 2007a). "Very likely" is defined as greater than 90% probability of occurrence (IPCC, 2007a).

Climate change is a global occurrence. The degree to which climate change occurs and the associated impacts will vary worldwide. The most recent and authoritative work in predicting the future impacts of global greenhouse gas emissions on Australian climate patterns and the Australian economy is the Garnaut Climate Change Review (Garnaut, 2008).

The Garnaut Review builds on the climate change modelling undertaken by the CSIRO, and global greenhouse gas emissions scenarios developed by the IPCC. It also builds on previous attempts to quantify the social and economic impacts of climate change, in particular, the Stern Review on the Economics of Climate Change, which was prepared for the British Government and released in October 2006 (Stern, 2006). The impacts associated with climate change predicted by the Garnaut Review are described in Appendix B. It should be noted that the Garnaut Review 2011 (Garnaut, 2011) does not provide an updated set of predictions, only a reaffirmation of the 2008 predictions in the Australian context.

Attributing the potential impacts associated with climate change to a single source of greenhouse gas emissions is problematic. The potential impacts associated with greenhouse gas emissions from the Arrow Surat Gas Project will be in proportion with its contribution to global greenhouse gas emissions. The aggregate scope 1 and scope 2 emissions from the Arrow Surat Gas Project associated with the worst case scenario for each period of the life of the project were calculated. These emissions seem to be insignificant in comparison with Global 2007 fossil fuel consumption emissions (i.e., 0.012% for worst-case operational year (i.e., 2030)). When compared with Australia's 2007 emissions for the energy sector, the Arrow Surat Gas Project is equivalent to 0.85% of Australia's total emissions for worst-case operational year (see Table 12). Australia's total emission inventory in 2007 represents approximately 1.4% of global greenhouse gas emissions. Therefore the potential impacts associated with climate change directly attributable to the Arrow Surat Gas Project can be expected to be negligible.

Table 12: Estimates of Greenhouse Gas Emissions

Geographic Coverage	Source Coverage	Timescale	Emissions (Mt CO_2-e)
Global [a]	Consumption of fossil fuels	2007	29,335
Australia [b]	Energy sector	2007	408.2
Queensland [c]	Total greenhouse gas emissions including Land Use, Land Use Change and Forestry (LULUCF) activities	2007	181.6
Surat Gas Project [d]	**Scope 1 emissions (Year 2030) [d]**	**Estimated annual**	**2.8**
	Scope 2 emissions (Year 2030) [d]	**Estimated annual**	**0.7**
	Scope 1 & 2 emissions (Year 2030)	**Estimated annual**	**3.5**

a. UNSD (2011)

b. Section 2, DCCEE (2009a) - Energy sector includes stationary energy, transport and fugitive emissions.

c. DCCEE (2009c) - Emissions including land use change.

d. Refer to Table 8.

5.2 Residual Impacts

Implementing abatement measures (refer to Section 7) could reduce direct greenhouse gas emissions from the Arrow Surat Gas Project. Given that the potential impacts of greenhouse gas emissions from the Arrow Surat Gas Project's current design are negligible in a global context, the residual impact after implementing the abatement measures will also be negligible when considered globally.

6 BENCHMARKING COAL SEAM GAS

6.1 Emissions per GJ of Fuel Produced

Scope 3 emission factors published in NGA Factors (DCCEE, 2010f) provide average values for the quantity of greenhouse gas emissions (expressed as kg CO_2-e) per GigaJoule (GJ) of fuel produced. In other words, this measure relates to the *amount of emissions produced during the process of extracting, producing and transporting the fuel*. It does not relate to the emissions from the *end use* of the fuel.

A comparison of the emissions per GJ of fuel produced, between gas from Arrow's gas fields, and other fossil fuels can be seen in Table 13. The process of producing coal seam gas (i.e., the process of extracting and processing the gas ready for sale) holds higher emission values than the average values for producing (i.e., extracting and processing ready for sale) black and brown coal, and natural gas.

It should be noted that the Arrow Surat Gas Project includes significant energy requirements for reverse osmosis water treatment. The combustion of extracted gas to provide this energy is a significant contributor to the overall emission intensity of the project.

Gaseous fuels are generally associated with greater potential for fugitive emissions in comparison to other fuels. Therefore Arrow's coal seam gas production and natural gas production both have higher emissions from extraction than for coals.

Table 13: Emissions per GJ of Fuel Produced

Fuel	Emission Factor (kg CO_2-e / GJ)
Brown coal [a]	0.3
Black coal [b]	4.6
Coal seam gas/ natural gas [c]	7.8
Arrow Surat Gas Project Ramp-up (2019) [d]	8.2
Arrow Surat Gas Project Ramp-down (2040) [d]	9.4
Arrow Surat Gas Project Operational (2030) [d]	9.8
Coking coal [a]	20.7

a. Table 37, (DCCEE, 2010f).
b. Table 37, (DCCEE, 2010f) - for uses other than electricity and coking.
c. Table 38, (DCCEE, 2010f) - non-metro factors (Queensland) selected. Metro is defined as located on or east of the dividing range in NSW, including Canberra and Queanbeyan, Melbourne, Brisbane, Adelaide or Perth. Otherwise, the non-metro factor should be used (DCCEE, 2010f).
d. Based on worst case scope 1 and scope 2 emissions for the year indicated and the project's coal seam gas production rate of that year.

6.2 Greenhouse Gas Emissions Intensity of Coal Seam Gas

The most significant source of greenhouse gas emissions associated with the Arrow Surat Gas Project is the use of gas by end-users for energy production (scope 3 for this project).

Electricity sourced from gas has a significant advantage over other fossil fuels with respect to greenhouse gas emissions. The majority of Australia's electricity is currently produced by coal-fired power stations. Each unit of electricity generated from gas produces approximately 50 per cent lower full-cycle greenhouse gas emissions than conventional coal-fired electricity. Full cycle emissions account for the emissions associated with the extraction, production and transport of the fuel, and the emissions associated with combustion (Figure 2).

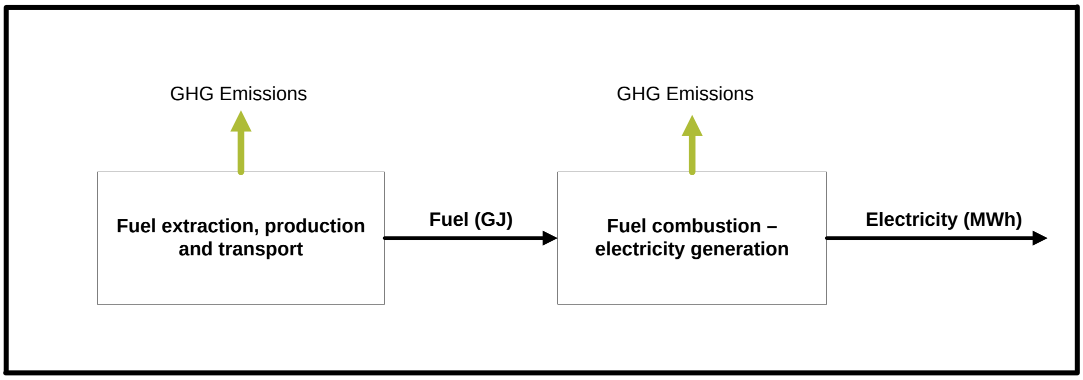

Figure 2: Full-Cycle Greenhouse Gas (GHG) Emissions Associated with Electricity Production

The low emissions of electricity generated from gas in comparison to coal, can be attributed to:

- Gas producing lower greenhouse gas emissions (expressed as kg CO_2-e) per unit of thermal energy produced by combustion; and
- Energy from gas combustion can be converted to electricity at a higher thermal efficiency.

6.3 Emissions per GJ Heat Produced from Combustion

Scope 1 and Scope 3 emission factors published in NGA Factors (DCCEE, 2010f) provide average values for the quantity of greenhouse gas emissions (expressed as kg CO_2-e) per GJ of fuel combusted. Coal seam gas and natural gas have significantly lower emissions per unit of energy released when combusted, in comparison to traditional fossil fuels, as presented in Figure 3.

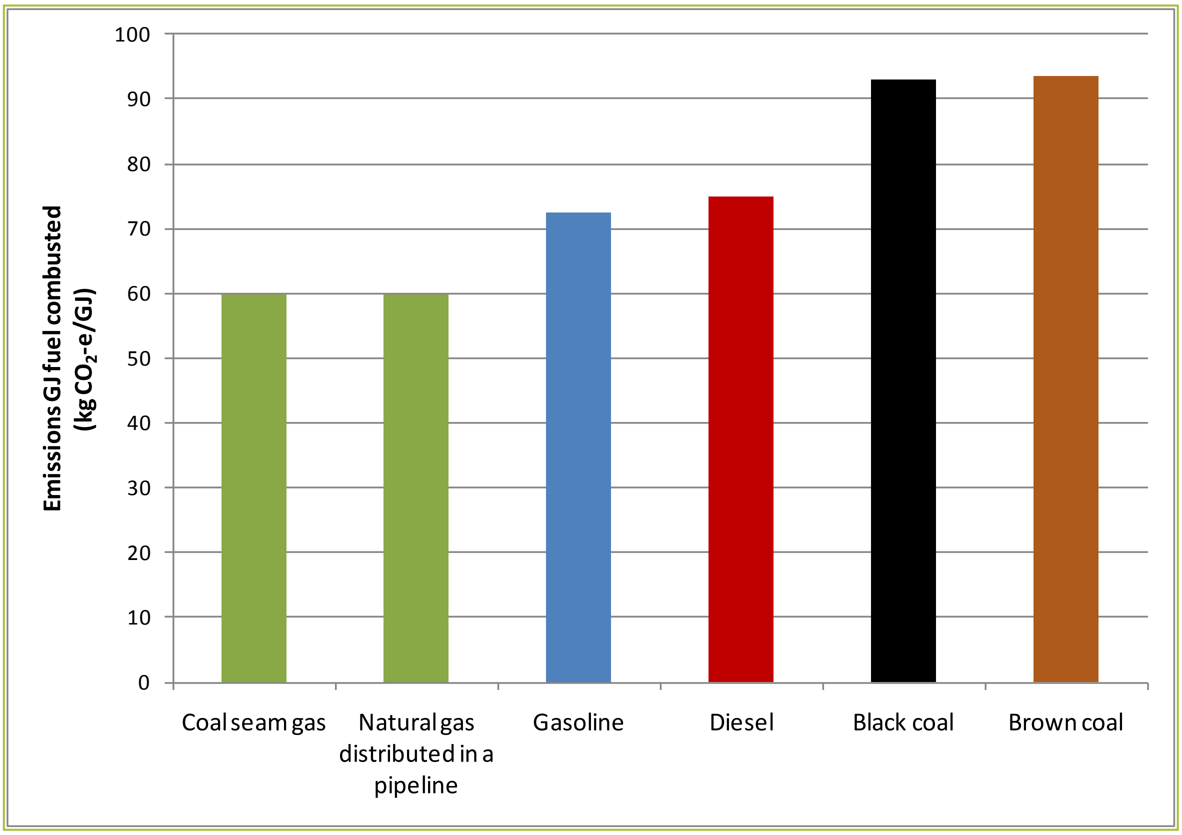

Figure 3: Aggregated Scope 1 and Scope 3 Emissions per GJ of Fuel Combusted

6.4 Emissions per MWh Electricity Sent Out

Full-cycle emissions per MWh of electricity sent out incorporate scope 1 and scope 3 emission factors and the thermal efficiency of the power cycle used to convert the heat produced from fuel combustion to electricity (Table 14). Based on Best Available Technology (BAT) standards for power cycle efficiencies (AGO, 2006), a gas-fired combined cycle gas turbine (GT) power configuration (in the absence of standards for gas engines) produces emissions per MWh sent out equal to:

- 46% of those produced by a brown coal-fired ultra super critical power station;
- 59% of those produced by a black coal-fired ultra super critical power station; and
- 64% of those produced by a gas-fired open cycle gas turbine.

Table 14: Scope 1 and Scope 3 Emissions per MWh of Electricity Sent Out

Power cycle	Fuel	$\eta_{thermal}$ [a] (%)	Scope 1 EF [b] (kg CO_2-e / GJ)	Scope 3 EF [b] (kg CO_2-e / GJ)	Emissions per MWh of Electricity [c] (kg CO_2-e / MWh)
USC - wet cooled	Brown coal	32.3	93.11	0.3 [d]	1,041
USC - wet cooled	Black coal	41.2	88.43	4.6 [d]	813
Open cycle GT	Gas	33.1	51.33	8.6 [e]	652
Combined cycle GT - wet cooled	Gas	51.6	51.33	8.6 [e]	418
Open cycle GT	Coal Seam Gas - Surat Gas Project [f]	33.1	48.83 [g]	7.9	617
Combined cycle GT - wet cooled	Coal Seam Gas – Surat Gas Project [f]	51.6	48.83 [g]	7.9	396

Note: USC – Ultra Super Critical; GT – Gas Turbine;

a. Thermal efficiencies based on Best Available Technology standards sourced from the Australian Greenhouse Office (AGO, 2006).

b. Table 1 and Table 2, DCCEE (2010f).

c. Based on 1MWh = 3.6GJ.

d. Table 37, DCCEE (2010f).

e. Table 38, DCCEE (2010f) – The metro emission factor for Queensland is used.

f. The scope 1 and scope 3 emissions used are associated with the base case scenario (i.e., integrated power generation). Please note that scope 1 emissions correspond to the direct emissions associated with combustion of coal seam gas by an end-user, while scope 3 emissions correspond to the indirect emissions associated with the extraction, production and transport of coal seam gas.

g. The site-specific Scope 1 emission factor was estimated based on the CSG composition (Coffey Environments, 2011a) using method 2 of division 2.3.3 of the *NGER Technical Guidelines* (DCCEE, 2010e). However, scope 1 emissions associated with the project were calculated based on the default emission factor provided in NGA (DCCEE, 2010f) for conservativeness purpose.

7 AVOIDANCE, MANAGEMENT AND MITIGATION MEASURES

7.1 Direct Emissions Reduction

Process features that could decrease emissions from the Arrow Surat Gas Project are detailed below. It should be noted that the decision to implement emission reduction technologies is usually weighed against economic viability and other aspects such as community concerns.

Arrow's greenhouse gas management strategy involves two approaches to reducing the company's greenhouse gas emissions. The first approach seeks to identify the company's major greenhouse gas emitting activities. This approach focuses on identifying measures to reduce greenhouse gas emissions from the various emissions sources in Arrow's areas of operation. The second approach involves mitigation measures that Arrow can implement on a company-wide basis or support in the communities in which it operates.

7.1.1 Project Activities

Arrow is committed to applying a hierarchy of controls in order to minimise environmental impact. Selection of equipment will be completed in regards to protecting environmental values. Equipment that results in environmental impact will be:

- avoided;
- substituted out; or
- have mitigations imposed to reduce the impact.

In order to determine what equipment should be installed for the project (and therefore what equipment should be avoided), equipment will be selected that provides:

- low source of noise emissions;
- low emissions to air (pollutants: NO_x, SO_x);
- high energy efficiency and fuel efficiency;
- low generation of waste;
- low greenhouse gas emissions;
- avoidance of ozone depleting substances;
- avoidance of particularly hazardous chemicals;
- low emissions of pollutants to water; and
- low water use.

The impact of the project's activities on environmental values will also be considered during site selection. Arrow is developing standard operating procedures to avoid or eliminate (i.e., "design out") potential impacts to environmental values, and to minimise to the greatest extent practicable any impacts that cannot be eliminate through design.

Across all of Arrow's Surat Gas Project activities, Arrow has committed to the mitigation measures listed in Table 15 to minimise greenhouse impacts. These measures are included in the Surat Gas Project Environmental Management Plan.

Table 15: Mitigation commitments

Project Phase	Mitigation Measures
Exploration and Appraisal	• Minimise land cleared for exploration activities by utilising already cleared areas where possible (e.g. exploration well leases and equipment lay-down areas). • Progressively rehabilitate disturbed areas through revegetation or mulching. • Selection of gaskets, seals and vehicle exhaust systems that are suitable for the task, and maintained according to manufacturer's recommendations. • Manufacturer's recommendations and guidelines with respect to air emissions are followed at all times. • Air pollution control technologies are to be maintained in good working order and kept in place at all times the equipment is operating. • Air emissions will be monitored at the source in accordance with Environmental Authority conditions. • Minimise flaring and eliminate venting of gas where possible.
Construction activities (production well, gathering line, production facilities, pipeline installation)	• Minimise land cleared for construction purposes (e.g. production well leases and equipment lay-down areas). • Progressively rehabilitate disturbed areas through revegetation or mulching. • Selection of gaskets, seals and vehicle exhaust systems that are suitable for the task, and maintained according to manufacturer's recommendations. • Manufacturer's recommendations and guidelines with respect to air emissions are followed at all times. • Air pollution control technologies are to be maintained in good working order and kept in place at all times the equipment is operating. • Minimise flaring and venting of gas where possible.
Operational Phase	• Implement a preventative maintenance program to ensure engines are operating efficiently to minimise CO, methane and VOC emissions. • Optimise gas engine operation to minimise time of operation at low efficiency levels that may result in elevated greenhouse gas or NO_X emissions. • Implement a quantifiable monitoring and measuring program. • Selection of gaskets, seals and vehicle exhaust systems that are suitable for the task, and maintained according to manufacturer's recommendations. • Manufacturer's recommendations and guidelines with respect to air emissions are followed at all times. • Air pollution control technologies are to be maintained in good working order and kept in place at all times the equipment is operating. • Equipment that deteriorates so that it no longer meets acceptable standards is to be shut down and intervention maintenance is to be conducted to return emissions to acceptable levels. Where practical, the equipment should not be brought back into service until normal operational emissions are achieved. • Minimise flaring and venting of gas where possible.
Decommissioning Phase	• Rehabilitate disturbed areas to the maximum extent possible through revegetation or mulching.
Vehicles and machinery	• Ensure all vehicles and machinery are fitted with appropriate emission control equipment, maintained frequently and serviced to the manufacturer's specifications.

7.1.2 Energy Efficiency and Offset Opportunities

Arrow will consider greenhouse gas emissions in the planning and preparation phase of the project, and impacts of greenhouse gas emissions will be reduced and mitigated. Measures relevant to energy efficiency are as follows:

- For the selection of all new equipment, energy efficiency and emissions to air are to be adequately addressed prior to procurement.

- Potential sources of greenhouse gas emissions and management strategies to reduce emissions must be communicated to relevant personnel.
- All plant and equipment are to be maintained as per manufacturer's standard, or other best practice guidelines, to ensure that all operations are conducted at maximum efficiency.
- Equipment that becomes significantly less efficient over the course of its operation is to be shut down and intervention maintenance is to be conducted to return emissions to acceptable levels. Where practical, it should not be brought back into service until normal operational emission levels are achieved.

Arrow also has opportunities to reduce its emissions through the support of energy efficiency programs and also investigating opportunities to offset greenhouse gas emissions produced by the company, its staff, and the communities in which it operates.

Measures explored by the company will include:

- Energy efficiency programs both locally and across the company that contribute to greenhouse gas emission reductions.
- Active participation in any government approved emissions trading scheme.
- Arrow will support gas industry initiatives that seek to improve technology or processes, such as contributions or sponsorship of research and development.
- Arrow will, through corporate community involvement programs, support the development of energy efficiency initiatives in the areas where it operates.

Due to the nature of greenhouse gas emissions from gas extraction, capture and direct sequestration of the emissions is not a viable option for the Surat Gas Project. However, Arrow is committed to exploring options for offsetting greenhouse gas emissions from the project. These options may include indirect sequestration through tree plantation, and carbon trading in recognised markets.

7.1.3 Renewable Energy

Renewable sources of energy, such as solar and wind power, could be considered to supplement gas-fired power generation. Utilising renewable energy would decrease gas consumption, decreasing greenhouse gas emissions and increasing gas production. However, given the amount of reliable renewable energy required in comparison to that able to be generated, it is unlikely to be significantly incorporated within the Arrow Surat Gas Project's total energy consumption. Renewable energy may only be feasible for small infrastructures such as wells and onsite offices (currently Arrow is considering switching wells to solar power where possible).

7.2 Emissions Offsetting Opportunities

Greenhouse gas emissions produced by the Arrow Surat Gas Project could be offset by investing in third party projects that reduce emissions below a demonstrated baseline. Examples of projects that reduce emissions are:

- forestry projects that reduce emissions by:
  - sequestering carbon through reforestation or afforestation;
  - prevent deforestation; or
  - increase the carbon contained in soils through soil management.

- renewable energy, such as wind farms, geothermal or solar; and
- destruction of methane produced from landfills, wastewater treatment plants etc.

7.3 Emissions Trading

Arrow Energy will be able to trade emission permits to meet their permitting liabilities during the second phase (i.e., cap and trade emissions trading scheme) of the proposed carbon price mechanism if their internal costs of abatement are higher than the price of permits, and to directly reduce their emissions if their internal costs of abatement are lower than the price of permits.

8 GREENHOUSE GAS AND ENERGY MANAGEMENT PLAN

8.1 Arrow Policies

In addition to mandatory commitments, such as greenhouse gas and energy reporting under NGER, Arrow Energy is developing a greenhouse gas standard as part of its integrated Health, Safety and Environmental Management System (HSEMS).

The environmental component of the HSEMS focuses on environmental aspects and potential environmental impacts and then integrates the environmental risks into the overall management plans to reduce the risk of these impacts. The intent of the risk management process and the management plans is to reduce the assessed risk to acceptable level.

Arrow Energy has numerous performance criteria that enable auditing of their adherence to their HSEMS, such as reducing the "Environmental Footprint" of the project where practicable, and considering energy and waste generation in all activities. A key tool in meeting Arrow Energy's performance criteria will be regular estimations of emissions that will help to keep track of emissions targets, and ensure that equipment is kept at acceptable standards.

8.2 Voluntary Initiatives

Arrow Energy recognises the challenges posed by climate change and intends to develop a greenhouse gas standard as part of its HSEMS. It is expected that the standard will cover items such as:

- Arrow Energy's commitment to reduce the greenhouse intensity of its operations;
- compliance with relevant greenhouse legislation on emissions reporting, energy efficiency and greenhouse management;
- targets, including their evaluation and reporting;
- preparing for the changes relating to carbon constraints; and
- venting and flaring commitments.

Arrow Energy supports the development of technologies and management practices that reduce greenhouse emissions and will maintain effective reporting and measurement systems. Furthermore, Arrow Energy will evaluate its greenhouse performance with respect to the design and selection of equipment for the project.

8.3 Mandatory Reporting

In addition to the voluntary initiatives detailed above, greenhouse gas emissions, energy usage and energy efficiency opportunities for the Arrow Surat Gas Project operations must be estimated and publicly reported under:

- NGERs (refer to Section 2.2.3); and
- the Energy Efficiency Opportunities Program (refer to Section 2.2.4).

9 CLIMATE CHANGE ADAPTATION

9.1 Climate Change Risks

This section assesses the significance of the impacts identified in Section 5 specifically for the Surat Gas Project. Table 16 lists the results of this assessment. For further description of each impact, please refer to Section 5.

Table 16: Climate Change-Related Impacts for the Surat Gas Project

Category	Impact	Implications	Risk	Applicable framework
Heatwaves	Temperature increase	Average temperature increases are not expected to impact project infrastructure significantly. However, the efficiency of power generation through gas engines can decrease with increasing ambient temperature. Frequency of extreme temperature events may require more frequent activation of workplace health and safety policies regarding working in hot weather and dehydration.	Low	Design specifications will include consideration of these potential impacts. It is expected that the project will not be impacted by changes to climate.
Rainfall	Decrease in precipitation	Decreases in average annual rainfall are not expected to impact the project significantly, as the process does not require a dedicated water supply.		
Extreme weather	Cyclones and storms	Increased intensity of storms (at the same or lower frequency) should be addressed in current designs for flood management, which are typically part of local planning schemes.		
Extreme fire weather	Bushfires	Increased frequencies of days of extreme fire weather should be addressed through existing bushfire management practices (which may need to be activated more frequently in future).		
Associated water storage	Increased evaporation	Increased evaporation rates from dams are not expected to impact the project adversely, as dedicated water supply is not required. Relevant evaporation rates are considered as part of the design of water treatment infrastructure of the project.		

As the project is not in a coastal area, the impacts related to ocean acidity and sea level rise on the project are considered insignificant. Impacts on agriculture and ecosystems due to climate change are not considered relevant to the project. While geopolitical stability in Asia Pacific and international trade are a driver for the project, climate change impacts on these aspects are not considered relevant within the lifespan of the project.

9.2 Adaptation Strategies

Table 16 shows that the impacts related to climate change for this project are considered low. However, the following issues may require ongoing management:

- Ongoing operational management of extreme temperatures.
- Design to address increased intensities of storm events in future.
- Small increases to water-related infrastructure for staff.

- Management procedures to address potential increase in frequency of bushfire events.

All of these issues will be examined during risk workshops conducted for the project, and will be taken into consideration during detailed design.

Arrow's environmental policy makes a public commitment to comply with local planning laws. Arrow's HSEMS includes the regular review of relevant environmental legislation, to ensure that this commitment is met.

Arrow's health and safety policy makes a similar commitment to comply with relevant occupational, health and safety legislation. The company's HSEMS aims for zero safety incidents and is designed for continuous improvement in the identification, monitoring and management of health and safety issues.

Design for storm events (e.g., flood planning), increased pressure on water-related infrastructure and bushfire management are assumed to be addressed via Arrow's commitment for ongoing compliance with relevant environmental regulations under its HSEMS. Management of the effects of extreme temperatures will be addressed through Arrow's commitment to compliance with occupational health and safety laws and the company's existing HSEMS.

10 CONCLUSIONS

This assessment describes the greenhouse gas emissions from the construction, operation and decommissioning of the Arrow Surat Gas Project, and predicts the impacts associated with these emissions.

Direct (scope 1) and indirect (scope 2) greenhouse gas emissions from the operation of the Arrow Surat Gas Project have been estimated to be 3.5 Mt CO_2-e/annum for worst-case operational year (i.e., 2030), with the majority of emissions associated with gas combustion. The worst-case scenario represents approximately 0.85% of Australia's 2007 greenhouse gas emission inventory.

The scope 1 and scope 2 greenhouse gas emissions associated with the worst case scenario from the Arrow Surat Gas Project are minor (approximately 13.1% of the total emissions) in comparison with scope 3 emissions, which are primarily due to greenhouse gas emissions associated with the end use of the product fuel. In comparison with other fossil fuels, particularly coal, combusting gas or LNG for heating purposes emits less greenhouse gas emissions per unit of thermal energy produced. If gas or LNG is combusted to produce electricity, the greenhouse gas reductions, when compared to other fossil fuels, are even greater, per MWh of electricity generated.

The impacts associated with the Arrow Surat Gas Project's greenhouse gas emissions, with respect to climate change, will be in proportion with the project's contribution to global greenhouse gas emissions. As such, the impacts are expected to be negligible.

However, a number of greenhouse gas emission mitigation measures have been included in the Arrow Surat Gas Project design, demonstrating that the Arrow Surat Gas Project utilises Best Available Technology (BAT). In addition, Arrow has committed to the ongoing measurement and monitoring of the Arrow Surat Gas Project's emissions and energy consumption, through a range of voluntary and mandatory schemes, including:

- a greenhouse gas standard as part of an integrated Health, Safety and Environmental Management System (HSEMS);
- the National Greenhouse and Energy Reporting System (NGERs); and
- the Energy Efficiency Opportunities Program (EEO).

While the Arrow Surat Gas Project utilises BAT and is producing a low emissions fossil fuel, it is recommended that Arrow continues to investigate greenhouse gas abatement measures. Such investigation is relevant for both ongoing monitoring and maintenance programs at the site-level, reducing fugitive emissions from equipment leaks, and new technologies, such as combined cycle power generation and carbon capture and storage, where viable.

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APPENDIX A

Greenhouse Gas Emission Estimation Methodology

A.1 GAS PRODUCTION ESTIMATION

Data was only provided for the time period 2013 - 2035. The cumulative total gas production and the number of production wells decommissioned were thus extrapolated for each of the remaining years of the project's life (i.e., 2036 until 2047) based on the following assumptions:

- The ramp-up period will last 6 years (i.e., from 2014 until 2019).
- The gas production plateau (i.e., 970 TJ/d) is expected to be sustained for 20 years (i.e., from 2020 until 2039).
- The decommissioning of the wells is expected to start in 2030 after 15 to 20 years of service while decommissioning of the facilities is expected to start in 2040 and finish in 2047.
- The decommissioning of the production wells and the facilities will occur in the same order as their commissioning.
- The gas production decay rate for the time period 2040-2047 will be proportional to the number of wells on-line. The cumulative total gas production for this period was estimated using the following equation:

$$P_{cum,y} = P_{cum,x=2039} \times \frac{N_{w,cum,y}}{N_{w,cum,x=2039}} \quad [1]$$

where:

$P_{cum,y}$	=	Cumulative total gas production for year y	(TJ/d)
$P_{cum,x=2039}$	=	Cumulative total gas production for year 2039	(TJ/d)
$N_{w,cum,y}$	=	Cumulative number of wells for year y	(-)
$N_{w,cum,x=2039}$	=	Cumulative number of wells for year 2039	(-)

The cumulative total gas production and the cumulative number of production wells on-line used for this assessment, which includes the data provided by Coffey Environment for years 2014 until 2035 and the extrapolated data for years 2036 until 2047, are provided in Table 17.

Table 17: Cumulative Total Gas Production and Cumulative Number of Wells On-Line

Year	Total Wells Commissioned for Year [a]	Total Wells Decommissioned for Year [b]	Cumulative Number of Wells for Year [c]	Cumulative Total Gas Production [a] (TJ/d) [a, b]	(TJ/a) [d]
2013	0	0	0	0	0
2014	174	0	174	0	0
2015	233	0	407	119	43,435
2016	365	0	772	300	109,500
2017	386	0	1,158	490	178,850
2018	497	0	1,655	676	246,740
2019	196	0	1,851	866	316,090
2020	456	0	2,307	970	354,050
2021	464	0	2,771	970	354,050
2022	382	0	3,153	970	354,050
2023	166	0	3,319	970	354,050
2024	351	0	3,670	970	354,050
2025	311	0	3,981	970	354,050
2026	305	0	4,286	970	354,050
2027	152	0	4,438	970	354,050
2028	440	0	4,878	970	354,050
2029	361	0	5,239	970	354,050
2030	733	174	5,798	970	354,050
2031	308	233	5,873	970	354,050
2032	0	365	5,508	970	354,050
2033	0	386	5,122	970	354,050
2034	0	497	4,625	970	354,050
2035	0	196	4,429	970	354,050
2036	0	456	3,973	970	354,050
2037	0	464	3,509	970	354,050
2038	0	382	3,127	970	354,050
2039	0	166	2,961	970	354,050
2040	0	351	2,610	855	312,081
2041	0	311	2,299	753	274,894
2042	0	305	1,994	653	238,425
2043	0	152	1,842	603	220,250
2044	0	440	1,402	459	167,639
2045	0	361	1,041	341	124,474
2046	0	733	308	101	36,828
2047	0	308	0	0	0

a. Table 2.1, Coffey Environments (2011c) – data provided for time period 2013-2035.

b. PAEHolmes' assumption: The figures were extrapolated for the time period 2036-2047 based on the assumptions listed above.

c. PAEHolmes' estimation.

d. PAEHolmes' estimation - based on the worst case scenario of 365 operating days a year.

A.2 COAL SEAM GAS (CSG) MASS BALANCE

As the total volume of processed gas has not been provided, a mass balance of gas flows (equation [2]) which includes production, use and fugitive emissions was completed to determine total fugitive emissions (refer to section A.5.2). Equations [3 - 5] were used to estimate all the gas flows used in equation [2]. The associated parameters are presented in Table 18 and the resulting gas flows for each year are presented in Table 19.

$$CSG_{in} = \frac{\{CSG_{out} + CSG_T + CSG_{Fu} + CSG_{Fl}\} \times \mathrm{EC_{ss}}}{\rho_{\mathrm{CSG}}} \quad [2]$$

where:

CSG_{in}	=	Total amount of processed CSG in the year	(TJ/a)
CSG_{out}	=	Total amount of CSG produced for export or domestic use in the year	(t/a)
CSG_T	=	Total leaks of CO_2 and CH_4 during transmission in the year	(t/a)
CSG_{Fu}	=	Total leaks of CO_2 and CH_4 from processing and gas field facilities (excluding wells workovers) in the year	(t/a)
CSG_{Fl}	=	Total amount of CSG flared (excluding ramp-up flaring) in the year (refer to Table 37 and Table 41)	(t/a)
$\mathrm{EC_{ss}}$	=	Site-specific energy content of CSG	(GJ/Sm^3 CSG)
ρ_{CSG}	=	Site-specific CSG density at standard conditions	(kg CSG/ Sm^3 CSG)

$$CSG_{out} = \frac{CSG_{out,E} \times \rho_{\mathrm{CSG}}}{\mathrm{EC_{ss}}} \quad [3]$$

where:

CSG_{out}	=	Total amount of CSG produced for export or domestic use in the year	(t CSG/a)
$CSG_{out,E}$	=	Total amount of CSG produced (energy) for export or domestic use in the year (refer to Table 17)	(TJ/a)
ρ_{CSG}	=	Site-specific CSG density at standard conditions	(kg CSG/Sm^3 CSG)
$\mathrm{EC_{ss}}$	=	Site-specific energy content of CSG	(GJ/Sm^3 CSG)

$$CSG_T = \frac{CSG_{T,CO_2}}{GWP_{CO_2}} + \frac{CSG_{T,CH_4}}{GWP_{CH_4}} \; [4]$$

where:

CSG_T	=	Total leaks of CO_2 and CH_4 during transmission in the year	(t/a)
CSG_{T,CO_2}	=	Total leaks of CO_2 during transmission in the year (refer to Table 51)	(t CO_2-e/a)
CSG_{T,CH_4}	=	Total leaks of CH_4 during transmission in the year (refer to Table 51)	(t CO_2-e/a)
GWP_{CO_2}	=	Global warming potential of CO_2	(t CO_2-e /t CO_2)
GWP_{CH_4}	=	Global warming potential of CH_4	(t CO_2-e /t CH_4)

$$CSG_{Fu} = \frac{CSG_{in} \times \left\{\frac{\%\mathrm{LW}}{100} \times \left\{\frac{\mathrm{mol\%}_{\mathrm{ss}\,(\mathrm{CO_2})}}{100} \times \mathrm{MW}_{\mathrm{CO_2}} + \frac{\mathrm{mol\%}_{\mathrm{ss}\,(\mathrm{CH_4})}}{100} \times \mathrm{MW}_{\mathrm{CH_4}}\right\} + \frac{\mathrm{EF}_{\mathrm{CH_4}}}{\mathrm{GWP}_{\mathrm{CH_4}}}\right\}}{\rho_{\mathrm{CSG}} \times \mathrm{V}} \; [5]$$

where:

CSG_{Fu}	=	Total leaks of CO_2 and CH_4 from processing and gas field facilities (excluding wells workovers) in the year	(t/a)
CSG_{in}	=	Total quantity of CSG processed in the year	(t CSG/a)
$\%\mathrm{LW}$	=	Percentage of gas losses from water gathering system	(%)
$\mathrm{mol\%}_{\mathrm{ss,j}}$	=	Site-specific mole percentage of gas j in CSG processed	(mol%)
$\mathrm{MW_j}$	=	Molecular weight of gas j	(kg /kmole)
$\mathrm{EF}_{\mathrm{CH_4}}$	=	Site-specific facility-level average emission factor for CH_4	(t CO_2-e/ t CSG processed)
$\mathrm{GWP}_{\mathrm{CH_4}}$	=	Global warming potential of CH_4	(t CO_2-e/t CH_4)
ρ_{CSG}	=	Site-specific CSG density at standard conditions	(kg CSG/ Sm^3 CSG)
V	=	Volume of 1 kilomole of the gas at standard conditions	(Sm^3/kmole)

Table 18: Parameters Associated with the Estimation of Processed Gas

Data Required	Value	Units
Site-specific coal seam gas density at standard conditions [a]	0.726	kg/Sm^3
Site-specific energy content factor [b]	0.03729	GJ/m^3
Global warming potential of CO_2 [c]	1	t CO_2-e/ t CO_2
Global warming potential of CH_4 [c]	21	t CO_2-e/ t CH_4
Percentage of gas losses from water gathering system [d]	0.01%	% of gas produced at wellhead
Site-specific CO_2 molar percentage of coal seam gas processed [e]	0.22	mol%
Site-specific CH_4 molar percentage of coal seam gas processed [e]	98.69	mol%
Molecular weight of CO_2 [f]	44.01	kg CO_2/kmole CO_2
Molecular weight of CH_4 [f]	16.043	kg CH_4/kmole CH_4
Site-specific CH_4 facility-level average fugitive emission factor associated with gas processing plants [g]	0.0339	t CO_2-e/ t coal seam gas processed
Volume of 1 kilomole of the gas at standard conditions [h]	23.6444	Sm^3/kmole

a. Coffey Environments (2011a) - based on an average real gas density (at 0°C and 1 atm) from existing facilities including Daandine (D-1), Kogan (K-1) and Tipton (T-1).

b. Coffey Environments (2011a) – based on an average real gross calorific value from existing facilities including Daandine (D-1), Kogan (K-1) and Tipton (T-1).

c. Appendix C, DCCEE (2010e).

d. From previous greenhouse assessment – refer to section A.5.2.1.

e. Coffey Environments (2011a) - based on an average molar composition from existing facilities including Daandine (D-1), Kogan (K-1) and Tipton (T-1).

f. Section 2.22 (3), DCCEE (2010e).

g. PAEHolmes' estimation based on the emission factors sourced from the API Compendium (2009) – refer to Table 43.

h. Section 2.22 (1), DCCEE (2010e).

Table 19: Coal Seam Gas (CSG) Mass Balance Inputs for Time Period (2013-2047)

Year	CSG Out (TJ/a) [a]	CSG Out (t/a)	CSG Transmission (t/a) [b]	CSG General Leaks (t/a) [c]	CSG Flaring (t/a) [d]	CSG In (t/a) [c]	CSG In (TJ/a) [e]
2013	0	0	0	0	0	0	0
2014	0	0	83	19	10,850	10,952	563
2015	43,435	845,637	194	1,485	21,700	869,017	44,636
2016	109,500	2,131,858	369	3,706	32,550	2,168,483	111,381
2017	178,850	3,482,035	553	6,055	54,250	3,542,894	181,976
2018	246,740	4,803,788	801	8,337	65,101	4,878,026	250,553
2019	316,090	6,153,965	906	10,667	75,951	6,241,488	320,586
2020	354,050	6,893,009	1,124	11,969	97,651	7,003,753	359,738
2021	354,050	6,893,009	1,345	11,988	108,501	7,014,844	360,308
2022	354,050	6,893,009	1,528	12,007	119,351	7,025,895	360,876
2023	354,050	6,893,009	1,607	12,007	119,351	7,025,974	360,880
2024	354,050	6,893,009	1,775	12,008	119,351	7,026,142	360,888
2025	354,050	6,893,009	1,934	12,027	130,201	7,037,171	361,455
2026	354,050	6,893,009	2,080	12,027	130,201	7,037,317	361,462
2027	354,050	6,893,009	2,153	12,027	130,201	7,037,390	361,466
2028	354,050	6,893,009	2,363	12,046	141,051	7,048,469	362,035
2029	354,050	6,893,009	2,546	12,065	151,901	7,059,521	362,603
2030	354,050	6,893,009	2,824	12,084	162,751	7,070,668	363,175
2031	354,050	6,893,009	2,860	12,102	173,601	7,081,573	363,735
2032	354,050	6,893,009	2,686	12,102	173,601	7,081,398	363,726
2033	354,050	6,893,009	2,512	12,120	184,452	7,092,093	364,276
2034	354,050	6,893,009	2,275	12,120	184,452	7,091,855	364,263
2035	354,050	6,893,009	2,181	12,138	195,302	7,102,630	364,817
2036	354,050	6,893,009	1,963	12,138	195,302	7,102,412	364,806
2037	354,050	6,893,009	1,741	12,138	195,302	7,102,190	364,794
2038	354,050	6,893,009	1,559	12,137	195,302	7,102,007	364,785
2039	354,050	6,893,009	1,480	12,137	195,302	7,101,927	364,781
2040	312,081	6,075,904	1,301	10,701	173,601	6,261,508	321,614
2041	274,894	5,351,917	1,142	9,424	151,901	5,514,384	283,239
2042	238,425	4,641,898	996	8,171	130,201	4,781,266	245,583
2043	220,250	4,288,052	923	7,528	108,501	4,405,005	226,257
2044	167,639	3,263,762	702	5,737	86,801	3,357,002	172,428
2045	124,474	2,423,378	508	4,261	65,101	2,493,248	128,062
2046	36,828	717,003	147	1,283	32,550	750,984	38,573
2047	0	0	0	0	0	0	0

a. Refer to Table 17.
b. Refer to Table 51 and equation [4].
c. PAEHolmes' estimation from mass balance over CSG.
d. Refer to Table 37 and Table 41.
e. PAEHolmes' estimation - based on energy content factor (refer to Table 18).

A.3 SCOPE 1 EMISSIONS – CONSTRUCTION, OPERATION AND DECOMMISSIONING

A.3.1 Fuel Combustion – Gas for Power Generation

During operation, a portion (i.e., 10%) of the maximum gas produced (i.e., 970 TJ/d) will be used as fuel gas for combustion in gas engines to provide power to the production wells, compression and water treatment facilities. Power generation stations may consist of large high-speed reciprocating gas engine generators sized at 2 or 3 MW each, incorporating lean burn technology to achieve efficiency in excess of 40%, which involves engine emission control.

As construction, operation and decommissioning will occur simultaneously, it is assumed that the 10% fuel gas usage (i.e., 97 TJ/d) will cover construction and decommissioning activities power requirement.

Emissions of CO_2, CH_4 and N_2O were estimated using Method 1 (Division 2.4.2, *Method 1-emissions of carbon dioxide, methane and nitrous oxide from liquid fuels other than petroleum based oils or greases,* of the *Technical Guidelines* (DCCEE, 2010e)):

$$E_j = \frac{Q \times EF_{joxec}}{1000} \quad [6]$$

where:

E_j	=	Estimated emissions of gas type (j) from gas combustion	(t CO_2-e/a)
Q	=	Estimated quantity of gas combusted in stationary engines in the year	(GJ/a)
EF_{joxec}	=	Emission factor for each gas type (j)	(kg CO_2-e/GJ)

The default emission factor associated with coal seam gas for each gas were sourced from Table 2.3.2A of the *Technical Guidelines* (DCCEE, 2010e) and are listed in Table 20. Equation [7] was used to calculate the quantity of gas combusted in stationary engines. The activity data associated with gas combusted for power generation and the resulting greenhouse gas emission estimates are presented in Table 21 and Table 22, respectively.

All the estimates are presented to the nearest tonne, in accordance with Australian greenhouse reporting convention, but should only be considered reliable to two significant figures.

Table 20: Emission Factors Associated with Gas Combusted in Stationary Engines for Construction, Operation and Decommissioning Power

Method Used	Constant	Value	Units
Method 1	Scope 1 default CO_2 emission factor [a]	51.1	kg CO_2-e/ GJ
Method 1	Scope 1 default CH_4 emission factor [a]	0.2	
Method 1	Scope 1 default N_2O emission factor [a]	0.03	
Method 1	Scope 1 overall emission factor [b]	51.33	

a. Table 2.3.2A, DCCEE (2010e)
b. PAEHolmes' estimation

$$Q = \frac{\%FG}{100} \times Q_{max} \times N_{od} \times 1000 \; [7]$$

where:

Q	=	Estimated quantity of gas combusted in stationary engines in the year	(GJ/a)
$\%FG$	=	Percentage of power required as fuel gas	(%)
Q_{max}	=	Gas production plateau	(TJ/day)
N_{od}	=	Number of operating days	(days/a)

Table 21: Activity Data Associated with Gas Combusted in Stationary Engines for Construction, Operation and Decommissioning Power

Data Required	Value	Units
Percentage of power required as fuel gas [a]	10	%
Gas production plateau [a]	970	TJ/days
Number of operating days [b]	365	days/a
Quantity of gas combusted in stationary engines in the year [c]	35,405,000	GJ/a
Annual quantity of energy consumed [c]	35	PJ/a

a. Section 1.5, Coffey Environments (2011c).
b. PAEHolmes' assumption – worst case scenario.
c. PAEHolmes' estimation.

Table 22: Greenhouse Gas Emissions Associated with Gas Combusted in Stationary Engines for Construction, Operation and Decommissioning Power

Description	Scope 1 Emissions (t CO_2-e / annum)			
	CO_2	CH_4	N_2O	Total CO_2-e
Annual emissions (2014 - 2047)	1,809,196	7,081	1,062	**1,817,339**
Total emissions for construction or operation (for time period 2014 - 2039)	47,039,083	184,106	27,616	**47,250,805**
Total emissions for decommissioning (for time period 2040 - 2047)	14,473,564	56,648	8,497	**14,538,709**
Total emissions (for time period 2014 - 2047)	**61,512,647**	**240,754**	**36,113**	**61,789,514**

A.3.2 Fuel Combustion – Diesel Used in Vehicles for Transport and Construction Energy

As the production wells, processing plants and other infrastructure required to be constructed for the extraction of gas are spread over large areas of land, the construction workforce will have to travel large distances. As a result, a significant quantity of diesel is expected to be used in passenger vehicles (i.e., light vehicles) for transport. Diesel will also be consumed in industrial vehicles (i.e., heavy vehicles) for construction, operation, maintenance and decommissioning of the facilities and associated infrastructure.

The activities likely to generate traffic and the specific types of vehicles selected for this project are summarised in Section 2 of the *Transport Assumptions Report* within the *Road Impact Assessment* (Cardno Eppell Olsen, 2011). Light vehicles have been classified as sedans, wagons, vans, utilities, 4WDs and motorcycles while anything other type of vehicle has been considered a HV (heavy vehicle) for the purposes of this estimate (Cardno Eppell Olsen, 2011).

Emissions of CO_2, CH_4 and N_2O were estimated using Method 1 (Division 2.4.2, *Method 1- emissions of carbon dioxide, methane and nitrous oxide from liquid fuels other than petroleum based oils or greases,* of the *Technical Guidelines* (DCCEE, 2010e)):

$$E_j = \frac{Q \times EC \times EF_{joxec}}{1000} \quad [8]$$

where:

E_j	=	Estimated emissions of gas type (j) from diesel combustion	(t CO_2-e/a)
Q	=	Estimated quantity of diesel combusted in light or heavy vehicles in the year	(kL/a)
EC	=	Energy content factor of diesel	(GJ/kL)
EF_{joxec}	=	Emission factor for each gas type (j)	(kg CO_2-e/GJ)

The composition of diesel oil is relatively consistent throughout Australia, and therefore the default emission factors are sufficient. The default energy content factor for diesel and the default emission factor for each gas were sourced from Table 2.4.2B, of the *Technical Guidelines* (DCCEE, 2010e) and are listed in Table 23. Equation [9] was used to calculate the quantity of diesel used in light and heavy vehicles and the associated parameters are listed in Table 24. The activity data associated with diesel combusted in light and heavy vehicles and the resulting greenhouse gas emission estimates are presented in Table 25 and Table 26, respectively.

Table 23: Energy Content Factor and Emission Factors Associated with Diesel Combusted in Light and Heavy Vehicles for Construction, Operation, Maintenance and Decommissioning Activities

Method Used	Constant	Value	Units
-	Default energy content factor [a]	38.6	GJ/kL
Method 1	Scope 1 default CO_2 emission factor [a]	69.2	kg CO_2-e/ GJ
Method 1	Scope 1 default CH_4 emission factor [a]	0.2	
Method 1	Scope 1 default N_2O emission factor [a]	0.5	
Method 1	Scope 1 overall emission factor [b]	69.9	

a. Table 2.4.2B, DCCEE (2010e).
b. PAEHolmes' estimation.

$$Q = \frac{D \times R_C}{1000} \quad [9]$$

where:

Q	=	Estimated quantity of diesel combusted in light or heavy vehicles in the year	(kL/a)
D	=	Total kilometres travelled in the year	(km/a)
R_C	=	Average rate of diesel consumption of light or heavy vehicles	(L/km)

Table 24: Parameters Associated with Diesel Combusted in Vehicles Estimation

Data Required	Value	Units
Average rate of diesel consumption of passenger vehicles (light vehicles) [a]	0.123	L/km
Average rate of diesel consumption of articulated trucks (heavy vehicles) [b]	0.559	L/km

a. ABS (2008) – PAEHolmes' assumption: the rate of fuel consumption for passenger vehicles was selected to represent the light vehicles. Passenger vehicles are defined as motor vehicles constructed primarily for the carriage of persons and containing up to nine seats (including the driver's seat). Included are cars, station wagons, four-wheel drive passenger vehicles, passenger vans or mini buses with fewer than 10 seats and campervans.

b. ABS (2008) – PAEHolmes' assumption: as a conservative approach, the rate of fuel consumption for articulated trucks was selected to represent the heavy vehicles (i.e., higher fuel consumption per kilometre).

Table 25: Activity Data Associated with Diesel Combusted in Light and Heavy Vehicles for Construction, Operation, Maintenance and Decommissioning Activities

Year	Light Vehicles		Heavy Vehicles	
	Total kilometres travelled for year (km) [a]	Total fuel consumption for year (kL) [b]	Total kilometres travelled for year (km) [a]	Total fuel consumption for year (kL) [b]
2013	279,000	34	539,000	301
2014	2,609,000	321	2,125,000	1,188
2015	4,305,000	530	2,675,000	1,495
2016	4,263,000	524	2,262,000	1,264
2017	6,784,000	834	3,439,000	1,922
2018	5,927,000	729	2,924,000	1,635
2019	5,311,000	653	2,027,000	1,133
2020	10,432,000	1,283	7,226,000	4,039
2021	6,844,000	842	2,821,000	1,577
2022	8,374,000	1,030	4,825,000	2,697
2023	7,736,000	952	2,530,000	1,414
2024	11,927,000	1,467	6,795,000	3,798
2025	8,726,000	1,073	4,193,000	2,344
2026	10,056,000	1,237	5,458,000	3,051
2027	9,170,000	1,128	5,223,000	2,920
2028	12,092,000	1,487	6,648,000	3,716
2029	12,517,000	1,540	7,544,000	4,217
2030	11,091,000	1,364	7,206,000	4,028
2031	13,617,000	1,675	9,531,000	5,328
2032	14,913,000	1,834	9,536,000	5,331
2033	16,345,000	2,010	9,488,000	5,304
2034	17,747,000	2,183	10,285,000	5,749
2035	18,880,000	2,322	10,250,000	5,730
2036	14,216,000	1,749	8,352,000	4,669
2037	13,942,000	1,715	8,192,000	4,579
2038	13,636,000	1,677	8,030,000	4,489
2039	12,338,000	1,518	6,953,000	3,887
2040	11,938,000	1,468	6,180,000	3,455
2041	10,939,000	1,345	6,627,000	3,704
2042	9,677,000	1,190	5,714,000	3,194
2043	9,725,000	1,196	6,176,000	3,452
2044	9,138,000	1,124	5,529,000	3,091
2045	8,582,000	1,056	5,121,000	2,863
2046	7,441,000	915	3,809,000	2,129
2047	6,997,000	861	3,787,000	2,117
Total for time period 2013 - 2047	**348,514,000**	**42,867**	**200,020,000**	**111,811**

a. Coffey Environments (2011f) - The VKT estimate includes all travel within the project area to Toowoomba including brine transportation.
b. PAEHolmes' estimation.

Table 26: Greenhouse Gas Emissions Associated with Diesel Combusted in Light and Heavy Vehicles for Construction, Operation, Maintenance and Decommissioning Activities

Year	Scope 1 Emissions (t CO_2-e / annum)			
	CO_2	CH_4	N_2O	Total CO_2-e
2013	896	3	6	**906**
2014	4,030	12	29	**4,071**
2015	5,409	16	39	**5,463**
2016	4,778	14	35	**4,826**
2017	7,364	21	53	**7,438**
2018	6,313	18	46	**6,377**
2019	4,772	14	34	**4,820**
2020	14,217	41	103	**14,361**
2021	6,461	19	47	**6,526**
2022	9,956	29	72	**10,056**
2023	6,319	18	46	**6,383**
2024	14,065	41	102	**14,207**
2025	9,128	26	66	**9,220**
2026	11,454	33	83	**11,569**
2027	10,812	31	78	**10,921**
2028	13,899	40	100	**14,040**
2029	15,377	44	111	**15,532**
2030	14,404	42	104	**14,549**
2031	18,705	54	135	**18,894**
2032	19,138	55	138	**19,332**
2033	19,537	56	141	**19,735**
2034	21,188	61	153	**21,402**
2035	21,508	62	155	**21,725**
2036	17,141	50	124	**17,315**
2037	16,813	49	121	**16,983**
2038	16,470	48	119	**16,637**
2039	14,436	42	104	**14,582**
2040	13,150	38	95	**13,283**
2041	13,489	39	97	**13,626**
2042	11,711	34	85	**11,830**
2043	12,417	36	90	**12,542**
2044	11,258	33	81	**11,372**
2045	10,466	30	76	**10,572**
2046	8,132	24	59	**8,214**
2047	7,953	23	57	**8,034**
Total emissions for time period 2013 - 2047	**413,165**	**1,194**	**2,985**	**417,344**

A.4 SCOPE 1 EMISSIONS – CONSTRUCTION

A.4.1 Fugitive Emissions – Ramp-Up Flaring

During exploration activities, Arrow must flare gas occasionally for safety reasons. Gas is also flared locally or accumulated and flared at the facility when new wells are drilled until the associated facility is commissioned.

Emissions of CO_2, CH_4 and N_2O were estimated using Method 1 (Division 3.44, *Method 1- oil or gas exploration,* of the *Technical Guidelines* (DCCEE, 2010e)):

$$E_j = Q \times EF_j \text{ [10]}$$

where:

E_j	=	Emissions of gas type (j) from coal seam gas flared in the gas exploration in the year	(t CO_2-e/a)
Q	=	Quantity of coal seam gas flared in the year	(t CSG flared/a)
EF_j	=	Scope 1 default emission factor for gas type (j)	(t CO_2-e/t CSG flared)

The site-specific energy content factor for coal seam gas was provided by Coffey Environments and the default emission factor for each gas were sourced from Section 3.44 (*Technical Guidelines* (DCCEE, 2010e)) and are listed in Table 27. Equation [11] was used to calculate the quantity of gas flared and the associated parameters are presented in Table 28. The activity data associated with ramp-up flaring and the resulting greenhouse gas emission estimates are presented in Table 29 and Table 30, respectively.

Table 27: Energy Content Factor and Emission Factors Associated with Ramp-Up Flaring

Method Used	Constant	Value	Units
-	Site-specific energy content factor [a]	0.03729	GJ/m^3
Method 1	Scope 1 default CO_2 emission factor [b]	2.8	t CO_2-e/t gas flared
Method 1	Scope 1 default CH_4 emission factor [b]	0.7	
Method 1	Scope 1 default N_2O emission factor [b]	0.03	
Method 1	Scope 1 overall emission factor [c]	3.53	

a. Coffey Environments (2011a) – based on an average real gross calorific value from existing facilities including Daandine (D-1), Kogan (K-1) and Tipton (T-1).
b. Section 3.44, DCCEE (2010e).
c. PAEHolmes' estimation.

$$Q = \frac{Q_E \times \rho_{CSG}}{EC_{ss}} \text{ [11]}$$

where:

Q	=	Quantity of gas flared in the year	(t CSG flared/a)
Q_E	=	Quantity of gas (energy) flared in the year	(TJ/a)
ρ_{CSG}	=	Gas density at standard conditions	(kg CSG/Sm^3 CSG)
EC_{ss}	=	Site-specific energy content of gas	(GJ/Sm^3 CSG)

Table 28: Parameters Associated with the Estimation of the Quantity of Gas Flared

Data Required	Value	Units
Coal seam gas density at standard conditions [a]	0.726	kg/Sm^3

a. Coffey Environments (2011a) - based on an average real gas density (at 0°C and 1 atm) from existing facilities including Daandine (D-1), Kogan (K-1) and Tipton (T-1).

Table 29: Activity Data Associated with Gas Ramp-Up Flaring

Year	Facility [a]	Total amount of gas flared (TJ/annum) [b]	Total amount of gas flared (t/annum) [c]
2014	N1CGPF1	218	4,244
2014	N1IPF1	357	6,950
2015	C1CGPF1	1,945	37,867
2016	N1CGPF2	349	6,795
2016	C1IPF1	732	14,251
2018	C1IPF2	1,077	20,968
2020	C2IPF1	878	17,094
2022	N2CGPF1	203	3,952
2022	N2IPF1	207	4,030
2028	C2CGPF1	3,623	70,536
2030	SIPF1	360	7,009
2030	SCGPF1	240	4,673
Total amount of gas flared for time period 2014 - 2030	**All CGPFs**	**6,578**	**128,067**
	All IPFs	**3,611**	**70,303**

a. Coffey Environments (2011b) - it is assumed that wells will not be brought online adjacent to FCFs until it is commissioned; hence no gas will be flared at an FCF during field ramp up.
b. Coffey Environments (2011b) - 3 months of flaring required prior to facility commissioning based on drilling commencing 6 months prior, 1st month for completions and, 2nd and 3rd month for dewatering only.
c. PAEHolmes' estimation.

Table 30: Greenhouse Gas Emissions Associated with Gas Ramp-Up Flaring

Year	Facility	Scope 1 Emissions (t CO_2-e/annum)			
		CO_2	CH_4	N_2O	Total CO_2-e
2014	N1CGPF1	11,884	2,971	127	**14,982**
2014	N1IPF1	19,461	4,865	209	**24,535**
2015	C1CGPF1	106,028	26,507	1,136	**133,671**
2016	N1CGPF2	19,025	4,756	204	**23,985**
2016	C1IPF1	39,904	9,976	428	**50,307**
2018	C1IPF2	58,711	14,678	629	**74,018**
2020	C2IPF1	47,863	11,966	513	**60,341**
2022	N2CGPF1	11,066	2,767	119	**13,951**
2022	N2IPF1	11,284	2,821	121	**14,226**
2028	C2CGPF1	197,502	49,375	2,116	**248,993**
2030	SIPF1	19,625	4,906	210	**24,741**
2030	SCGPF1	13,083	3,271	140	**16,494**
Total emissions for time period 2014 - 2030	**All CGPFs**	**358,588**	**89,647**	**3,842**	**452,077**
	All IPFs	**196,847**	**49,212**	**2,109**	**248,168**
	All facilities	**555,436**	**138,859**	**5,951**	**700,246**

A.4.2 Vegetation Clearing

Clearing existing vegetation for the purposes of constructing project infrastructure will release an amount of stored carbon within the vegetation's biomass. Table 31 provides the emission factor used to calculate greenhouse gas emissions from this activity, sourced from the Australian Greenhouse Office (AGO).

Table 31: Emission Factor Associated with Vegetation Clearance

Constant	Value	Units
Default emission factor for vegetation clearance [a]	3.67	t CO_2-e/t carbon

a. AGO (1999, 2000, 2002 and 2003).

Greenhouse gas emissions due to vegetation clearance are calculated on a per hectare basis. For the purposes of this assessment, some assumptions have been made to obtain approximate emission factors for the vegetation clearance component of the Arrow Surat Gas Project. This information has been drawn from various technical reports (AGO, 1999, 2000, 2002 and 2003). One important assumption is that 50% of the biomass in an area is carbon. In reality this value differs between each species in the range of 40-50% (AGO, 2000).

As the precise locations for clearing of vegetation cannot be determined at this stage of the project, it is difficult to generate site-specific emission factors. If the areas to be cleared were known, the FullCAM model from the National Carbon Accounting Toolbox could be used to determine vegetation clearing emission factors. Instead, the general biomass densities that have been used by the Australian Greenhouse Office for land clearing inventory purposes will be used in this assessment. Of the three forest classes provided in Table 2.5 of "*Synthesis of Allometrics, Review of Root Biomass and Design of Future Woody Biomass Sampling Strategies*" (AGO, 2000), Open Forest has been deemed the most appropriate for this assessment. The biomass density presented (90 t/ha) corresponds well with values determined with the FullCAM model using benchmark plots modified with spatial data for the region. Table 32 summarises the estimated emissions from land clearing associated with different project activities. The resulting greenhouse gas emission estimates are presented in Table 33.

The estimated emissions of greenhouse gases over the life of the Surat Gas Project for vegetation clearing are approximately 987,740 t CO_2-e (refer to Table 33). These values do not take into account the planned rehabilitation of all areas cleared for project purposes and have been estimated conservatively. The bulk of these land clearing emissions are due to well installation, however Arrow are committed to rehabilitate the well areas to a nominal 10 m by 10 m area from the 85 m by 85 m clearance zone once drilling is complete.

Table 32: Activity Data Associated with Vegetation Clearance

Project Activity	Total Area Cleared per Activity (ha)	Biomass [a] (t/ha)	Carbon [b] (t/ha)	Total Carbon per Activity (t)	Total Emission per Activity [h] (t CO_2-e)
Well construction	0.72[c]	90	45	32.5	119.2
Field compression facility construction	0.5[d]			22.5	82.5
Central gas processing facility construction	15[e]			675	2,475
Integrated processing facility and associated dam construction	220[f]			900	3,300
Electricity sub-station construction	3[g]			135	495

a, Table 2.5, AGO (2000).

b. Assuming 50% of biomass is carbon.

c. Section 2.1, Coffey Environments (2011c) – based on a drilling lease of 85 m by 85 m.

d. Table 3.3, Coffey Environments (2011c) – based on an approximate land requirement of 100 m by 50 m.

e. Table 3.3, Coffey Environments (2011c) – based on an approximate land requirement of 600 m by 250 m.

f. Table 3.3, Coffey Environments (2011c) – based on an approximate land requirement of 800 m by 250 m for integrated processing facilities and 2km^2 for dams.

g. Table 3.3, Coffey Environments (2011c) – based on an approximate land requirement of 200 m by 150 m.

h. PAEHolmes' estimation – based on the emission factor listed in Table 31.

Table 33: Estimated Greenhouse Gas Emissions Associated with Vegetation Clearance

Year	Wells (t CO_2-e / a)	Field Compression Facilities (t CO_2-e / a)	Central Gas Processing Facilities (t CO_2-e / a)	Integrated Processing Facilities and Dams (t CO_2-e / a)	Sub Stations (t CO_2-e / a)	Total (t CO_2-e / a)
2013	0	0	0	0	0	0
2014	20,743	0	0	36,300	495	57,538
2015	27,777	0	0	36,300	495	64,572
2016	43,513	0	2,475	36,300	990	83,278
2017	46,016	0	2,475	0	495	48,986
2018	59,249	83	0	0	0	59,331
2019	23,366	83	2,475	0	495	26,418
2020	54,361	0	0	36,300	495	91,156
2021	55,315	0	0	36,300	495	92,110
2022	45,539	0	2,475	0	495	48,509
2023	19,789	0	0	0	0	19,789
2024	41,844	0	0	0	0	41,844
2025	37,075	83	0	0	0	37,158
2026	36,360	0	0	0	0	36,360
2027	18,120	0	0	0	0	18,120
2028	52,454	0	2,475	0	495	55,424
2029	43,036	83	0	0	0	43,118
2030	87,383	83	0	0	0	87,465
2031	36,717	0	0	36,300	495	73,512
2032	0	0	0	0	0	0
2033	0	83	0	0	0	83
2034	0	0	0	0	0	0
2035	0	0	2,475	0	495	2,970
2036	0	0	0	0	0	0
2037	0	0	0	0	0	0

Year	Wells (t CO_2-e / a)	Field Compression Facilities (t CO_2-e / a)	Central Gas Processing Facilities (t CO_2-e / a)	Integrated Processing Facilities and Dams (t CO_2-e / a)	Sub Stations (t CO_2-e / a)	Total (t CO_2-e / a)
2038	0	0	0	0	0	0
2039	0	0	0	0	0	0
2040	0	0	0	0	0	0
2041	0	0	0	0	0	0
2042	0	0	0	0	0	0
2043	0	0	0	0	0	0
2044	0	0	0	0	0	0
2045	0	0	0	0	0	0
2046	0	0	0	0	0	0
2047	0	0	0	0	0	0
Total emissions for time period 2013 - 2047	**748,655**	**495**	**14,850**	**217,800**	**5,445**	**987,740**

A.5 SCOPE 1 EMISSIONS – OPERATION

A.5.1 Fugitive Emissions – Exploration and Process Flaring

A.5.1.1 Fugitive Emissions - Pilot Flaring

Flaring will not be used at Arrow Surat Gas for continuous disposal of process gas; instead, gas will be used by neighbouring facilities and for power requirements at construction camps where possible. However, under normal operating conditions the pilot flares will be continuously lit to ensure its readiness state should there be an event due to upset conditions.

Emissions of CO_2, CH_4 and N_2O from gas flared at processing facilities (i.e., IPF and CGPF) were estimated using Method 1 (Division 3.3.9, *Method 1- gas flared from natural gas production and processing)* while emissions of CO_2, CH_4 and N_2O from gas flared at gas field facilities (i.e., FCF) were estimated using Method 1 (Division 3.44, *Method 1- oil or gas exploration),* both sourced from the *Technical Guidelines* (DCCEE, 2010e). The following equation applies to both flaring type:

$$E_j = Q \times EF_j \ [12]$$

where:

E_j	=	Emissions of gas type (j) from coal seam gas flared in the year	(t CO_2-e/a)
Q	=	Quantity of coal seam gas flared in the year	(t CSG flared/a)
EF_j	=	Scope 1 emission factor for gas type (j)	(t CO_2-e/ t CSG flared)

The site-specific energy content factor for coal seam gas was provided by Coffey Environments and the default emission factor for each gas was sourced from Section 3.44 for exploration flaring and Section 3.85 for processing flaring (*Technical Guidelines* (DCCEE, 2010e)), and are listed in Table 34. Equation [13] was used to calculate the quantity of gas flared for the time period 2014-2039. The activity data associated with pilot flaring are presented in Table 35 and Table 36. The resulting greenhouse gas emission estimates are presented in Table 37.

Table 34: Energy Content Factor and Emission Factors Associated with Pilot Flaring

Category	Method Used	Constant	Value	Units
Both	-	Site-specific energy content factor [a]	0.03729	GJ/m^3
Exploration flaring	Method 1	Scope 1 default CO_2 emission factor [b]	2.8	t CO_2-e/t gas flared
		Scope 1 default CH_4 emission factor [b]	0.7	
		Scope 1 default N_2O emission factor [b]	0.03	
		Scope 1 overall emission factor [c]	3.53	
Production or processing flaring	Method 1	Scope 1 default CO_2 emission factor [d]	2.7	t CO_2-e/t gas flared
		Scope 1 default CH_4 emission factor [d]	0.1	
		Scope 1 default N_2O emission factor [d]	0.03	
		Scope 1 overall emission factor [c]	2.83	

a. Coffey Environments (2011a) – based on an average real gross calorific value from existing facilities including Daandine (D-1), Kogan (K-1) and Tipton (T-1).
b. Section 3.44, DCCEE (2010e).
c. PAEHolmes' estimation.
d. Section 3.85, DCCEE (2010e).

$$Q_{2014-2039} = \frac{R \times N_f \times D \times \rho_{CSG}}{EC_{ss}} \ [13]$$

where:

$Q_{2014-2039}$	=	Quantity of gas flared (associated with pilot flaring) in the year	(t CSG flared/a)
R	=	Flare pilot light rate	(TJ/day/facility)
D	=	Duration of pilot flaring	(days/a)
N_f	=	Number of processing or gas field facilities on-line	(facilities)
ρ_{CSG}	=	Site-specific coal seam gas density at standard conditions	(kg CSG/Sm^3 CSG)
EC_{ss}	=	Site-specific energy content factor of coal seam gas	(GJ/Sm^3)

Table 35: Activity Data Associated with Pilot Flaring (1)

Data Required	Value	Units
Site-specific gas density at standard conditions [a]	0.726	kg CSG/Sm^3 CSG
Flare pilot light rate per facility [b]	0.02	TJ/d/facility
Duration of pilot flaring [c]	365	days/a
Total energy flared per facility - pilot flaring [d]	7	TJ/a/facility

a. Coffey Environments (2011a) - based on an average real gas density (at 0°C and 1 atm) from existing facilities including Daandine (D-1), Kogan (K-1) and Tipton (T-1).
b. Table 3.1, Coffey Environments (2011c) – Flare pilot light rate between 0.005 and 0.02 TJ/d/facility. The maximum rate was used.
c. PAEHolmes' assumption: worst case scenario.
d. PAEHolmes' estimation.

Table 36: Activity Data Associated with Pilot Flaring (2)

Year	Facility [a]	Number of processing facilities	Number of gas field facilities	Total amount of gas flared at the processing facilities [b] (t / a)	Total amount of gas flared at the gas field facilities [b] (t / a)
2013	-	0	0	0	0
2014	Wandoan IPF1	1	0	142	0
2015	Dalby IPF2	2	0	284	0
2016	Wandoan CGPF1	3	0	426	0
	Dalby IPF1	4	0	568	0
2017	Wandoan CGPF2	5	0	711	0
2018	Dalby FCF1	5	1	711	142
2019	Dalby CGPF1	6	1	853	142
	Millmerran FCF2	6	2	853	284
2020	Millmerran IPF1	7	2	995	284
2021	Chinchilla IPF1	8	2	1,137	284
2022	Chinchilla CPGF1	9	2	1,279	284
2023	-	9	2	1,279	284
2024	-	9	2	1,279	284
2025	Millmerran FCF3	9	3	1,279	426
2026	-	9	3	1,279	426
2027	-	9	3	1,279	426
2028	Millmerran CGPF1	10	3	1,421	426
2029	Millmerran FCF4	10	4	1,421	568
2030	Millmerran FCF1	10	5	1,421	711
2031	Goondiwindi IPF1	11	5	1,563	711
2032	-	11	5	1,563	711
2033	Goondiwindi FCF1	11	6	1,563	853
2034	-	11	6	1,563	853

Year	Facility [a]	Number of processing facilities	Number of gas field facilities	Total amount of gas flared at the processing facilities [b] (t/a)	Total amount of gas flared at the gas field facilities [b] (t/a)
2035	Goondiwindi CGPF1	12	6	1,705	853
2036	-	12	6	1,705	853
2037	-	12	6	1,705	853
2038	-	12	6	1,705	853
2039	-	12	6	1,705	853
2040	Wandoan IPF1/Dalby IPF2	10	6	1,421	853
2041	Wandoan CGPF1/Dalby IPF1	8	6	1,137	853
2042	Wandoan CGPF2/Dalby FCF1	7	5	995	711
2043	Dalby CGPF1/Millmerran FCF2	6	4	853	568
2044	Millmerran IPF1/Chinchilla IPF1	4	4	568	568
2045	Chinchilla CPGF1/Millmerran FCF3	3	3	426	426
2046	Millmerran CGPF1/Millmerran FCF4/Millmerran FCF1	2	1	284	142
2047	Goondiwindi IPF1/Goondiwindi FCF1/Goondiwindi CGPF1	0	0	0	0
Total for time period 2013 - 2047	-	-	-	**39,084**	**16,486**

a. The timeline associated with the commissioning of the facilities were only provided until 2035. PAEHolmes' assumption: As decommissioning of the facilities is assumed to start in 2040, the order at which facilities will be decommissioned between 2040 and 2047 was assumed to be the same as their commissioning.

b. PAEHolmes' estimation.

Table 37: Greenhouse Gas Emissions Associated with Pilot Flaring

Year	Scope 1 Emissions (t CO_2-e / annum)			
	CO_2	CH_4	N_2O	Total CO_2-e
2013	0	0	0	**0**
2014	384	14	4	**402**
2015	767	28	9	**804**
2016	1,535	57	17	**1,609**
2017	1,919	71	21	**2,011**
2018	2,317	171	26	**2,513**
2019	3,098	284	34	**3,417**
2020	3,482	298	38	**3,819**
2021	3,866	313	43	**4,221**
2022	4,250	327	47	**4,623**
2023	4,250	327	47	**4,623**
2024	4,250	327	47	**4,623**
2025	4,647	426	51	**5,125**
2026	4,647	426	51	**5,125**
2027	4,647	426	51	**5,125**
2028	5,031	441	55	**5,527**
2029	5,429	540	60	**6,029**
2030	5,827	640	64	**6,531**
2031	6,211	654	68	**6,933**
2032	6,211	654	68	**6,933**
2033	6,609	753	72	**7,435**
2034	6,609	753	72	**7,435**
2035	6,992	767	77	**7,837**
2036	6,992	767	77	**7,837**
2037	6,992	767	77	**7,837**
2038	6,992	767	77	**7,837**
2039	6,992	767	77	**7,837**
2040	6,225	739	68	**7,032**
2041	5,458	711	60	**6,228**
2042	4,676	597	51	**5,324**
2043	3,894	483	43	**4,420**
2044	3,127	455	34	**3,616**
2045	2,345	341	26	**2,712**
2046	1,165	128	13	**1,306**
2047	0	0	0	**0**
Total emissions for time period 2013 - 2047	**147,837**	**15,221**	**1,624**	**164,683**

A.5.1.2 Fugitive Emissions - Flaring due to Upset Conditions

During operation, flaring is one of the potential strategies for gas field management at all the Surat facilities for the following events:

- Unscheduled trips associated with upset conditions e.g. equipment or process malfunction;
- upset conditions at Arrow's LNG Plant; and
- scheduled trips associated with maintenance.

Emissions of CO_2, CH_4 and N_2O were estimated using Method 1 (Division 3.3.9, *Method 1- gas flared from natural gas production and processing,* of the *Technical Guidelines* (DCCEE, 2010e)):

$$E_j = Q \times EF_j \quad [14]$$

where:

E_j	=	Emissions of gas type (j) from process coal seam gas flared in the year	(t CO_2-e/a)
Q	=	Quantity of coal seam gas flared in the year	(t CSG flared/a)
EF_j	=	Scope 1 emission factor for gas type (j)	(t CO_2-e/ t CSG flared)

The site-specific energy content factor for coal seam gas was provided by Coffey Environments and the default emission factor for each gas were sourced from Section 3.44 for exploration flaring and Section 3.85 for production or processing flaring (*Technical Guidelines* (DCCEE, 2010e)), and are listed in Table 38. Equation [15] was used to calculate the quantity of gas flared for the time period 2014-2039. The activity data associated with emergency and maintenance flaring is presented in Table 39 and Table 40. The resulting greenhouse gas emission estimates are presented in Table 41.

Table 38: Energy Content Factor and Emission Factors Associated with Flaring due to Upset Conditions

Category	Method Used	Constant	Value	Units
Both	-	Site-specific energy content factor [a]	0.03729	GJ/m^3
Exploration flaring	Method 1	Scope 1 default CO_2 emission factor [b]	2.8	t CO_2-e/t CSG flared
		Scope 1 default CH_4 emission factor [b]	0.7	
		Scope 1 default N_2O emission factor [b]	0.03	
		Scope 1 overall emission factor [c]	3.53	
Flaring due to upset conditions (during production or processing)	Method 1	Scope 1 default CO_2 emission factor [d]	2.7	t CO_2-e/t CSG flared
		Scope 1 default CH_4 emission factor [d]	0.1	
		Scope 1 default N_2O emission factor [d]	0.03	
		Scope 1 overall emission factor [c]	2.83	

a. Coffey Environments (2011a) – based on an average real gross calorific value from existing facilities including Daandine (D-1), Kogan (K-1) and Tipton (T-1).
b. Section 3.44, DCCEE (2010e).
c. PAEHolmes' estimation.
d. Section 3.85, DCCEE (2010e).

$$Q_{2014-2039} = \frac{FC \times N \times D \times N_f \times \rho_{CSG}}{EC_{ss}} \quad [15]$$

where:

$Q_{2014-2039}$	=	Quantity of coal seam gas flared (associated with upset conditions) in the year	(t CSG flared/a)
FC	=	Flaring capacity per facility	(TJ/day/facility)
N	=	Number of occurrences of the event	(-)
D	=	Duration of flaring event per facility	(days/a)
N_f	=	Number of processing or gas field facilities	(facilities)
ρ_{CSG}	=	Site-specific coal seam gas density at standard conditions	(kg CSG/Sm^3 CSG)
EC_{ss}	=	Site-specific energy content factor of coal seam gas	(GJ/Sm^3)

Table 39: Activity Data Associated with Flaring due to Upset Conditions (1)

Data Required	Value	Units
Coal seam gas density at standard conditions [a]	0.726	kg CSG/Sm^3 CSG
Flaring capacity per facility - Event 1 [b]	150	TJ/d/facility
Number of occurrences - Event 1 [b]	1	-
Duration of flaring per facility - Event 1 [b]	1	day/a
Total energy flared per facility - Event 1 [c]	150	TJ/a/facility
Flaring capacity per facility - Event 2 [b]	30	TJ/d/facility
Number of occurrences - Event 2 [b]	2	-
Duration of flaring per facility - Event 2 [b, d]	4	day/a
Total energy flared per facility - Event 2 [c]	240	TJ/a/facility
Flaring capacity per facility - Event 3 [b]	10	TJ/d/facility
Number of occurrences - Event 3 [b]	4	-
Duration of flaring per facility - Event 3 [b, d]	4	day/a
Total energy flared per facility - Event 3 [c]	160	TJ/a/facility

a. Coffey Environments (2011a) - based on an average real gas density (at 0°C and 1 atm) from existing facilities including Daandine (D-1), Kogan (K-1) and Tipton (T-1).

b. Section 3.2.3, Coffey Environments (2011d) – expected maximum (i.e., worst case) flaring frequencies due to upset conditions at each facility.

c. PAEHolmes' estimation.

d. PAEHolmes' estimation – based on 8 hours/month (Coffey Environments, 2011d).

Table 40: Activity Data Associated with Flaring due to Upset Conditions (2)

Year	Facility [a]	Number of processing facilities	Number of gas field facilities	Total amount of gas flared at the processing facilities [b] (t/a)	Total amount of gas flared at the gas field facilities [b] (t/a)
2013	-	0	0	0	0
2014	Wandoan IPF1	1	0	10,708	0
2015	Dalby IPF2	2	0	21,416	0
2016	Wandoan CGPF1	3	0	32,124	0
	Dalby IPF1	4	0	42,832	0
2017	Wandoan CGPF2	5	0	53,540	0
2018	Dalby FCF1	5	1	53,540	10,708
2019	Dalby CGPF1	6	1	64,248	10,708
	Millmerran FCF2	6	2	64,248	21,416
2020	Millmerran IPF1	7	2	74,956	21,416
2021	Chinchilla IPF1	8	2	85,664	21,416
2022	Chinchilla CPGF1	9	2	96,372	21,416
2023	-	9	2	96,372	21,416
2024	-	9	2	96,372	21,416
2025	Millmerran FCF3	9	3	96,372	32,124
2026	-	9	3	96,372	32,124
2027	-	9	3	96,372	32,124
2028	Millmerran CGPF1	10	3	107,080	32,124
2029	Millmerran FCF4	10	4	107,080	42,832
2030	Millmerran FCF1	10	5	107,080	53,540
2031	Goondiwindi IPF1	11	5	117,788	53,540
2032	-	11	5	117,788	53,540
2033	Goondiwindi FCF1	11	6	117,788	64,248
2034	-	11	6	117,788	64,248

Year	Facility [a]	Number of processing facilities	Number of gas field facilities	Total amount of gas flared at the processing facilities [b] (t/a)	Total amount of gas flared at the gas field facilities [b] (t/a)
2035	Goondiwindi CGPF1	12	6	128,496	64,248
2036	-	12	6	128,496	64,248
2037	-	12	6	128,496	64,248
2038	-	12	6	128,496	64,248
2039	-	12	6	128,496	64,248
2040	Wandoan IPF1/Dalby IPF2	10	6	107,080	64,248
2041	Wandoan CGPF1/Dalby IPF1	8	6	85,664	64,248
2042	Wandoan CGPF2/Dalby FCF1	7	5	74,956	53,540
2043	Dalby CGPF1/Millmerran FCF2	6	4	64,248	42,832
2044	Millmerran IPF1/Chinchilla IPF1	4	4	42,832	42,832
2045	Chinchilla CPGF1/Millmerran FCF3	3	3	32,124	32,124
2046	Millmerran CGPF1/Millmerran FCF4/Millmerran FCF1	2	1	21,416	10,708
2047	Goondiwindi IPF1/Goondiwindi FCF1/Goondiwindi CGPF1	0	0	0	0
Total for time period 2013 - 2047	-	-	-	**2,944,690**	**1,242,124**

a. The timeline associated with the commissioning of the facilities were only provided until 2035. PAEHolmes' assumption: As decommissioning of the facilities is assumed to start in 2040, the order at which facilities will be decommissioned between 2040 and 2047 was assumed to be the same as their commissioning.

b. PAEHolmes' estimation.

Table 41: Greenhouse Gas Emissions Associated with Flaring due to Upset Conditions

Year	Scope 1 Emissions (t CO_2-e / annum)			
	CO_2	CH_4	N_2O	Total CO_2-e
2013	0	0	0	**0**
2014	28,912	1,071	321	**30,304**
2015	57,823	2,142	642	**60,607**
2016	115,646	4,283	1,285	**121,214**
2017	144,558	5,354	1,606	**151,518**
2018	174,540	12,850	1,927	**189,317**
2019	233,434	21,416	2,570	**257,419**
2020	262,345	22,487	2,891	**287,723**
2021	291,257	23,558	3,212	**318,027**
2022	320,168	24,628	3,534	**348,330**
2023	320,168	24,628	3,534	**348,330**
2024	320,168	24,628	3,534	**348,330**
2025	350,150	32,124	3,855	**386,129**
2026	350,150	32,124	3,855	**386,129**
2027	350,150	32,124	3,855	**386,129**
2028	379,062	33,195	4,176	**416,433**
2029	409,044	40,690	4,497	**454,232**
2030	439,027	48,186	4,819	**492,031**
2031	467,938	49,257	5,140	**522,335**
2032	467,938	49,257	5,140	**522,335**
2033	497,920	56,752	5,461	**560,134**
2034	497,920	56,752	5,461	**560,134**
2035	526,832	57,823	5,782	**590,437**
2036	526,832	57,823	5,782	**590,437**
2037	526,832	57,823	5,782	**590,437**
2038	526,832	57,823	5,782	**590,437**
2039	526,832	57,823	5,782	**590,437**
2040	469,009	55,681	5,140	**529,830**
2041	411,186	53,540	4,497	**469,223**
2042	352,292	44,973	3,855	**401,120**
2043	293,398	36,407	3,212	**333,018**
2044	235,575	34,265	2,570	**272,411**
2045	176,681	25,699	1,927	**204,308**
2046	87,805	9,637	964	**98,406**
2047	0	0	0	**0**
Total emissions for time period 2013 - 2047	**11,138,425**	**1,146,823**	**122,392**	**12,407,640**

A.5.2 Fugitive Emissions – Facility-Level Fugitive Emissions from Production and Processing, and Transmission

A.5.2.1 Facility-Level Fugitives from Production and Processing

Methane is the primary greenhouse gas in fugitive leak emissions from processing and compression. Three methods are available to estimate fugitive leaks (other than venting and flaring) from natural gas production or processing:

- The emission factor (in tonnes CO_2-e/ tonne gas processed) for methane from general leaks in the natural gas production or processing sourced from the *Technical Guidelines* (DCCEE, 2010e).
- The facility-level average fugitive emission factor (in tonnes CH_4/ Sm^3 gas processed) associated with gas processing plants sourced from the *American Petroleum Institute Compendium* (API, 2009) – this default emission factor was derived by combining component emission measurements and activity factors for a "typical" facility.
- The facility-level average fugitive emission factor (in tonnes CH_4/ Sm^3 gas processed) associated with onshore gas production sourced from the *API Compendium* (API, 2009).

Equation [16] was used to convert the API default facility-level average fugitive emission factors to site-specific emission factors and the associated parameters are presented in Table 42. The comparison of the three available emission factors associated with general leaks is presented in Table 43. The selected emission factors and assumption used in the estimation of fugitive emissions from processing and gas field facilities are presented in Table 44.

$$EF_{ss(CH_4)} = \frac{EF_{d(CH_4)} \times \frac{mol\%_{ss\,(CH_4)}}{mol\%_{d\,(CH_4)}} \times GWP_{CH_4}}{\rho_{CSG}} \times 1000 \quad [16]$$

where:

$EF_{ss(CH_4)}$	=	Site-Specific CH_4 facility-level average fugitive emission factor	(t CO_2-e/t CSG processed)
$EF_{d(CH_4)}$	=	Default CH_4 facility-level average fugitive emission factor	(t CH_4/Sm^3 CSG processed)
$mol\%_{ss\,(CH_4)}$	=	Site-specific CH_4 mole percentage of gas processed	(mol%)
$mol\%_{d\,(CH_4)}$	=	Default CH_4 mole percentage of gas processed	(mol%)
GWP_{CH_4}	=	Global warming potential of CH_4	(t CO_2-e/ t CH_4)
ρ_{CSG}	=	Coal seam gas density at standard conditions	(kg CSG/ Sm^3 CSG)

Table 42: Parameters for Facility-Level Fugitive Emission Factors (Site-Specific) Estimation

Data Description	Value	Units
Site-specific CH_4 molar percentage of coal seam gas processed [a]	98.69	mol%
Global warming potential of CH_4 [b]	21	t CO_2-e/ t CH_4
Coal seam gas density at standard conditions [c]	0.726	kg/ Sm^3 CSG
Default CH_4 facility-level average fugitive emission factor associated with gas processing plants (at standard conditions) [d]	1.03×10^{-6}	t CH_4/ Sm^3 CSG processed
Default CH_4 mole percentage of coal seam gas processed [d]	86.8	mol%
Default CH_4 facility-level average fugitive emission factor associated with onshore gas production (at standard conditions) [d]	9.184×10^{-7}	t CH_4/ Sm^3 CSG processed
Default CH_4 molar percentage of coal seam gas processed [d]	78.8	mol%

a. Coffey Environments (2011a) - based on an average molar composition from existing facilities including Daandine (D-1), Kogan (K-1) and Tipton (T-1).
b. Appendix C, DCCEE (2010e).
c. Coffey Environments (2011a) - based on an average real gas density (at 0°C and 1 atm) from existing facilities including Daandine (D-1), Kogan (K-1) and Tipton (T-1).
d. Table 6-2, API (2009).

Table 43: Facility-Level Fugitive Emission Factors Comparison

Data Description	Value	Units
Default CH_4 emission factor for general leaks [a]	0.0012	t CO_2-e/ t CSG processed
Site-specific CH_4 facility-level average fugitive emission factor associated with gas processing plants (at standard conditions) [b]	0.0339	
Site-specific CH_4 facility-level average fugitive emission factor associated with onshore gas production (at standard conditions) [b]	0.0333	

a. Section 3.72 (1) of the *Technical Guidelines*, DCCEE (2010e).
b. PAEHolmes' estimation based on the emission factors sourced from the API Compendium (2009).

According to the American Petroleum Institute of Greenhouse Gas Emissions Methodologies for the Oil and Natural Gas Industry Compendium (API, 2009), applying average facility-level emission factors is the simplest method for estimating CH_4 emissions from oil and natural gas operation. While these emission factors are not directly related to the gas industry, it is the best available method for forecasting emissions from production facilities (i.e., field compression facilities) and processing facilities (i.e., integrated processing facilities and central gas processing facilities) for this project.
It is assumed that the API Compendium emission factor associated with gas processing plants covers all fugitive emissions from gas processing and compression. On the other hand, the API Compendium emission factor associated with onshore gas production includes leaks from the following equipment:

- gas wells;
- heaters;
- separators;
- small reciprocating compressors;
- meters/piping; and
- pipelines.

Table 43 shows that the facility-level average fugitive emission factor associated with gas processing plants sourced from the API Compendium is the most conservative option as its use will result in higher emissions. This emission factor will be used to estimate emissions associated with facility-level leaks for all the facilities.

Arrow will use a mix of downhole and surface separators on wells to prevent inefficient loss of entrained gas in the water gathering system. Typically, 5% of gas produced from the well will come out in the water stream. By applying downhole and surface separators, 80 % of this 5 % will be captured (i.e., 4 % of gas produced from well that has come out in water stream will be captured and 1 % will be lost into the gathering system). Of the gas lost to the gathering system, 99% is captured in high point valves and returned to the gathering system (resulting in 0.01% of gas produced from the well escaping as saturated gas).
For conservativeness purpose, these losses based on site-specific data will be included in the estimation of fugitive emissions for both processing and gas field facilities, as extracted gas can by-pass gas field facilities.

Table 44: Emission Factor and Assumption Used to Estimate Greenhouse Gas Fugitive Emissions from Processing and Gas Field Facilities.

Data Description	Value	Units
Site-specific CH_4 facility-level average fugitive emission factor associated with gas processing plants [a]	0.0359	t CO_2-e/ t CSG processed
Percentage of gas losses from water gathering system [b]	0.01%	% of gas produced at wellhead

a. PAEHolmes' estimation based on the emission factor sourced from the API Compendium (2009).
b. Refer to the paragraph above.

Emissions of CO_2 and CH_4 for both processing and gas field facilities were estimated using equation [17] and [18] respectively. The activity data associated with fugitive emissions from gas processing facilities and gas field facilities are presented in Table 45 and Table 46. The resulting greenhouse gas emission estimates are presented in Table 47.

$$E_{CO_2} = \frac{Q \times \frac{\%LW}{100} \times \frac{mol\%_{ss\,(CO_2)}}{100} \times MW_{CO_2} \times GWP_{CO_2}}{\rho_{CSG} \times V} \quad [17]$$

where:

E_{CO_2}	=	Emissions of CO_2-e from facility-level leaks of CO_2	(t CO_2-e/ a)
Q	=	Total quantity of gas processed in the year	(t CSG/a)
$\%LW$	=	Percentage of gas losses from water gathering system	(%)
$mol\%_{ss\,(CO_2)}$	=	Site-specific CO_2 molar percentage of gas processed	(mol%)
MW_{CO_2}	=	Molecular weight of CO_2	(kg CO_2/kmole CO_2)
GWP_{CO_2}	=	Global warming potential of CO_2	(t CO_2-e/t CO_2)
ρ_{CSG}	=	Site-specific coal seam gas density at standard conditions	(kg CSG/ Sm^3 CSG)
V	=	Volume of 1 kilomole of the gas at standard conditions	(Sm^3/kmole)

$$E_{CH_4} = \frac{Q \times \left[EF_{CH_4} + \frac{\%LW}{100} \times \frac{mol\%_{SS\,(CH_4)}}{100} \times MW_{CH_4} \times GWP_{CH_4}\right]}{\rho_{CSG} \times V} \quad [18]$$

where:

E_{CH_4}	=	Emissions of CO_2-e from facility-level leaks of CH_4	(t CO_2-e/ a)
Q	=	Total quantity of gas processed in the year	(t CSG/a)
EF_{CH_4}	=	Site-specific facility-level average emission factor for CH_4	(t CO_2-e/ t CSG processed)
%LW	=	Percentage of gas losses from water gathering system	(%)
$mol\%_{SS\,(CH_4)}$	=	Site-specific CH_4 molar percentage of gas processed	(mol%)
MW_{CH_4}	=	Molecular weight of CH_4	(kg CH_4/kmole CH_4)
GWP_{CH_4}	=	Global warming potential of CH_4	(t CO_2-e/t CH_4)
ρ_{CSG}	=	Site-specific gas density at standard conditions	(kg CSG/ Sm^3 CSG)
V	=	Volume of 1 kilomole of the gas at standard conditions	(Sm^3/kmole)

Table 45: Activity Data Associated with Facility-Level Fugitive Emissions from Gas Production and Processing (1)

Data Required	Value	Units
Site-specific CO_2 mole percentage of gas processed [a]	0.22	mol%
Site-specific CH_4 mole percentage of gas processed [a]	98.69	mol%
Molecular weight of CO_2 [b]	44.01	kg CO_2/kmole CO_2
Molecular weight of CH_4 [b]	16.043	kg CH_4/kmole CH_4
Global warming potential of CO_2 [c]	1	t CO_2-e/t CO_2
Global warming potential of CH_4 [c]	21	t CO_2-e/t CH_4
Site-specific gas density at standard conditions [d]	0.726	kg CSG/ Sm^3 CSG
Volume of 1 kilomole of the gas at standard conditions [e]	23.6444	Sm^3/kmole

a. Coffey Environments (2011a) - based on an average molar composition from existing facilities including Daandine (D-1), Kogan (K-1) and Tipton (T-1).

b. Section 2.22 (3), DCCEE (2010e).

c. Appendix C, DCCEE (2010e).

d. Coffey Environments (2011a) - based on an average real gas density (at 0°C and 1 atm) from existing facilities including Daandine (D-1), Kogan (K-1) and Tipton (T-1).

e. Section 2.22 (1), DCCEE (2010e).

Table 46: Activity Data Associated with Facility-Level Fugitives Emissions from Gas Production and Processing (2)

Year	Processing facilities cumulative installed capacity (t / a) [a]
2013	0
2014	10,952
2015	869,017
2016	2,168,483
2017	3,542,894
2018	4,878,026
2019	6,241,488
2020	7,003,753
2021	7,014,844
2022	7,025,895
2023	7,025,974
2024	7,026,142
2025	7,037,171
2026	7,037,317
2027	7,037,390
2028	7,048,469
2029	7,059,521
2030	7,070,668
2031	7,081,573
2032	7,081,398
2033	7,092,093
2034	7,091,855
2035	7,102,630
2036	7,102,412
2037	7,102,190
2038	7,102,007
2039	7,101,927
2040	6,261,508
2041	5,514,384
2042	4,781,266
2043	4,405,005
2044	3,357,002
2045	2,493,248
2046	750,984
2047	0

a. Refer to Table 17

Table 47: Greenhouse Gas Emissions Associated with Facility-Level Fugitives from Gas Production or Processing

Year	Scope 1 Emissions (t CO_2-e / annum)		
	CO_2 Emissions	CH_4 Emissions	Total CO_2-e
2013	0	0	**0**
2014	0	393	**393**
2015	0	31,178	**31,178**
2016	1	77,799	**77,800**
2017	2	127,109	**127,111**
2018	3	175,010	**175,013**
2019	4	223,927	**223,931**
2020	4	251,275	**251,279**
2021	4	251,673	**251,677**
2022	4	252,070	**252,074**
2023	4	252,073	**252,077**
2024	4	252,079	**252,083**
2025	4	252,474	**252,478**
2026	4	252,479	**252,483**
2027	4	252,482	**252,486**
2028	4	252,880	**252,884**
2029	4	253,276	**253,280**
2030	4	253,676	**253,680**
2031	4	254,067	**254,071**
2032	4	254,061	**254,065**
2033	4	254,445	**254,449**
2034	4	254,436	**254,440**
2035	4	254,823	**254,827**
2036	4	254,815	**254,819**
2037	4	254,807	**254,811**
2038	4	254,800	**254,804**
2039	4	254,798	**254,802**
2040	4	224,646	**224,649**
2041	3	197,841	**197,844**
2042	3	171,539	**171,541**
2043	2	158,039	**158,042**
2044	2	120,440	**120,442**
2045	1	89,451	**89,452**
2046	0	26,943	**26,944**
2047	0	0	**0**
Total emissions for time period 2013 - 2047	**105**	**6,691,803**	**6,691,909**

A.5.2.2 Transmission

According to the *Technical Guidelines* (DCCEE, 2010e), additional potential emissions of methane can be a result of:

- compressor blow downs for maintenance at compressor stations;
- maintenance on pipelines;
- leakage; and
- accidents.

According to Coffey Environments, the Arrow Surat Pipeline, the Surat Header Pipeline (an extension of the Arrow Surat Pipeline) and the Daandine Gas Hub (an interconnector that will facilitate the distribution of gas from Surat basin fields to local and export facilities) are not within the scope of the EIS and as a result, the emissions associated with gas transmission from the Arrow Surat Gas Project to Gladstone will not be included in this assessment.

Emissions of CO_2 and CH_4 were estimated using Method 1 (Division 3.3.7, *Method 1- natural gas transmission,* of the *Technical Guidelines* (DCCEE, 2010e)):

$$E_j = Q \times EF_j \; [19]$$

where:

E_j	=	Emissions of gas type (j) from natural gas transmission in the year	(t CO_2-e/a)
Q	=	Total length of pipeline system relevant to the study in the year	(km/a)
EF_j	=	Emission factor for gas type (j)	(t CO_2-e/km)

The default emission factor for each gas was sourced from Section 3.76, of the *Technical Guidelines* (DCCEE, 2010e), and are listed in Table 48. The activity data associated with fugitive emissions from transmission are presented in Table 49 and Table 50. The resulting greenhouse gas emission estimates are presented in Table 51.

Table 48: Emission Factors Associated with Gas Transmission

Method Used	Variable	Value	Units
Method 1	Scope 1 default CO_2 emission factor [a]	0.02	t CO_2-e/ km
Method 1	Scope 1 default CH_4 emission factor [a]	8.7	
Method 1	Scope 1 overall emission factor [b]	8.72	

a. Section 3.76, DCCEE (2010e).
b. PAEHolmes' estimation.

Table 49: Activity Data Associated with Gas Transmission (1)

Data Required	Value	Units
Length of medium pressure gas pipelines from FCFs [a]	25	km/FCF
Length of low pressure gas pipelines from wells [b]	1.1	km/well

a. Section 2.2.2, Coffey Environments (2011c).

b. Section 2.2.1, Coffey Environments (2011c).

Table 50: Activity Data Associated with Gas Transmission (2)

Year	Facility [a]	Total wells commissioned for year [b]	Total wells decommissioned for year [a]	Cumulative length of medium pressure gas pipelines from Field Compression Facilities (km/year)	Cumulative length of low pressure gas pipelines from wells (km/year)
2013	-	0	0	0	0
2014	Wandoan IPF1 a	174	0	0	191
2015	Dalby IPF2	233	0	0	448
2016	Wandoan CGPF1 b	365	0	0	849
	Dalby IPF1		0	0	
2017	Wandoan CGPF2	386	0	0	1,274
2018	Dalby FCF1 c	497	0	25	1,821
2019	Dalby CGPF1	196	0	25	2,036
	Millmerran FCF2		0	50	
2020	Millmerran IPF1	456	0	50	2,538
2021	Chinchilla IPF1	464	0	50	3,048
2022	Chinchilla CPGF1	382	0	50	3,468
2023	-	166	0	50	3,651
2024	-	351	0	50	4,037
2025	Millmerran FCF3	311	0	75	4,379
2026	-	305	0	75	4,715
2027	-	152	0	75	4,882
2028	Millmerran CGPF1	440	0	75	5,366
2029	Millmerran FCF4	361	0	100	5,763
2030	Millmerran FCF1	733	174	125	6,378
2031	Goondiwindi IPF1	308	233	125	6,460
2032	-	0	365	125	6,059
2033	Goondiwindi FCF1	0	386	150	5,634
2034	-	0	497	150	5,088

Year	Facility [a]	Total wells commissioned for year [b]	Total wells decommissioned for year [a]	Cumulative length of medium pressure gas pipelines from Field Compression Facilities (km/year)	Cumulative length of low pressure gas pipelines from wells (km/year)
2035	Goondiwindi CGPF1	0	196	150	4,872
2036	-	0	456	150	4,370
2037	-	0	464	150	3,860
2038	-	0	382	150	3,440
2039	-	0	166	150	3,257
2040	Wandoan IPF1/Dalby IPF2	0	351	125	2,871
2041	Wandoan CGPF1/Dalby IPF1	0	311	100	2,529
2042	Wandoan CGPF2/Dalby FCF1	0	305	100	2,193
2043	Dalby CGPF1/Millmerran FCF2	0	152	100	2,026
2044	Millmerran IPF1/Chinchilla IPF1	0	440	75	1,542
2045	Chinchilla CPGF1/Millmerran FCF3	0	361	25	1,145
2046	Millmerran CGPF1/Millmerran FCF4/Millmerran FCF1	0	733	0	339
2047	Goondiwindi IPF1/Goondiwindi FCF1/Goondiwindi CGPF1	0	308	0	0

a. Data was provided for years 2013 to 2035 only. PAEHolmes' assumption: The number of wells and facilities that will be decommissioned during the remaining years (i.e., 2036 until 2047) were estimated based on the assumption that wells and facilities decommissioning will occur in the same order as their commissioning. Decommissioning of the wells is expected to start in 2030 after 15 to 20 years of service while decommissioning of the facilities is only expected to start in 2040 (Section 5.4, Coffey Environments (2011c)). Refer to Table 17.
b. Table 2.1, Coffey Environments (2011c).

Table 51: Greenhouse Gas Emissions Associated with Gas Transmission

Year	Scope 1 Emissions (t CO_2-e / annum)		
	CO_2	CH_4	Total CO_2-e
2013	0	0	**0**
2014	4	1,665	**1,669**
2015	9	3,895	**3,904**
2016	17	7,388	**7,405**
2017	25	11,082	**11,108**
2018	37	16,056	**16,093**
2019	42	18,149	**18,191**
2020	52	22,513	**22,565**
2021	62	26,953	**27,015**
2022	70	30,609	**30,680**
2023	74	32,198	**32,272**
2024	82	35,557	**35,639**
2025	89	38,751	**38,840**
2026	96	41,670	**41,765**
2027	99	43,124	**43,223**
2028	109	47,335	**47,444**
2029	117	51,007	**51,124**
2030	130	56,574	**56,704**
2031	132	57,292	**57,424**
2032	124	53,799	**53,923**
2033	116	50,323	**50,438**
2034	105	45,566	**45,671**
2035	100	43,691	**43,791**
2036	90	39,327	**39,417**
2037	80	34,886	**34,966**
2038	72	31,230	**31,302**
2039	68	29,642	**29,710**
2040	60	26,065	**26,125**
2041	53	22,871	**22,924**
2042	46	19,953	**19,998**
2043	43	18,498	**18,540**
2044	32	14,070	**14,102**
2045	23	10,180	**10,203**
2046	7	2,948	**2,954**
2047	0	0	**0**
Total emissions for time period 2013 - 2047	**2,264**	**984,866**	**987,130**

A.5.2.3 Non-Routine Emissions - Well Workovers

Sections 5.7 of the API compendium (API, 2009) present numerous emission factors for non-routine emissions activities. Emissions of CH_4 from well workovers (i.e., tubing maintenance) were estimated as follows:

$$E_{CH_4} = N_{wo} \times N_w \times EF_{CH_4} \times GWP_{CH_4} \ [20]$$

where:

E_{CH_4}	=	Emissions of CH_4 from well workovers	($t\ CO_2$-e/a)
N_{wo}	=	Number of workovers per well in the year	(workover/well)
N_w	=	Cumulative number of wells in the year	(wells/a)
EF_{CH_4}	=	Emission factor of CH_4	($t\ CH_4$/workover)
GWP_{CH_4}	=	Global warming potential of CH_4	($t\ CO_2$-e/t CH_4)

The default emission factor of CH_4 was sourced from Table 5-23, of the *API Compendium* (API, 2009) and is listed in Table 52. The activity data associated with fugitive emissions from well workovers are presented in Table 53 and Table 54. The resulting greenhouse gas emission estimates are presented in and Table 55.

Table 52: Emission Factors Associated with Well Workovers

Variable	Value	Units
Scope 1 default CO_2 emission factor [a]	0.04707	t CH_4/workover

a. Table 5-23, API (2009).

Table 53: Activity Data Associated with Well Workovers (1)

Data Required	Value	Units
Global warming potential of CH_4 [a]	21	t CO_2-e/t CH_4
Number of workovers per well in the year [b]	0.33	workover/well

a. Appendix C, DCCEE (2010e).

b. PAEHolmes' estimation – based on 1 workover every 3 years per well (Table 5.5, Coffey Environments (2011c)).

Table 54: Activity Data Associated with Well Workovers (2)

Year	Total Wells Commissioned for Year [a]	Total Wells Decommissioned for Year [b]	Cumulative Number of Wells for Year [b]
2013	0	0	0
2014	174	0	174
2015	233	0	407
2016	365	0	772
2017	386	0	1,158
2018	497	0	1,655
2019	196	0	1,851
2020	456	0	2,307
2021	464	0	2,771
2022	382	0	3,153
2023	166	0	3,319
2024	351	0	3,670
2025	311	0	3,981
2026	305	0	4,286
2027	152	0	4,438
2028	440	0	4,878
2029	361	0	5,239
2030	733	174	5,798
2031	308	233	5,873
2032	0	365	5,508
2033	0	386	5,122
2034	0	497	4,625
2035	0	196	4,429
2036	0	456	3,973
2037	0	464	3,509
2038	0	382	3,127
2039	0	166	2,961
2040	0	351	2,610
2041	0	311	2,299
2042	0	305	1,994
2043	0	152	1,842
2044	0	440	1,402
2045	0	361	1,041
2046	0	733	308
2047	0	308	0

a. Table 2.1, Coffey Environments (2011c) – data provided for time period 2013-2035.
b. Refer to Table 17.

Table 55: Greenhouse Gas Emissions Associated with Well Workovers

Year	Scope 1 Emissions (t CO_2-e / annum) CH_4
2013	0
2014	57
2015	134
2016	254
2017	382
2018	545
2019	610
2020	760
2021	913
2022	1,039
2023	1,094
2024	1,209
2025	1,312
2026	1,412
2027	1,462
2028	1,607
2029	1,726
2030	1,910
2031	1,935
2032	1,815
2033	1,688
2034	1,524
2035	1,459
2036	1,309
2037	1,156
2038	1,030
2039	976
2040	860
2041	757
2042	657
2043	607
2044	462
2045	343
2046	101
2047	0
Total emissions for time period 2013 - 2047	**33,107**

A.6 SCOPE 2 EMISSIONS – CONSTRUCTION, OPERATION AND DECOMMISSIONING

It is assumed that no electricity will be supplied from the grid for construction and decommissioning activities. Construction power and decommissioning power will be supplied through power generation using fuel gas (refer to Section A.3.1), which represents the reference case that is to be modelled (as provided by Coffey Environments).

However, a portion (i.e., 20%) of the wellheads power requirement, from their installation until their decommissioning, will be met through the use of electricity supplied from the grid. Electricity from the grid is also expected to be supplied in combination with local electricity power generation to all the facilities for compression power, and to run the water treatment facility associated with IPFs. However, due to a lack of information in relation to the apportionment of power supply and because integrated power generation corresponds to the reference case to be modelled, it is assumed that the remaining power that will be supplied to all the facilities will be met through power generation using gas drives (refer to Section A.3.1).

The method to estimate Scope 2 emissions can be found in Chapter 7 of the *Technical Guidelines* (DCCEE, 2010e). Only one method is currently available for the estimation of emissions from electricity purchased from the grid. This method uses indirect emission factors based on the state, territory or electricity grid corresponding to the facility of interest. It should be noted that these indirect emission factors are intended to be updated each year.

Scope 2 emissions of CO_2 associated with purchased electricity were estimated using Method 1 (Division 7.2, *Method 1 – purchase of electricity from main electricity grid in a State or Territory,* of the *Technical Guidelines* (DCCEE, 2010e)):

$$Y = Q \times \frac{EF_{S2}}{1000} \quad [21]$$

where:

Y	=	Scope 2 greenhouse gas emissions in the year	(t CO_2-e/a)
Q	=	Quantity of electricity purchased from the grid in the year	(kWh/a)
EF_{S2}	=	Default Scope 2 emission factor specific to State or Territory in which the consumption occurs	(kg CO_2-e/kWh)

The default energy content factor for electricity and the emission factor for CO_2 were sourced from Part 7.2 (3) and Table 7.2 respectively (DCCEE, 2010e) and are listed in Table 56. Equation [22] was used to estimate the total quantity of electricity consumed in the year based on the number of wells on-line. The activity data associated with electricity consumed to power the wellheads are presented in Table 57 and Table 58. The resulting greenhouse gas emission estimates are presented in Table 59.

Table 56: Energy Content Factor and CO_2 Emission Factor of Electricity Purchased from the Grid in Queensland

Variable	Value	Units
Energy content factor [a]	0.0036	GJ/kWh
CO_2 emission factor [b]	0.89	kg CO_2–e/kWh

a. Section 6.3 (c), DCCEE (2010e).
b. Table 7.2, DCCEE (2010e).

$$Q = Q_w \times \%PG \times D \times (N_{wc} - N_{wd}) [22]$$

where:

Q	=	Quantity of electricity purchased from the grid in the year	(kWh/a)
Q_w	=	Power requirement per wellhead	(kW/well)
$\%PG$	=	Percentage of operating power provided by the grid	(%)
D	=	Number of hours associated with electricity usage at the wellheads in the year	(hours/a)
N_{wc}	=	Cumulative number of wells commissioned	(wells)
N_{wd}	=	Total wells decommissioned in the year	(wells)

Table 57: Activity Data Associated with Electricity Purchased from the Grid for Wellheads Power Requirement (1)

Data Required	Value	Unit
Power requirement per wellhead [a]	75	kW
Percentage of operating power provided by the grid [b]	20	%
Number of hours associated with electricity usage at the wellheads [c]	8,760	hrs/a
Total quantity of electricity usage per wellhead [d]	131,400	kWh/a

a. PAEHolmes' estimation - based on a total consumption per wellhead of 60 kVA (Coffey Environments, 2011e) and assuming a power factor equals to 0.8 so that power (W) = Voltage (V) × Current (A) / 0.8. The power requirement for each wellhead is assumed to remain the same during its life time.
b. Coffey Environments (2011e).
c. PAEHolmes' assumption – worst case scenario based on 365 operating days a year.
d. PAEHolmes' estimation.

Table 58: Activity Data Associated with Electricity Purchased from the Grid for Wellheads Power Requirement (2)

Year	Facility	Total wells commissioned for year [a]	Total wells decommissioned for year [a]	Electricity Usage at Wellheads (kWh/annum) [b]
2013	-	0	0	0
2014	Wandoan IPF1	174	0	22,863,600
2015	Dalby IPF2	233	0	53,479,800
2016	Wandoan CGPF1	365	0	101,440,800
	Dalby IPF1		0	
2017	Wandoan CGPF2	386	0	152,161,200
2018	Dalby FCF1	497	0	217,467,000
2019	Dalby CGPF1	196	0	243,221,400
	Millmerran FCF2		0	
2020	Millmerran IPF1	456	0	303,139,800
2021	Chinchilla IPF1	464	0	364,109,400
2022	Chinchilla CPGF1	382	0	414,304,200
2023	-	166	0	436,116,600
2024	-	351	0	482,238,000
2025	Millmeran FCF3	311	0	523,103,400
2026	-	305	0	563,180,400
2027	-	152	0	583,153,200
2028	Millmeran CGPF1	440	0	640,969,200
2029	Millmeran FCF4	361	0	688,404,600
2030	Millmeran FCF1	733	174	761,857,200
2031	Goondiwindi IPF1	308	233	771,712,200
2032	-	0	365	723,751,200
2033	Goondiwindi FCF1	0	386	673,030,800
2034		0	497	607,725,000
2035	Goondiwindi CGPF1	0	196	581,970,600
2036	-	0	456	522,052,200
2037	-	0	464	461,082,600
2038	-	0	382	410,887,800
2039	-	0	166	389,075,400
2040	Wandoan IPF1/Dalby IPF2	0	351	342,954,000
2041	Wandoan CGPF1/Dalby IPF1	0	311	302,088,600
2042	Wandoan CGPF2/Dalby FCF1	0	305	262,011,600
2043	Dalby CGPF1/Millmerran FCF2	0	152	242,038,800
2044	Millmerran IPF1/Chinchilla IPF1	0	440	184,222,800
2045	Chinchilla CPGF1/Millmerran FCF3	0	361	136,787,400
2046	Millmerran CGPF1/Millmerran FCF4/Millmerran FCF1	0	733	40,471,200
2047	Goondiwindi IPF1/Goondiwindi FCF1/Goondiwindi CGPF1	0	308	0

a. Refer to Table 17.
b. PAEHolmes' estimation.

Table 59: Emissions of Scope 2 CO_2 and Energy Consumption from Electricity Purchased from the Grid in Queensland for Wellheads Power Requirement

Year	Scope 2 CO_2 Emissions (t CO_2-e / annum)	Energy Consumption (PJ / annum) [a]
2013	0	0.0
2014	20,349	0.1
2015	47,597	0.2
2016	90,282	0.4
2017	135,423	0.0
2018	193,546	0.5
2019	216,467	0.8
2020	269,794	0.9
2021	324,057	0.0
2022	368,731	1.1
2023	388,144	1.3
2024	429,192	1.5
2025	465,562	1.6
2026	501,231	1.7
2027	519,006	1.9
2028	570,463	2.0
2029	612,680	2.1
2030	678,053	2.3
2031	686,824	2.5
2032	644,139	2.7
2033	598,997	2.8
2034	540,875	2.6
2035	517,954	2.4
2036	464,626	2.2
2037	410,364	2.1
2038	365,690	1.9
2039	346,277	1.7
2040	305,229	1.5
2041	268,859	1.4
2042	233,190	1.2
2043	215,415	1.1
2044	163,958	0.9
2045	121,741	0.9
2046	36,019	0.7
2047	0	0.5
Total for time period 2014 - 2047	**11,750,734**	**47.5**

a. PAEHolmes' estimation based on data in Table 58 and energy content factor of electricity provided in Table 56.

A.7 SCOPE 3 EMISSIONS – CONSTRUCTION, OPERATION AND DECOMMISSIONING

A.7.1 Full Fuel Cycles

Diesel that will be used during the construction, operation and decommissioning of the Arrow Surat Gas facilities (which is not produced onsite) have associated indirect emissions due to its exploration, processing and transport. The consumption of purchased electricity also have associated scope 3 emissions from the extraction, production and transport of fuel combusted at generation and the indirect emissions attributable to the electricity lost in delivery in the transmission and distribution (T&D) network.

Full life cycle emissions associated with the construction material (raw material extraction though to manufacturing) are not considered in this study.

In order to estimate the greenhouse gas emissions from full fuel cycles, the total amount of fuel combusted and electricity purchased from the grid are required. Equations [23] and [24] were used to calculate the scope 3 emissions from fuel combustion and electricity consumption by end-users.

$$E_{CO_2-e} = \frac{Q \times EC \times EF_{S3}}{1000} \quad [23]$$

where:

E_{CO_2-e}	=	Scope 3 emissions of greenhouse gases from fuel combustion in the year	(t CO_2-e/a)
Q	=	Quantity of fuel combusted in the year	(kL/a)
EC	=	Energy content factor of diesel	(GJ/kL)
EF_{S3}	=	Scope 3 emission factor	(kg CO_2-e/GJ)

$$E_{CO_2-e} = \frac{Q \times EF_{S3}}{1000} \quad [24]$$

where:

E_{CO_2-e}	=	Scope 3 emissions of greenhouse gases from electricity consumption in the year	(t CO_2-e/a)
Q	=	Quantity of electricity purchased from the grid in the year	(kWh/a)
EF_{S3}	=	Default Scope 3 emission factor specific to State or Territory in which the consumption occurs	(kg CO_2-e/ kWh)

The default energy content factor of diesel was sourced from Table 2.4.2B, of the *Technical Guidelines* (DCCEE, 2010e). The default scope 3 emission factors of diesel and electricity were sourced from Table 39 and Table 40, of the *National Greenhouse Account Factors* (DCCEE, 2011f), and are listed in Table 60. The activity data associated with the full fuel cycle of diesel and the resulting greenhouse gas emission estimates are presented in Table 61 and Table 62, respectively. The activity data associated with the full fuel cycle of electricity and the resulting greenhouse gas emission estimates are presented in Table 63 and Table 64, respectively.

Table 60: Energy Content Factor and Scope 3 Emission Factors Associated with Full Fuel Cycles

Variable	Value	Units
Energy content factor of diesel [a]	38.6	GJ/kL
Scope 3 emission factor of diesel [b]	5.3	kg CO_2–e/GJ
Scope 3 emission factor of electricity (QLD) [c]	0.13	kg CO_2–e/kWh

a. Table 2.4.2B, DCCEE (2010e).
b. Table 39, *NGA Factors* DCCEE (2011f).
c. Table 40, *NGA Factors* DCCEE (2011f) – latest estimate for Queensland.

Table 61: Activity Data Associated with Full Fuel Cycle of Diesel

Year	Total Fuel Consumed for Year [a] (kL/annum)
2013	336
2014	1,509
2015	2,025
2016	1,789
2017	2,757
2018	2,364
2019	1,786
2020	5,322
2021	2,419
2022	3,727
2023	2,366
2024	5,265
2025	3,417
2026	4,288
2027	4,048
2028	5,204
2029	5,757
2030	5,392
2031	7,003
2032	7,165
2033	7,314
2034	7,932
2035	8,052
2036	6,417
2037	6,294
2038	6,166
2039	5,404
2040	4,923
2041	5,050
2042	4,384
2043	4,649
2044	4,215
2045	3,918
2046	3,044
2047	2,978
Total fuel consumed for time period 2014 - 2047	**154,678**

a. Refer to Table 25.

Table 62: Scope 3 Greenhouse Gas Emissions from Full Fuel of Diesel

Year	Scope 3 Emissions ($t\ CO_2$-e / annum)
2013	69
2014	309
2015	414
2016	366
2017	564
2018	484
2019	365
2020	1,089
2021	495
2022	763
2023	484
2024	1,077
2025	699
2026	877
2027	828
2028	1,065
2029	1,178
2030	1,103
2031	1,433
2032	1,466
2033	1,496
2034	1,623
2035	1,647
2036	1,313
2037	1,288
2038	1,261
2039	1,106
2040	1,007
2041	1,033
2042	897
2043	951
2044	862
2045	802
2046	623
2047	609
Total emissions for time period 2013 - 2047	**31,644**

Table 63: Activity Data Associated with Full Fuel Cycle of Electricity

Year	Total Electricity Used for Year [a] (kL / annum)
2013	0
2014	22,863,600
2015	53,479,800
2016	101,440,800
2017	152,161,200
2018	217,467,000
2019	243,221,400
2020	303,139,800
2021	364,109,400
2022	414,304,200
2023	436,116,600
2024	482,238,000
2025	523,103,400
2026	563,180,400
2027	583,153,200
2028	640,969,200
2029	688,404,600
2030	761,857,200
2031	771,712,200
2032	723,751,200
2033	673,030,800
2034	607,725,000
2035	581,970,600
2036	522,052,200
2037	461,082,600
2038	410,887,800
2039	389,075,400
2040	342,954,000
2041	302,088,600
2042	262,011,600
2043	242,038,800
2044	184,222,800
2045	136,787,400
2046	40,471,200
2047	0
Total electricity used for time period 2014 - 2047	**13,203,072,000**

a. Refer to Table 58

Table 64: Scope 3 Greenhouse Gas Emissions from Full Fuel Cycle of Electricity

Year	Scope 3 Emissions (t CO_2-e / annum)
2013	0
2014	2,972
2015	6,952
2016	13,187
2017	19,781
2018	28,271
2019	31,619
2020	39,408
2021	47,334
2022	53,860
2023	56,695
2024	62,691
2025	68,003
2026	73,213
2027	75,810
2028	83,326
2029	89,493
2030	99,041
2031	100,323
2032	94,088
2033	87,494
2034	79,004
2035	75,656
2036	67,867
2037	59,941
2038	53,415
2039	50,580
2040	44,584
2041	39,272
2042	34,062
2043	31,465
2044	23,949
2045	17,782
2046	5,261
2047	0
Total emissions for time period 2013 - 2047	**1,716,399**

A.7.2 End Use of Gas

Scope 3 emissions associated with the end use of gas refer to the full combustion of product gas and as a result scope 1 emission factors will be used. End use of the product gas will be the most significant scope 3 emission associated with the Arrow Surat Gas Project.

In order to estimate the greenhouse gas emissions from the end use of coal seam gas, it has been assumed that no fugitive losses will occur after the product gas leaves Arrow Surat Gas facilities. The equation used to calculate the Scope 3 emissions associated with the end use of gas is as follows:

$$E_{CO_2-e} = \frac{Q \times EF_{S1}}{1000} \quad [25]$$

where:

E_{CO_2-e}	=	Emissions of greenhouse gases from end use of produced gas in the year	(t CO_2-e/a)
Q	=	Quantity of gas combusted in the year	(GJ/a)
EF_{S1}	=	Greenhouse gas scope 1 emission factor for coal seam gas combustion	(kg CO_2-e/GJ)

The default scope 3 emission factors (i.e., scope 1 emission factors used as scope 3 emission factors) of coal seam gas were sourced from Table 2.3.2A, of the *Technical Guidelines* (DCCEE, 2010e) and are listed in Table 65. The activity data associated with the end use of gas and the resulting greenhouse gas emission estimates are presented in Table 66 and Table 67, respectively.

Table 65: Energy Content Factor and Scope 3 Emission Factors Associated with End-Use of Gas

Method Used	Variable	Value	Units
Method 1	Scope 1 CO_2 emission factor of coal seam gas [a]	51.1	kg CO_2–e/GJ
Method 1	Scope 1 CH_4 emission factor of coal seam gas [a]	0.2	
Method 1	Scope 1 N_2O emission factor of coal seam gas [a]	0.03	
Method 1	Scope 1 overall emission factor of coal seam gas[b]	51.33	

a. Table 2.3.2A, DCCEE (2010e).
b. PAEHolmes' estimation.

Table 66: Activity Data Associated with End-Use of Gas

Year	Cumulative total gas production (TJ/a) [b]
2013	0
2014	0
2015	43,435
2016	109,500
2017	178,850
2018	246,740
2019	316,090
2020	354,050
2021	354,050
2022	354,050
2023	354,050
2024	354,050
2025	354,050
2026	354,050
2027	354,050
2028	354,050
2029	354,050
2030	354,050
2031	354,050
2032	354,050
2033	354,050
2034	354,050
2035	354,050
2036	354,050
2037	354,050
2038	354,050
2039	354,050
2040	312,081
2041	274,894
2042	238,425
2043	220,250
2044	167,639
2045	124,474
2046	36,828
2047	0

a. Refer to Table 17.

Table 67: Scope 3 Greenhouse Gas Emissions Associated with End-Use of Gas

Year	Scope 3 Emissions (t CO_2-e / annum)			
	CO_2	CH_4	N_2O	Total CO_2-e
2013	0	0	0	0
2014	0	0	0	0
2015	2,219,529	8,687	1,303	2,229,519
2016	5,595,450	21,900	3,285	5,620,635
2017	9,139,235	35,770	5,366	9,180,371
2018	12,608,414	49,348	7,402	12,665,164
2019	16,152,199	63,218	9,483	16,224,900
2020	18,091,955	70,810	10,622	18,173,387
2021	18,091,955	70,810	10,622	18,173,387
2022	18,091,955	70,810	10,622	18,173,387
2023	18,091,955	70,810	10,622	18,173,387
2024	18,091,955	70,810	10,622	18,173,387
2025	18,091,955	70,810	10,622	18,173,387
2026	18,091,955	70,810	10,622	18,173,387
2027	18,091,955	70,810	10,622	18,173,387
2028	18,091,955	70,810	10,622	18,173,387
2029	18,091,955	70,810	10,622	18,173,387
2030	18,091,955	70,810	10,622	18,173,387
2031	18,091,955	70,810	10,622	18,173,387
2032	18,091,955	70,810	10,622	18,173,387
2033	18,091,955	70,810	10,622	18,173,387
2034	18,091,955	70,810	10,622	18,173,387
2035	18,091,955	70,810	10,622	18,173,387
2036	18,091,955	70,810	10,622	18,173,387
2037	18,091,955	70,810	10,622	18,173,387
2038	18,091,955	70,810	10,622	18,173,387
2039	18,091,955	70,810	10,622	18,173,387
2040	15,947,316	62,416	9,362	16,019,094
2041	14,047,080	54,979	8,247	14,110,306
2042	12,183,505	47,685	7,153	12,238,343
2043	11,254,772	44,050	6,607	11,305,430
2044	8,566,336	33,528	5,029	8,604,893
2045	6,360,596	24,895	3,734	6,389,225
2046	1,881,905	7,366	1,105	1,890,376
2047	0	0	0	0
Total emissions for time period 2013 - 2047	**477,795,438**	**1,870,041**	**280,506**	**479,945,985**

A.7.3 Emissions Associated with Third Party Infrastructure Required to Export Coal Seam Gas

Scope 3 emissions associated with the third party infrastructure required to export gas as LNG refer to the gas losses through transmission to Arrow LNG Plant, the emissions associated with downstream processing of the gas that results in the production and export of LNG.

A.7.3.1 Transmission

According to the *Technical Guidelines* (DCCEE, 2010e), additional potential emissions of methane can be a result of:

- maintenance on pipelines; and
- leakage.

Even though the Arrow Surat Pipeline, the Surat Header Pipeline and the Daandine Gas Hub are not within the scope of the EIS, the scope 3 emissions associated with the transmission of CSG to Arrow LNG will be included in this assessment in line with the Terms of Reference.

Emissions of CO_2 and CH_4 were estimated using Method 1 (Division 3.3.7, *Method 1- natural gas transmission,* of the *Technical Guidelines* (DCCEE, 2010e)):

$$E_j = Q \times EF_j \; [26]$$

where:

E_j	=	Emissions of gas type (j) from natural gas transmission in the year	(t CO_2-e/a)
Q	=	Total length of pipeline system relevant to the study in the year	(km/a)
EF_j	=	Emission factor for gas type (j)	(t CO_2-e/km)

The default emission factor for each gas was sourced from Section 3.76, of the *Technical Guidelines* (DCCEE, 2010e), and are listed in Table 68. The activity data associated with fugitive emissions from transmission are presented in Table 69. The resulting greenhouse gas emission estimates are presented in Table 70.

Table 68: Emission Factors Associated with Gas Transmission to Arrow LNG Plant (Scope 3)

Method Used	Variable	Value	Units
Method 1	Scope 1 default CO_2 emission factor [a]	0.02	t CO_2-e/ km
Method 1	Scope 1 default CH_4 emission factor [a]	8.7	
Method 1	Scope 1 overall emission factor [b]	8.72	

a. Section 3.76, DCCEE (2010e).
b. PAEHolmes' estimation.

Table 69: Activity Data Associated with Gas Transmission to Arrow LNG Plant (Scope 3)

Data Required	Value	Units
Maximum length of high pressure gas pipelines from CGPFs and IPFs to Arrow LNG [a]	923.6	km

a. PAEHolmes' estimate: The total pipeline length include the following distances: Goodiwindi - Millemeran (161 kms), Millmeran-Dalby (98.6 kms), Dalby - Chinchilla (82 kms), Chinchilla - Wandoan (115 kms) and Dalby (mid-point of the shaded area presented in Attachment 1, Coffey Environments, 2011c) - Arrow LNG (Gladstone) (522 kms). Full length of Arrow Surat Pipeline will be commissioned in 2016. However, high pressure pipeline infrastructure (as yet undefined) will be installed to ensure that gas from the facilities that are developed before 2016 can be distributed for use (Table 2.1, Coffey Environments (2011c)). PAEHolmes' assumption: the maximum pipeline length is used for each year (worst-case).

Table 70: Greenhouse Gas Emissions Associated with Gas Transmission to Arrow LNG Plant (Scope 3)

Year	Scope 3 Emissions (t CO_2-e / annum)		
	CO_2	CH_4	Total CO_2-e
Annual emissions (2015 - 2046)	18	8,035	**8,054**
Total emissions for time period 2015 – 2046 [a]	**591**	**257,130**	**257,721**

a. No emissions associated with transmission of coal seam gas to Arrow LNG Plant occur for years 2013 – 2014 and 2047 as no gas is produced at any of the facilities (Table 2.1, Coffey Environments (2011c)).

A.7.3.2 Emissions Associated with Downstream Processing of Coal Seam Gas

In order to estimate the greenhouse gas emissions associated with downstream processing of coal seam gas to produce and export LNG, the scope 1 and scope 2 annual emissions associated with the “all electrical” scenario (worst-case) for Arrow LNG Plant were used (refer to Arrow’s LNG EIS Greenhouse Gas chapter (PAEHolmes, 2011)). The fugitive losses from gas transmission to Arrow LNG Plant were then excluded from the total scope 1 and scope 2 emissions.

Scope 3 emissions of CO_2 CH_4 and N_2O based on the Arrow LNG Plant estimated scope 1 and scope 2 annual emissions for the “all electrical” option for four LNG trains were scaled down to the amount of CSG delivered by the Project as follows:

$$E_{j,S3} = E_{j,S1\&2} \times \frac{Q_{upstream}}{Q_{downstream}} \quad [27]$$

where:

$E_{j,S3}$	=	Scope 3 emissions of gas type (j) associated with downstream gas processing in the year	(t CO_2-e/a)
$E_{j,S1\&2}$	=	Scope 1 and scope 2 emissions of gas type (j) associated with gas processing at Arrow LNG Plant in the year	(t CO_2-e/a)
$Q_{upstream}$	=	Total amount of gas fed to Arrow LNG from the project	(Sm^3/a)
$Q_{downstream}$	=	Total amount of gas processed downstream for four LNG trains (Arrow LNG Plant)	(Sm^3/a)

Equation [27] presents the energy balance used to determine the total amount of gas fed to Arrow LNG Plant from the Project. Equation [29] was used to convert CO_2 equivalent emissions from gas transmission (refer to Table 70) to a volume of gas and the associated parameters are presented in Table 71. The activity data associated with the downstream processing of coal seam gas are presented in Table 72 and Table 73. The greenhouse gas emission estimates are presented in Table 74.

$$Q_{upstream} = \frac{(CSG_P - CSG_T) \times 1000}{EC_{ss}} \quad [28]$$

where:

$Q_{upstream}$	=	Total amount of gas fed to Arrow LNG from the project	(Sm^3/a)
CSG_P	=	Cumulative total gas produced by the project in the year	(TJ/a)
CSG_T	=	Total leaks of CO_2 and CH_4 during transmission to Arrow LNG Plant in the year	(TJ/a)
EC_{ss}	=	Site-specific energy content of CSG	(GJ/Sm^3 CSG)

$$CSG_T = \frac{\left(\frac{CSG_{T,CO2}}{GWP_{CO2}} + \frac{CSG_{T,CH4}}{GWP_{CH4}}\right) \times EC_{ss}}{\rho_{CSG}} \quad [29]$$

where:

CSG_T	=	Total leaks of CO_2 and CH_4 during transmission in the year	(TJ/a)
$CSG_{T,CO2}$	=	Total leaks of CO_2 during transmission in the year (refer to Table 70)	(t CO_2-e/a)
$CSG_{T,CH4}$	=	Total leaks of CH_4 during transmission in the year (refer to Table 70)	(t CO_2-e/a)
GWP_{CO2}	=	Global warming potential of CO_2	(t CO_2-e /t CO_2)
GWP_{CH4}	=	Global warming potential of CH_4	(t CO_2-e /t CH_4)
EC_{ss}	=	Site-specific energy content of CSG	(GJ/Sm^3 CSG)
ρ_{CSG}	=	Site-specific CSG density at standard conditions	(kg CSG/ Sm^3 CSG)

Table 71: Parameters Associated with the Estimation of the Volume of CSG losses during Transmission to Arrow LNG Plant

Data Required	Value	Units
Site-specific coal seam gas density at standard conditions [a]	0.726	kg/Sm^3
Site-specific energy content factor [b]	0.03729	GJ/m^3
Global warming potential of CO_2 [c]	1	t CO_2-e/ t CO_2
Global warming potential of CH_4 [c]	21	t CO_2-e/ t CH_4

a. Coffey Environments (2011a) - based on an average real gas density (at 0°C and 1 atm) from existing facilities including Daandine (D-1), Kogan (K-1) and Tipton (T-1).

b. Coffey Environments (2011a) – based on an average real gross calorific value from existing facilities including Daandine (D-1), Kogan (K-1) and Tipton (T-1).

c. Appendix C, DCCEE (2010e).

Table 72: Activity Data Associated with Downstream Processing of CSG (Scope 3) (1)

Year	Cumulative total gas produced by the project (TJ/a) [a]	Amount of CSG losses through transmission to Arrow LNG (TJ/a) [b]	Amount of gas fed to Arrow LNG (Sm^3/a)
2013	0	0	0
2014	0	0	0
2015	43,435	21	1,164,237,000
2016	109,500	21	2,935,891,599
2017	178,850	21	4,795,639,521
2018	246,740	21	6,616,234,854
2019	316,090	21	8,475,982,776
2020	354,050	21	9,493,950,060
2021	354,050	21	9,493,950,060
2022	354,050	21	9,493,950,060
2023	354,050	21	9,493,950,060
2024	354,050	21	9,493,950,060
2025	354,050	21	9,493,950,060
2026	354,050	21	9,493,950,060
2027	354,050	21	9,493,950,060
2028	354,050	21	9,493,950,060
2029	354,050	21	9,493,950,060
2030	354,050	21	9,493,950,060
2031	354,050	21	9,493,950,060
2032	354,050	21	9,493,950,060
2033	354,050	21	9,493,950,060
2034	354,050	21	9,493,950,060
2035	354,050	21	9,493,950,060
2036	354,050	21	9,493,950,060
2037	354,050	21	9,493,950,060
2038	354,050	21	9,493,950,060
2039	354,050	21	9,493,950,060
2040	312,081	21	8,368,461,916
2041	274,894	21	7,371,234,529
2042	238,425	21	6,393,246,256
2043	220,250	21	5,905,855,378
2044	167,639	21	4,494,987,050
2045	124,474	21	3,337,433,717
2046	36,828	21	987,055,342
2047	0	0	0

a. Refer to Table 17.
b. Refer to Table 70.

Table 73: Activity Data Associated with Downstream Processing of CSG (Scope 3) (2)

Data Required	Value	Units
Total amount of gas processed downstream for four LNG trains (Arrow LNG Plant) [a]	28,707,604,758	Sm^3/a

a. Arrow LNG Greenhouse Assessment EIS Chapter (PAEHolmes, 2011): Full fuel cycle of CSG processed.

Table 74: Scope 3 Greenhouse Gas Emissions Associated with Downstream Processing of CSG

Year	Scope 3 Emissions (t CO_2-e / annum)			
	CO_2	CH_4	N_2O	Total CO_2-e
2013	0	0	0	0
2014	0	0	0	0
2015	9,660	4	12	9,676
2016	24,359	10	31	24,400
2017	39,790	16	51	39,856
2018	1,581,433	172,768	1,108	1,755,310
2019	1,928,212	220,288	1,026	2,149,526
2020	2,159,791	246,745	1,149	2,407,685
2021	2,159,791	246,745	1,149	2,407,685
2022	2,159,791	246,745	1,149	2,407,685
2023	2,238,563	246,776	1,249	2,486,588
2024	2,238,563	246,776	1,249	2,486,588
2025	2,238,563	246,776	1,249	2,486,588
2026	4,429,064	494,658	2,740	4,926,462
2027	4,319,582	493,489	2,299	4,815,369
2028	4,319,582	493,489	2,299	4,815,369
2029	4,319,582	493,489	2,299	4,815,369
2030	4,319,582	493,489	2,299	4,815,369
2031	4,319,582	493,489	2,299	4,815,369
2032	4,319,582	493,489	2,299	4,815,369
2033	4,319,582	493,489	2,299	4,815,369
2034	4,319,582	493,489	2,299	4,815,369
2035	4,319,582	493,489	2,299	4,815,369
2036	4,319,582	493,489	2,299	4,815,369
2037	4,319,582	493,489	2,299	4,815,369
2038	4,319,582	493,489	2,299	4,815,369
2039	4,319,582	493,489	2,299	4,815,369
2040	3,807,504	434,987	2,026	4,244,517
2041	3,353,783	383,152	1,785	3,738,720
2042	2,908,815	332,317	1,548	3,242,680
2043	0	0	0	0
2044	0	0	0	0
2045	0	0	0	0
2046	0	0	0	0
2047	0	0	0	0
Total emissions for time period 2013 - 2047	**87,432,240**	**9,934,122**	**47,404**	**97,413,766**

APPENDIX B

Climate Change Impacts Predicted by the Garnaut Review

Predicted climate change impacts and emission trajectories identified by the Garnaut Review are divided into three global emission scenarios, no mitigation, 550 ppm stabilisation and 450 ppm stabilisation with overshoot.

- ***No mitigation***

  No action to mitigate climate change. Emissions continue to increase throughout the 21st century, leading to an accelerating rate of increase in atmospheric concentrations of greenhouse gases. Greenhouse gas concentrations reach 1,565 ppm CO_2-e, more than 3.5 times higher than pre-industrial concentrations by 2100.

- ***550 ppm stabilisation***

  Emissions peak and decline steadily, so that atmospheric concentrations stop rising in 2060 and stabilise around 550 ppm CO_2-e (one third the concentration reached in the no mitigation scenario).

- ***450 ppm stabilisation with overshoot***

  Emissions are reduced immediately and decline more sharply than in the 550 ppm case. Atmospheric concentrations overshoot to 530 ppm CO_2-e mid-century and decline toward stabilisation at 450 ppm CO_2-e early in the 22nd century.

The Garnaut review details Australian emission trajectories for each of the three global emission scenarios, in the context of Australia playing a fair and proportionate part in an effective global agreement to constrain greenhouse gas emissions. The trajectories give an indication of the greenhouse emission cuts required in Australia to achieve the 550 ppm and 450 ppm CO_2-e stabilisation goals.

Annual greenhouse gas emissions associated with the Arrow Surat Gas Project, as a proportion of emissions trajectories detailed by the Garnaut Review are shown in Appendix Table A-1. Predicted climate change impacts presented in the Garnaut Review are shown in Appendix Table A-2. The climate change predictions and impacts presented in Appendix Table A-2 have been made as specific to the Arrow Surat Gas Project's location as possible, based on the information provided in the Garnaut Review.

Table 75: Garnaut Target Emissions for 2020 and 2050 for Australia

Global agreement	Australian Target 2020	Australian Target 2050
450 ppm stabilisation with overshoot	**405.8 Mt CO_2-e / a** 32% reduction from current Kyoto commitment target 2008-2012	**59.7 Mt CO_2-e / a** 90% reduction from current Kyoto commitment target 2008-2012
550 ppm stabilisation	**495.3 Mt CO_2-e / a** 17% reduction from current Kyoto commitment target 2008-2012	**107.4 Mt CO_2-e / a** 82% reduction from current Kyoto commitment target 2008-2012
No global agreement	**519.2 Mt CO_2-e / a** 13% reduction from current Kyoto commitment target 2008-2012	**220.8 Mt CO_2-e / a** 63% reduction from current Kyoto commitment target 2008-2012

Source: Garnaut (2008)

Table 76: Climate Change Impacts Predicted by the Garnaut Review

Aspect	Location	Year	Predicted impact			Notes	Reference
			No mitigation	450 ppm	550 ppm		
Temperature	Global	2030	Predicted increase in average temperature 1.3°C	Predicted increase in average temperature 1.2°C	Predicted increase in average temperature 1.2°C	Approximates estimated from Figure 4.5 Garnaut Climate Change review, best estimate median probability, increases over 1990 levels	Chapter 4 Figure 4 p88
		2070	Predicted increase in average temperature 3.5°C	Predicted increase in average temperature 2°C	Predicted increase in average temperature 2°C		
		2100	Predicted increase in average temperature 4.5°C	Predicted increase in average temperature 1.5 °C	Predicted increase in average temperature 2°C		
Sea level rise	Global	2100	29 to 59 cm rapid changes in ice flow could add another 10 to 20cm to the upper range	Not specifically determined	Not specifically determined	Based on IPCC estimations for SRES scenario A1F1 similar to no mitigation case	Chapter 4 p93
Ocean acidity	Global	NA	Increasing ocean acidity proportionate to increased atmospheric carbon dioxide concentrations, consequences for aquatic life, increased impact in colder waters			This is directly related to CO_2 concentration in atmosphere	Chapter 4 p80
Precipitation	Queensland	2030	Decrease from 1990 level - 2.4%	Not specifically determined	Not specifically determined	Based on median annual average	Chapter 5 Table 5.1 p115
		2070	Decrease from 1990 level - 8.6%	Not specifically determined	Not specifically determined	Based on median annual average	
		2100	Decrease from 1990 level - 12.7%	Not specifically determined	Not specifically determined	Based on median annual average	
Cyclones and storms	Global	NA	Increased intensity			Not based on a specific scenario	Chapter 5 p117
		NA	Frequency same or decreased			Not based on a specific scenario	
Bushfires	Australia	2013	5 to 25% increase in number of days with extreme fire weather	Not specifically determined	Not specifically determined	Based on 0.4°C increase	Chapter 5 Table 5.4 p118
		2034	15 to 65% increase in number of days with extreme fire weather	Not specifically determined	Not specifically determined	Based on 1°C increase	
		2067	100 to 300% increase in number of days with extreme fire weather	Not specifically determined	Not specifically determined	Based on 2.9°C increase	
Heatwaves	Brisbane	2008	0.9 days over 35°C	Not specifically determined	Not specifically determined	Increase over 1990 baseline	Chapter 5 Table 5.3 p117
		2030	1.7 days over 35°C	Not specifically determined	Not specifically determined		
		2070	8 days over 35°C	Not specifically determined	Not specifically determined		

Aspect	Location	Year	Predicted impact: No mitigation	Predicted impact: 450 ppm	Predicted impact: 550 ppm	Notes	Reference
		2100	21 days over 35°C	Not specifically determined	Not specifically determined		
Agriculture	Australia	NA	Crop production affected by changes in average rainfall and temperature. Livestock affected by quantity and quality of pastures. Severe weather events (bushfire, flooding) reduce production. Increased temperature alters occurrence of pests and disease. Potential for carbon fertilisation if not crop growth is not restricted by temperature and rainfall.			Not based on specific scenario	Chapter 6 p129
Dryland cropping - wheat	Dalby, Queensland	2030	8.2% cumulative yield change	1.6% cumulative yield change	4.8% cumulative yield change	Percentage cumulative yield change from 1990 Based on median probability of rainfall, relative humidity, temperature	Chapter 6 Table 6.5 p132
		2100	-18.5% cumulative yield change	-3.7% cumulative yield change	-1.0% cumulative yield change		
Dryland cropping - wheat	Emerald, Queensland	2030	7.2% cumulative yield change	1.8% cumulative yield change	4.4% cumulative yield change	Percentage cumulative yield change from 1990 Based on median probability of rainfall, relative humidity, temperature	Chapter 6 Table 6.5 p132
		2100	-10.1% cumulative yield change	-2.5% cumulative yield change	0% cumulative yield change		
Irrigated agriculture	Murray Darling	2030	12% decline in economic value of production	3% decline in economic value of production	3% decline in economic value of production	Based on median probability of rainfall, relative humidity, temperature	Chapter 6 Table 6.4 p130
		2050	49% decline in economic value of production	6% decline in economic value of production	6% decline in economic value of production	Based on median probability of rainfall, relative humidity, temperature	
		2100	92% decline in economic value of production	6% decline in economic value of production	20% decline in economic value of production	Based on median probability of rainfall, relative humidity, temperature	
Water supply infrastructure	Australia	2100	34% increase in cost of supplying water	4% increase in cost of supplying water	5% increase in cost of supplying water	Based on median probability	Chapter 6 Table 6.3
Coastal buildings	Queensland	2030	Medium magnitude of net impact	Medium magnitude of net impact	Medium magnitude of net impact	Based on median probability of rainfall, relative humidity, temperature	Chapter 6 Table 6.8
	Queensland	2100	Extreme magnitude of net impact	Medium magnitude of net impact	Medium magnitude of net impact		
Temperature related deaths	Queensland	2100	Over 4000 additional heat-related deaths relative to no climate change	Fewer deaths relative to no climate change	Fewer than 80 additional heat-related deaths relative to no climate change	Based on median probability	Chapter 6 Table 6.3 p128
Geopolitical stability in Asia-Pacific	Asia Pacific	2100	Displacement of people from South East Asian cities (sea rise)	Less displacement (lower sea rise)	Less displacement (lower sea rise)	Based on median probability	Chapter 6 Table 6.3 p128
Ecosystems	Global	NA	Loss of biodiversity in high altitudes, wet tropics, coastal freshwater wetlands, coral reefs			Impact is specific to each	Chapter 6

Aspect	Location	Year	Predicted impact: No mitigation	Predicted impact: 450 ppm	Predicted impact: 550 ppm	Notes	Reference
			increasing with higher impact scenarios			ecosystem	p142
International trade	Global	NA	Affected economies (China, India, Indonesia) reducing demand for Australian goods			not based on a specific scenario	Chapter 6 p145

Source: Garnaut, 2008

Qld Government Predictions

Table 77 and Table 78 present a summary of the predicted impacts of climate change by 2070, under a “high emissions scenario - 50th percentile projection”.

Table 77: Qld Government's Climate Change Predictions

	Queensland Average	Cape York	Central Queensland	Central West Queensland	Eastern Downs	Far North Queensland	Gulf Region
Temperature							
Change previous decade	0.4	-0.1°C	0.5°C	0.7°C	0.5°C	0.1°C	0.2°C
Predicted change by 2070	4.4	3.7°C	4.5°C	5.2°C	4.5°C	3.9°C	4.4°C
Predicted no. days above 35°C (% change)	437	200-300%	400%	150%	300%	800%	200%
Rainfall							
Change in last decade in comparison with previous 30years[a]	-8	0%	-14%	-9%	-12%	-2%	3%
Predicted change (% change)[b]	-4.3	-21 to 24%	-35 to 17%	-37 to 22%	-32 to 16%	-26 to 22%	-26 to 24%
Evaporation							
Predicted change (% change)	10.5	7-14%	7-15%	3-14%	7-15%	7-15%	7-14%

[a]This is generally consistent with natural variability experienced over the last 110 years, which makes it difficult to detect any influence of climate change at this stage
[b]The ‘best estimate’ of projected rainfall change shows a decrease under all emissions scenarios
Source: Queensland Government (2009).

Table 78: Qld Government's Climate Change Predictions contd.

	Maranoa and District	North West Queensland	South East Queensland	South West Queensland	Townsville Thuringowa	Whitsunday, Hinterland and Mackay	Wide Bay Burnett
Temperature							
Change previous decade	0.5°C	0.4°C	0.4°C	0.8°C	0.2°C	0.3°C	0.4°C
Predicted change by 2070	5°C	4.9°C	4°C	5.2°C	4.2°C	4.2°C	4.1°C
Predicted no. days above 35°C (% change)	200-300%	150%	300-600%	150-200%	200-1000%	1200%	300-1200%
Rainfall							
Change in last decade in comparison with previous 30years[a]	-8%	-2%	-16%	-16%	-4%	-14%	-12%
Predicted change (% change)[b]	-34 to 17%	-31 to 24%	-30 to 17%	-38 to 20%	-32 to 19%	-35-17%	-33 to 16%
Evaporation							
Predicted change (% change)	6-15%	6-14%	6-16%	3-15%	7-15%	7-15%	7-16%

[a]This is generally consistent with natural variability experienced over the last 110 years, which makes it difficult to detect any influence of climate change at this stage

[b]The 'best estimate' of projected rainfall change shows a decrease under all emissions scenarios

Source: Chapter 5, Qld Government (2009).

APPENDIX C

ToR Cross-Reference Table

Table 79: Terms of Reference Cross Reference Table for the Greenhouse Gas Assessment Technical Study

Terms of Reference		PAEHolmes	
Section	EIS requirement	Technical Study Name	Technical Specialist Report Section
4.6.3.1 Greenhouse gas inventory	Detail the applicable international, national and state regulatory framework for greenhouse gas emissions, and which regulations would apply to emission sources associated with the proposed development	Arrow Energy Surat Gas Project – Greenhouse Gas Assessment	Section 2
	Provide an inventory of expected annual emissions for each relevant greenhouse gas, with totals expressed in 'CO2 equivalent', including Scopes 1, 2 and 3, as defined by WRI/WBC Greenhouse Gas Protocol – Scope 3 emissions should confine its consideration to direct associations only		Section 4
	Detail methods by which estimates were made		Section 3
	Present CO_2 equivalent emissions as a percentage of Australia and Queensland's existing Greenhouse inventory		Section 5.1
	Detail intended audit and review procedures		Section 3.1.2.4, 8
	The Australian Department of Climate Change's National Greenhouse Accounts (NGA) Factors are to be used as the reference source for emission estimation and supplemented by other sources where practicable and appropriate		Section 3, 4
4.6.3.2 Greenhouse gas abatement	Description of the proposed measures, alternatives and preferred, to avoid and/or minimise greenhouse emissions from the project – this should also include a description of how the preferred measures minimise emissions and achieve maximum energy efficiency	Arrow Energy Surat Gas Project – Greenhouse Gas Assessment	Section 7.1
	Compare the preferred measures for emission controls and energy consumption with best practice environmental management in the relevant industry sector		Section 6, 7.1
	Description of indirect greenhouse offsets available		Section 7.2
	The Environmental Management Plan is to include a greenhouse module, containing commitments to: - abate greenhouse gas emissions - manage energy with details of periodic audits to progressively improve energy efficiency		Section 8

Terms of Reference		PAEHolmes	
Section	EIS requirement	Technical Study Name	Technical Specialist Report Section
	- regular review of technology to identify opportunities to reduce emissions and use energy efficiently - voluntary initiatives including the National Greenhouse Challenge Plus program and other research - investigate opportunities for greenhouse offset including carbon sequestration and renewable energy - monitor, audit and report on greenhouse emissions from all relevant activities and the success of offset measures		
4.6.3.3 Climate change adaptation	Provide an assessment of the project's vulnerabilities to climate change, and describe possible adaptation strategies	Arrow Energy Surat Gas Project – Greenhouse Gas Assessment	Section 9.1
	A risk assessment of changing rainfall and hydrology, temperature, extreme weather and sea level and their ability to affect the viability of the environmental management of the project		Section 9.1
	Include the alternate and preferred adaptation strategies		Section 9.2
	Detail commitments to undertaking a co-operative approach to climate change adaptation with governments, other industry and other sectors		Section 9.2
	Climate change adaptation should be incorporated in EIS and project design, while considering the balance between the uncertainty of outcomes and the costs of preparing for climate change		Section 9.2