APPENDIX 3

ARROW LNG PLANT

Greenhouse Gas Impact Assessment - Supplementary Report

arrow energy
go further

REPORT

ARROW LNG PLANT – GHG IMPACT ASSESSMENT – SUPPLEMENTARY REPORT

Coffey Environments

Job No: 3678d

13 November 2012

A PEL Company

PROJECT TITLE:	Arrow LNG Plant – GHG Impact Assessment – Supplementary Report
JOB NUMBER:	3678d
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DOCUMENT CONTROL			
VERSION	**DATE**	**PREPARED BY**	**REVIEWED BY**
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02	18.09.2012	Kelsey Bawden	Chaim Kolominskas
03	02.10.2012	Kelsey Bawden	Chaim Kolominskas
04	03.10.2012	Kelsey Bawden	Coffey Environments
05	26.10.2012	Kelsey Bawden	Arrow Energy
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ES1 EXECUTIVE SUMMARY

Arrow CSG (Australia) Pty Ltd (Arrow Energy) proposes to develop a liquefied natural gas (LNG) facility on Curtis Island off the central Queensland coast near Gladstone. The project, known as the Arrow LNG Plant, is a component of the larger Arrow LNG Project.

A greenhouse gas (GHG) assessment (PAEHolmes, 2011) was submitted that addresses the impact assessment of the estimated greenhouse gas emissions from the proposed Arrow LNG plant under the two following operating scenarios:

- an "all mechanical option" (also known as "Power Island Mode") using gas turbine compressor drives and generators
- an "all electrical option" (also known as "Power Import Mode") using electricity from the grid (mains power).

Following submission of the Environmental Impact Statement (EIS), further developments regarding the design of the Arrow LNG plant occurred and a number of design changes are proposed.

This supplementary report therefore addresses consequent relevant changes to the greenhouse gas assessment (PAEHolmes, 2011) due to the proposed project design changes.

The main change to project description that has the potential to affect the greenhouse gas impact assessment involves the consideration of the following two options for power generation:

- **"All mechanical option"**. This is the base case that was assessed in the EIS, and was modelled as part of the EIS greenhouse gas impact assessment.
- **"Mechanical/electrical option"** (also known as "Partial Auxiliary Power Import Mode"). This reflects the 'mechanical/electrical' case that was identified during the EIS. This case was not modelled in the original greenhouse gas assessment.

The "all electrical option", which was modelled as part of the EIS greenhouse gas impact assessment and the most emissions intensive option considered, has been discontinued.

Other changes in project design that impact the original greenhouse gas impact assessment include refined activity data (e.g. LNG production rates, coal seam gas (CSG) intake rates, estimated diesel usage requirements) and changes in flare design and areas of vegetation clearance.

The estimated emissions are shown to be lower than previously assessed in the original EIS for the "all mechanical option" and "all electrical option" operating scenarios. However, there is no change in estimated impacts of GHG emissions from the Arrow LNG Plant characterised in the original EIS.

The revised direct (scope 1) and indirect (scope 2) greenhouse gas emissions from the operation of Arrow LNG Plant were estimated to be 4.7 Mt CO_2-e/annum (excluding start-up flaring) for both the "mechanical/electrical option" and the "all mechanical option" (excluding start-up flaring). The majority of emissions are associated with gas combustion for the facility's power requirements and start-up flaring. The operating scenarios represent approximately 0.9% of the Australian Government's 2020 emissions target (i.e., 5% emissions reduction from 2000 levels).

The aggregate (direct and indirect) greenhouse gas emissions from the Arrow LNG Plant are minor (i.e., 8.5 – 8.6%) in comparison with greenhouse gas emissions associated with the end-use of the product fuel. These end-use emissions will occur as a result of the combustion of LNG for heating and electricity. In comparison with other fossil fuels, particularly coal, combusting LNG for heating purposes emits less greenhouse gas emissions per unit of thermal energy produced. If LNG is combusted to produce electricity as opposed to direct heating use, the reductions in greenhouse gas emission intensity, when compared to other fossil fuels, are even greater per MWh of electricity generated.

The Arrow LNG Plant is a significant project in the Gladstone region, regardless of which power option is adopted, and as a result, its activities will contribute significantly to the total greenhouse gas emissions of the region. Arrow LNG Plant's greenhouse gas emissions' contribution to climate change will however be in proportion with Arrow LNG Plant's contribution to global greenhouse gas emissions. As the Arrow LNG Plant's contribution to global greenhouse gas emissions are negligible (0.016%) the impacts of the project on climate change are also expected to be negligible.

Consistent with the commitments and mitigation measures presented in the original assessment, a number of measures have been included in the Arrow LNG Plant design, including high efficiency gas turbines for power generation for both operating scenarios. The estimated emissions intensity (t CO_2-e/t LNG) is amongst the lowest emission intensities of existing and proposed LNG facilities in Australia and abroad, demonstrating that the Arrow LNG Plant utilises Best Available Technology (BAT). In addition, Arrow Energy has committed to the ongoing measurement and monitoring of the LNG plant's emissions and energy consumption, through a range of schemes, including:

- the National Greenhouse and Energy Reporting (NGER) System
- the Energy Efficiency Opportunities Program (EEO).

While the Arrow LNG Plant utilises BAT and is producing a low emissions fossil fuel, it is recommended that Arrow continues to investigate GHG abatement measures. This includes both ongoing monitoring and proactive and preventative maintenance programs at the site-level, to reduce fugitive emissions from equipment leaks, and high-level investigations into new technologies as they become available.

Arrow Energy is a direct participant in the carbon price mechanism. This means that Arrow Energy must report their emissions annually and acquit their carbon liability by submitting carbon units equivalent to their liable emissions under the *Clean Energy Act 2011*.

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1.1 Purpose of Report

Arrow CSG (Australia) Pty Ltd (Arrow Energy) proposes to develop a liquefied natural gas (LNG) facility on Curtis Island off the central Queensland coast near Gladstone. The project, known as the Arrow LNG Plant, is a component of the larger Arrow LNG Project.

A greenhouse gas (GHG) assessment (PAEHolmes, 2011) was submitted that addresses the impact assessment of the estimated greenhouse gas emissions from the proposed Arrow LNG plant under the two following operating scenarios:

- an "all mechanical option" (also known as "Power Island Mode") using gas turbine compressor drives and generators
- an "all electrical option" (also known as "Power Import Mode") using electricity from the grid (mains power).

Following submission of the Environmental Impact Statement (EIS), further developments regarding the design of the Arrow LNG occurred a number of design changes are proposed.

This supplementary report therefore addresses consequent relevant changes to the greenhouse gas assessment (PAEHolmes, 2011) due to the proposed project design changes.

1.2 Relevant Changes to the Project Description

The main change to project description that has the potential to affect the greenhouse gas impact assessment involves the consideration of the following two options for power generation:

- **"All mechanical option"**. This is the base case that was assessed in the EIS, and was modelled as part of the EIS greenhouse gas impact assessment.
- **"Mechanical/electrical option"** (also known as "Partial Auxiliary Power Import Mode"). This reflects the 'mechanical/electrical' case that was identified during the EIS. This case was not modelled in the original greenhouse gas assessment.

The "all electrical option", which was modelled as part of the EIS greenhouse gas impact assessment, has been discontinued.

Other changes in project design that impact the original greenhouse gas impact assessment include refined activity data (e.g. LNG production rates, coal seam gas (CSG) intake rates, estimated diesel usage requirements) and changes in flare design and areas of vegetation clearance.

The changes to project design that have the potential to affect greenhouse gas emissions are summarised in Table 1.1.

Table 1.1: Changes to Project Design that have the Potential to Affect Assessed Greenhouse Gas Emissions

Change to Project Description	Description
Power generation option	The main change to project description that has the potential to affect the greenhouse gas impact assessment involves the consideration of the following two options for power generation: ▪ **"All mechanical option"**. This is the base case that was assessed in the EIS, and was modelled as part of the EIS greenhouse gas impact assessment. ▪ **"Mechanical/electrical option"**. This reflects the 'mechanical/electrical' case which was identified during the EIS. This case was not modelled in the original greenhouse gas assessment. The 'all electrical' option, which was modelled as part of the EIS greenhouse gas impact assessment, has been discontinued. **"All mechanical option"** In this option, all the power required will be generated at the LNG plant site. The refrigerant compressors will be powered by gas turbines and all the auxiliary electrical power will be provided by gas turbine generators without importation of power (i.e., no change to the arrangement described in the EIS). For this option, 5 x 30 MW (megawatt) gas turbine generators are required for trains 1 and 2 and an additional 3 x 30 MW gas turbine generators will be required for trains 3 and 4. The 10-20 MW of power required during the construction phase (site construction activities and camp) will be generated on the construction site by means of diesel engine driven generators. **"Mechanical/electrical option"** In this option, power import from the Gladstone North Substation on the mainland includes: ▪ Two (redundant) high voltage (132 kilovolt (kv)) feeders to supply up to 80 megavolt ampere (MVA), installed underground from the Gladstone North Substation to the LNG plant. ▪ 3 x 30 MW gas turbine generators for trains 1 and 2. ▪ 3 x 30 MW gas turbine generators for trains 3 and 4 The worst case scenario for this option is assumed to involve one gas turbine generator tripping out while another gas turbine generator is undergoing maintenance. During this scenario, as much as 45 MW could be imported to meet the power demand for full capacity LNG production. Power will also be imported during the construction phase under this option. Diesel engine powered generators will be installed on site to supply construction power of approximately 5 MW during the initial phase of the construction work (first 16 months). After completion of the connection to the electricity grid, the power supply for construction will be taken from the grid and the on-site generation by diesel generators will be discontinued. Establishment of the power import connection is expected to be 14 months after the final investment decision. Prior to connection, power to the site will be provided by diesel generators. Following connection, major electrical users such as the construction camp and main temporary offices will be switched over to be powered by the electrical connection while smaller and relatively isolated users will continue to be powered by diesel generators. Electrical power after commissioning will be provided by the permanent electrical

Change to Project Description	Description
	connection.
Refinement of activity data for the Arrow LNG plant.	This includes: ▪ Refined projected LNG production data for the LNG plant of approximately 16.2 megatonnes per annum (Mtpa) compared to 18 Mtpa as previously assessed (and associated estimates of CSG requirements for each scenario). ▪ Refined diesel consumption requirements for construction activities (e.g. dredging volumes and associated diesel consumption, vessel movements – inclusion of landing craft transport (LCT) vessels). ▪ Refined estimates for the transport of materials, waste and employees.
Change to flare design for the Arrow LNG plant.	The design of the flares is now as follows: ▪ The operational flare is no longer present. ▪ All the flares will be gas-assisted during turn-down operation. Three flare stacks are required for the two train development (stage 1): ▪ An emergency/operational system for warm, wet (but not free water) streams (warm flare relief system, identified as 'F-WW'). ▪ An emergency/operational system for cold, dry streams (cold flare relief system, identified as 'F-CD'). ▪ An emergency/operational system for LNG storage and loading (storage and loading flare relief system, identified as 'F-LP'). With stage 2 (trains 3 and 4) an additional cold flare (F-CD) is required. For the overall four train development, the following is required (total four flare stacks): ▪ 1 X F-WW. ▪ 2 X F-CD. ▪ 1 X F-LP.
Vegetation clearance	Revised data indicates that an increased area of vegetation clearance is required for the Arrow LNG plant.
Increase in plant availability	In this revised assessment, plant availability has increased from 339 days annually to 346.3 days annually (94.8%).

Detailed greenhouse gas emission estimates for the "all mechanical option" and "mechanical/electrical option" are included in Appendix A.

1.3 Changes to Relevant Policy/Legislation

1.3.1 Change to Policies - International Context

The 17th United Nations Conference of Parties (COP-17) was held in November-December 2011 in Durban, South Africa. Countries agreed in Durban to begin work on a new climate change agreement that will cover all countries. Negotiations will begin immediately under a new group called the Ad Hoc Working Group on the Durban Platform for Enhanced Action. An agreement is to be completed by 2015 and set to come into effect from 2020 (DCCEE, 2012c).

Countries agreed at COP-17 there would be a second commitment period of the Kyoto Protocol from 1 January 2013. Parties who sign up to the Second Commitment Period are committing to reduce global emissions by at least 25%-40% below 1990 levels by 2020 (WRI, 2011). There will be further negotiations in 2012 to finalise the international rules for a second commitment period of the Kyoto Protocol. Emission reduction targets for countries joining a second commitment period of the Kyoto Protocol are expected to be concluded in late 2012.

Emissions from the Arrow LNG plant will count towards the second commitment period of the Kyoto Protocol if Australia is a signatory to the agreement.

1.3.2 Change to Policies – State

Under the Queensland government formed in April 2012, the *Smart Energy Savings Program* has been put on hold. This will have no effect on the outcomes of the greenhouse gas assessment for the Arrow LNG plant as the facility will be required to report under the Energy Efficiency Opportunities (EEO) Program.

No other changes to relevant policies or legislation that could potential impact the greenhouse gas assessment for the Arrow LNG plant were identified.

1.4 Change to Emission Estimation Techniques

The following emission estimation technique documents for greenhouse gas emissions have been updated since the original EIS was published:

- Australia National Greenhouse Accounts - National Greenhouse Accounts (NGA) Factors (DCCEE, 2012a).
- National Greenhouse and Energy Reporting System Measurement - Technical Guidelines for the estimation of greenhouse gas emissions by facilities in Australia 2012 (Technical Guidelines), (DCCEE, 2012b).

Greenhouse gas emissions presented in this supplementary report are based on the most recent published guidance documents approved by the Australian Government Department of Climate Change and Energy Efficiency (DCCEE).

2 REVISED GHG EMISSION ESTIMATES FOR THE ARROW LNG PLANT

2.1 Summary of Activities

Consistent with the original EIS, the Arrow LNG Plant will have a base-case capacity of 16 Mtpa, with a total plant capacity of up to 18 Mtpa. The plant will consist of four LNG trains, each with a nominal capacity of 4 Mtpa. The project will be undertaken in two phases of two trains (nominally 8 Mtpa), with a financial investment decision process for each phase.

Operations infrastructure associated with the LNG plant includes the LNG trains, LNG storage tanks, cryogenic pipelines, seawater inlet to supply a desalination plant and stormwater outlet pipelines, water and wastewater treatment, a 115 m high flare stack, power generators, administrative buildings and workshops.

Construction infrastructure associated with the LNG plant includes construction camps, a concrete batching plant and laydown areas.

The plant will also require marine infrastructure for the transport of materials, personnel and product (LNG) during construction and operations.

The plant will be constructed in two phases. Phase 1 will involve the construction of LNG trains 1 and 2, two LNG storage tanks, Curtis Island construction camp and, if additional capacity is required, a mainland workforce accommodation camp. Associated marine infrastructure will also be required as part of Phase 1. Phase 2 will involve the construction of LNG trains 3 and 4 and potentially a third LNG storage tank. Construction of Phase 1 is scheduled to commence in 2014 with train 1 producing the first LNG cargo in 2017. Construction of Phase 2 is anticipated to commence approximately five years after the completion of Phase 1 but will be guided by market conditions and a financial investment decision at that time.

A summary of the project phases considered in the assessment is provided in Table 2.1.

Table 2.1: Summary of project phases

Project Phase	Description	Phase Code	Estimated Year
Construction Phase 1	Construction Phase 1 involves the construction of LNG trains 1 and 2. Phase 1 is expected to commence in 2014 and occur for three and a half years.	C1	2014 (6 months)
		C2	2014-2015
		C3	2015-2016
		C4	2016-2017
Construction/operations period 1 (includes start-up flaring of LNG trains 1 and 2)	Construction/operations period of a year where the construction of LNG train 2 and the operation of LNG train 1 will occur simultaneously. Emissions included for this phase include the operation of LNG trains 1 and 2, start-up flaring (LNG Trains 1 and 2) and construction.	1	2017-2018
Full operation of LNG trains 1 and 2	Emissions associated with operation of LNG trains 1 and 2 are included in this phase.	2	2018-2019
		3	2019-2020
		4	2020-2021
		5	2021-2022
Construction Phase 2	Construction Phase 2 involves the construction of LNG trains 3 and 4. Phase 2 is expected to commence in Year 6 and end in Year 9 (included). During this stage, construction of LNG trains 3 and 4, and operation of LNG trains 1 and 2 will occur simultaneously. Emissions included for this phase include the operation of LNG trains 1 and 2 and construction of LNG trains 3 and 4.	6	2022-2023
		7	2023-2024
		8	2024-2025
Construction/operations period 2 (includes start-up flaring of LNG trains 3 and 4)	Construction/operations period of a year where the construction of LNG train 4 and the operation of LNG train 3 may occur in the same year. Emissions included in this phase include operation of LNG trains 1 to 4, start-up flaring (LNG Trains 3 and 4) and construction.	9	2025-2026
Full operation of LNG trains 3 and 4	The emissions from the operation of Arrow LNG are estimated to be similar for Year 10 to Year 25 and are based on operation of LNG trains 1 – 4.	10-25	2026-2042

GHG emission sources considered in the supplementary report include those described in Table 2.2.

Table 2.2: Emission sources considered in the greenhouse gas assessment

Scope 1 Emissions	Scope 2 Emissions	Scope 3 Emissions
CONSTRUCTION		
■ Fuel combustion – diesel for stationary energy and construction vehicles ■ Fuel combustion – diesel for transport energy - Marine vessels – dredging equipment - Marine vessels – tug boats and landing craft transport vessels ■ Fuel combustion – fuel oil for transport energy - Passenger marine vessels (fast cats) - Passenger/vehicle marine vessels (Ro-Pax) ■ Vegetation clearing	■ Electricity usage	■ Emissions from the extraction (and processing and transport) of diesel ■ Emissions from the extraction (and processing and transport) of fuel oil ■ Emissions from the production and transport and distribution losses of electricity ■ Emissions from the extraction and production of bulk materials (concrete, marine rock, sand, cement and fill) ■ Emissions from the transport of bulk materials (concrete, marine rock, sand and fill) ■ Personnel transport – air and road transport
OPERATION		
■ Fuel combustion – coal seam gas for stationary energy ■ Fuel combustion – diesel for transport energy - Marine vessels – tug boats - Vehicles ■ Fuel combustion – fuel oil for transport energy - Passenger marine vehicles (fast cats) - Passenger/vehicle marine vessels – (RoPax) ■ Fugitive emissions – venting from acid gas removal unit ■ Flares - Start up flaring - Pilot lights & maintenance flaring ■ Fugitive emissions - Facility level fugitives - Transmission	■ Electricity usage	■ Emissions from the extraction (and processing and transport) of CSG ■ Emissions from the extraction (and processing and transport) of diesel ■ Emissions from the extraction (and processing and transport) of fuel oil ■ End use of LNG

2.2 Revised Estimated Emissions

2.2.1 Construction

The total (scope 1, scope 2 and scope 3) greenhouse gas emissions associated with the construction of the Arrow LNG Plant are estimated to be approximately 0.6 Mt CO_2-e for Phase 1 (i.e., 2014-2022) and 0.4 Mt CO_2-e for Phase 2 (i.e., 2022-2042) for the "mechanical/electrical option" (refer to Table 2.7). Estimated emissions for the "all mechanical option" are similar and have been estimated to be 0.5 Mt CO_2-e for Phase 1 (i.e., 2014-2022) and 0.3 Mt CO_2-e for Phase 2 (i.e., 2022-2042). These emissions are considered insignificant in comparison with the total operational emissions for both phases (refer to Table 2.7).

The estimated emissions for both scenarios are broadly consistent with estimated emissions presented for the "all mechanical option" presented in the original EIS. A summary of changes in emission estimates is presented in Section 2.2.4.

As per the original EIS, Scope 1 construction emissions are associated with power generation (to run construction activities and the construction camp) for the "all mechanical option" and are associated with land clearing (in the first year) and fuel combusted for transport energy for both options.

Scope 2 construction emissions are associated with electricity consumed at Curtis Island for construction activities for the "mechanical/electrical option" and the electricity consumed at the TWAF for both options.

The "mechanical/electrical option" results in greater scope 3 greenhouse gas emissions when compared to the "all mechanical option" (approximately 131 kt CO_2-e for the "mechanical/electrical option" compared to 103 kt CO_2-e for the "all mechanical option"). This is due to the additional electricity usage associated with the "mechanical/electrical option" and associated upstream emissions from electricity generation in Queensland (e.g. coal mining/washery, coal rail transport).

Estimated annual emissions associated with construction activities for the "mechanical/electrical option" are presented in Table 2.3.

Estimated annual emissions associated with construction activities for the "all mechanical option" are presented in Table 2.4.

For detailed year by year emissions for the life of the project for both options, corresponding to project phases described in Table 2.1, please refer to Table 2.7.

Table 2.3: Annual Forecast Greenhouse Gas Emissions Associated with Construction Activities – "Mechanical/Electrical Option"

Category	Activity	Emissions (tonnes CO_2-e/annum) CO_2 [a]	CH_4	N_2O	Total (CO_2-e)
CONSTRUCTION - SCOPE 1 EMISSIONS					
Fuel Combustion	Construction power - construction activities and construction camp (diesel)	8,775	25	63	**8,863**
	Dredging equipment (diesel)	1,065	3	8	**1,076**
	Marine vessels - tug boats (diesel)	989	3	7	**999**
	Passenger marine vessels - fast cats (fuel oil)	1,606	1	13	**1,620**
	Passenger/vehicles marine vessels - Ro-Pax (fuel oil)	6,743	6	55	**6,804**
Land clearing	Vegetation removal (only included in Year 1)	67,753	0	0	**67,753**
CONSTRUCTION - SCOPE 2 EMISSIONS					
Energy Consumption	Electricity consumption at the TWAF and construction camp	80,506	-	-	**80,506**
CONSTRUCTION - SCOPE 3 EMISSIONS					
Energy Consumption/ Production	Full fuel cycle - diesel (marine vessels)	147	-	-	**147**
	Full fuel cycle - diesel (construction activities)	672	-	-	**672**
	Full fuel cycle - fuel oil (marine vessels)	607	-	-	**607**
	Full fuel cycle - electricity (TWAF and construction camp)	11,233	-	-	**11,233**
	Bulk construction materials - embodied energy	14,607	-	-	**14,607**
	Bulk construction materials - transportation	5,963	17	43	**6,023**
	Personnel transport	45,828	10	39	**5,877**
	Waste transportation	14	-	-	**14**
TOTAL SCOPE 1 EMISSIONS (excluding vegetation clearing)		**19,177**	**38**	**147**	**19,362**
TOTAL SCOPE 2 EMISSIONS		**80,506**	**-**	**-**	**80,506**
TOTAL SCOPE 3 EMISSIONS		**39,072**	**28**	**82**	**39,182**
OVERALL		**138,755**	**66**	**229**	**139,050**

Note: Calculated with activity data estimates and emission estimation techniques detailed in Appendix A.

a. Some 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.

Table 2.4: Annual Forecast Greenhouse Gas Emissions Associated with Construction Activities – "All Mechanical Option"

Category	Activity	Emissions (tonnes CO_2-e/annum)			
		CO_2 [a]	CH_4	N_2O	Total (CO_2-e)
CONSTRUCTION - SCOPE 1 EMISSIONS					
Fuel Combustion	Construction power - construction activities and construction camp (diesel)	35,099	63	139	**35,301**
	Dredging equipment (diesel)	1,065	3	8	**1,076**
	Marine vessels - tug boats (diesel)	989	3	7	**999**
	Passenger marine vessels - fast cats (fuel oil)	1,606	1	13	**1,620**
	Passenger/vehicle marine vessels - Ro-Pax (fuel oil)	6,743	6	55	**6,804**
Land clearing	Vegetation removal (only included in Year 1)	67,753	0	0	**67,753**
CONSTRUCTION - SCOPE 2 EMISSIONS					
Energy Consumption	Electricity consumption at the TWAF	16,894	0	0	**16,894**
CONSTRUCTION - SCOPE 3 EMISSIONS					
Energy Consumption/ Production	Full fuel cycle - diesel (marine vessels)	147	-	-	**147**
	Full fuel cycle - diesel (construction activities)	2,688	-	-	**2,688**
	Full fuel cycle - fuel oil (marine vessels)	607	-	-	**607**
	Full fuel cycle - electricity (TWAF)	2,357	-	-	**2,357**
	Bulk construction materials - embodied energy	14,607	-	-	**14,607**
	Bulk construction materials - transportation	5,963	17	43	**6,023**
	Personnel transport	5,828	10	39	**5,877**
	Waste transportation	14	-	-	**14**
TOTAL SCOPE 1 EMISSIONS (excluding vegetation clearing)		**45,501**	**76**	**223**	**45,800**
TOTAL SCOPE 2 EMISSIONS		**16,894**	**0**	**0**	**16,894**
TOTAL SCOPE 3 EMISSIONS		**32,212**	**28**	**82**	**32,322**
OVERALL		**94,607**	**104**	**305**	**95,017**

Note: Calculated with activity data estimates and emission estimation techniques detailed in Appendix A.

a. Some 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.

2.2.2 Operation

The total (scope 1, scope 2 and scope 3) greenhouse gas emissions associated with the operation of Arrow LNG Plant have been estimated to be approximately 59.6 Mt CO2-e per annum (excluding start-up flaring[a]) for both the "mechanical/electrical option" (refer to Table 2.5) and the "all mechanical option" (refer to Table 2.6).

The estimated emissions for both scenarios are similar to estimated emissions presented for the "all mechanical" option" presented in the original EIS. Specific differences in emission estimates are summarised in Section 2.2.4.

Estimated annual emissions associated with operational activities for the "mechanical/electrical option" are presented in Table 2.5.

Estimated annual emissions associated with construction activities for the "all mechanical option" are presented in Table 2.6.

For detailed year by year emissions for the life of the project for both options, corresponding to project phases described in Table 2.1, please refer to Table 2.7.

[a] Start-up flaring emissions are only included for Year 1 and Year 9, when the LNG trains are brought on-line. It is estimated that two trains are brought on line in Year 1 and two trains are brought on-line in Year 9 (following respective construction periods). Therefore emissions from flaring are excluding when considering average annual emissions as they are one-off events.

Table 2.5: Annual Forecast Greenhouse Gas Emissions Associated with Operational Activities (4 LNG Trains) – "Mechanical/Electrical Option"

Category	Activity	Emissions (tonnes CO_2-e/annum)			
		CO_2 [a]	CH_4	N_2O	Total (CO_2-e)
OPERATION - SCOPE 1 EMISSIONS					
Fuel Combustion	Stationary engines - power generation for utilities and LNG trains (CSG)	3,216,676	13,322	1,998	**3,231,996**
	Marine vessels – tug boats for LNG movement (diesel)	1,179	2	3	**1,184**
	Marine vessels – tug boats for bulk material movement (diesel)	746	1	2	**749**
	Personnel transport - vehicles (diesel)	160	0	0	**161**
	Passenger marine vessels –fast cats (fuel oil)	1,523	1	13	**1,537**
	Passenger/vehicle marine vessels – Ro-Pax (fuel oil)	6,397	5	53	**6,455**
Fugitive Emissions	Venting from AGRU	537,487	27,123	-	**564,610**
	Start-up flaring (only included in Year 1 and Year 9)	41,391	1,533	460	**43,384**
	Pilot flaring & maintenance flaring	149,886	5,551	1,665	**157,103**
	Facility-level fugitives	-	625,572	-	**625,572**
	Transmission	0.172	74.82	-	**75**
OPERATION - SCOPE 2 EMISSIONS					
Energy Consumption	Electricity consumption (utility shortfall)	143,189	-	-	**143,189**
OPERATION - SCOPE 3 EMISSIONS					
Energy Consumption/ Production	End-use - LNG	47,281,658	96,247	28,874	**47,406,779**
	Full fuel cycle - CSG processed (upstream emissions associated with extraction and transport of CSG)	7,447,008	-	-	**7,447,008**
	Full fuel cycle – diesel (marine vessels & vehicles)	160	-	-	**160**
	Full fuel cycle - fuel oil (marine vessels)	576	-	-	**576**
	Full fuel cycle - electricity (utility shortfall)	19,980			**19,980**
TOTAL SCOPE 1 EMISSIONS (excluding start-up flaring)		**3,914,054**	**671,652**	**3,735**	**4,589,442**
TOTAL SCOPE 2 EMISSIONS		**143,189**	**-**	**-**	**143,189**
TOTAL SCOPE 3 EMISSIONS		**54,749,381**	**96,247**	**28,874**	**54,874,502**
OVERALL		**58,806,624**	**767,899**	**32,609**	**59,607,132**

Note: Calculated with activity data estimates and emission estimation techniques detailed in Appendix A.

a. 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.

Table 2.6: Annual Forecast Greenhouse Gas Emissions Associated with Operational Activities (4 LNG Trains) – "All Mechanical Option"

Category	Activity	Emissions (tonnes CO_2-e/annum)			
		CO_2 [a]	CH_4	N_2O	Total (CO_2-e)
OPERATION - SCOPE 1 EMISSIONS					
Fuel Combustion	Stationary engines - power generation for utilities and LNG trains (CSG)	3,302,761	13,679	2,052	**3,318,492**
	Marine vessels – tug boats for LNG movement (diesel)	1,179	2	3	**1,184**
	Marine vessels – tug boats for bulk material movement (diesel)	746	1	2	**749**
	Personnel transport - vehicles (diesel)	160	0	0	**161**
	Passenger marine vessels –fast cats (fuel oil)	1,523	1	13	**1,537**
	Passenger/vehicle marine vessels – Ro-Pax (fuel oil)	6,397	5	53	**6,455**
Fugitive Emissions	Venting from AGRU	537,487	27,123	-	**564,610**
	Start-up flaring (only included in Year 1 and Year 9)	*41,864*	*1,551*	*465*	**43,879**
	Pilot flaring & maintenance flaring	151,522	5,612	1,684	**158,818**
	Facility-level fugitives	-	632,713	-	**632,713**
	Transmission	0.172	74.82	-	**75**
OPERATION - SCOPE 2 EMISSIONS					
Energy Consumption	Electricity consumption (utility shortfall)	-	-	-	**0**
OPERATION - SCOPE 3 EMISSIONS					
Energy Consumption/ Production	End-use - LNG	47,281,658	96,247	28,874	**47,406,779**
	Full fuel cycle - CSG processed (upstream emissions associated with extraction and transport of CSG)	7,511,799	-	-	**7,511,799**
	Full fuel cycle – diesel (marine vessels & vehicles)	160	-	-	**160**
	Full fuel cycle - fuel oil (marine vessels)	576	-	-	**576**
	Electricity consumption (utility shortfall)	-	-	-	**0**
TOTAL SCOPE 1 EMISSIONS (excluding start-up flaring)		**4,001,776**	**679,210**	**3,807**	**4,684,793**
TOTAL SCOPE 2 EMISSIONS		**-**	**-**	**-**	**0**
TOTAL SCOPE 3 EMISSIONS		**54,794,192**	**96,247**	**28,874**	**54,919,313**
OVERALL		**58,795,968**	**775,457**	**32,681**	**59,604,106**

Note: Calculated with activity data estimates and emission estimation techniques detailed in Appendix A.

a. 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.

2.2.3 Revised Annual Summary of Emissions

A summary of the revised annual greenhouse gas emissions estimated to be generated from the construction and operational activities of the Arrow LNG Plant for both the "mechanical/electrical option" and the "all mechanical option" are presented in Table 2.7.

The methodology used to estimate emissions is consistent with the methodology used to estimate greenhouse gas emissions as described the original EIS. Greenhouse gas emissions have been re-estimated using revised activity data described in Section 1.2 and in accordance with the methodology described in Appendix A.

The following key aspects, generally consistent with the original assessment, influence when emissions are projected to occur:

- Vegetation clearing is estimated to occur in the first year of Construction Phase 1 (C1).
- Start-up flaring emissions were only included for Year 1 and Year 9, when the LNG trains are brought on-line. It is estimated that two trains are brought on line in Year 1 and two trains are brought on-line in Year 9 (following respective construction periods). In the original assessment it was incorrectly assumed that four trains would undergo start-up flaring in Year 9.
- Consistent with the original assessment, operational emissions are estimated based on the number of trains in operation for a given year.
- Emissions associated with construction activities (excluding vegetation clearing) are estimated to be similar for both construction phases (as per the original assessment).
- Scope 3 emissions associated with upstream activities (i.e., extraction and processing of CSG) were estimated using scope 1 emission intensities in kg CO_2-e/GJ (based on the average scope 1 emissions and the average CSG throughput), sourced from the Surat Gas Greenhouse Assessment (PAEHolmes, 2011).

A detailed comparison of emission estimates for the "mechanical/electrical option" and "all mechanical option" to estimated emissions presented in the original EIS is presented in Section 2.2.4.

Table 2.7: Revised Greenhouse Emissions by Scope Associated with Arrow LNG Plant - "Mechanical/Electrical Option" versus "All Mechanical Option"

Phase	Operational Year		Scope 1 and Scope 2: "Mechanical/Electrical Option"	Scope 1 and Scope 2: "All Mechanical Option"	Scope 3 (Including End-Use of LNG): "Mechanical/Electrical Option"	Scope 3 (Including End-Use of LNG): "All Mechanical Option"
			Emissions [t CO_2-e/annum]			
Construction Phase 1[a]	C1[b]	2014	83,321	83,254	3,419	3,419
	C2	2014-2015	50,099	43,006	39,861	38,649
	C3	2015-2016	100,484	62,739	53,242	46,339
	C4	2016-2017	99,868	62,694	30,237	23,377
Construction/operations period 1 (includes start-up flaring of LNG Trains 1 and 2) [c]	1	2017-2018	2,509,648	2,449,050	29,626,475	29,676,822
Full operation of LNG trains 1 and 2	2	2018-2019	2,366,396	2,342,477	27,426,893	27,459,289
	3	2019-2020	2,366,396	2,342,477	27,426,893	27,459,289
	4	2020-2021	2,366,396	2,342,477	27,426,893	27,459,289
	5	2021-2022	2,366,396	2,342,477	27,426,893	27,459,289
TOTAL – Construction Phase 1	**C1 -1**	**2014-2022**	**433,640**	**314,454**	**152,762**	**130,927**
TOTAL – Operation Phase 1	**1 - 5**	**2017-2022**	**11,875,362**	**11,756,263**	**139,308,046**	**139,494,836**
Construction Phase 2 [d]	6	2022-2023	2,449,370	2,388,277	27,453,745	27,479,281
	7	2023-2024	2,449,370	2,388,277	27,456,144	27,481,680
	8	2024-2025	2,449,370	2,388,277	27,454,309	27,479,845
Construction/operations period 2 (includes start-up flaring of LNG Trains 3 and 4) [e]	9	2025-2026	4,859,150	4,774,633	54,876,968	54,934,899
Full operation of LNG trains 3 and 4 [f]	10 - 25	2026-2042	4,732,791	4,684,954	54,853,786	54,918,578
TOTAL – Construction Phase 2	**6 - 9**	**2022-2026**	**331,896**	**183,201**	**106,700**	**79,260**
TOTAL – Operation Phase 2	**6 - 25**	**2022-2042**	**87,600,024**	**86,715,520**	**1,014,795,050**	**1,015,993,690**

a. Construction Phase 1 involves the construction of LNG trains 1 and 2. Phase 1 is expected to commence in 2014 and occur for three and a half years.

b. All the emissions associated with vegetation clearing were included in Year C1, as clearing is expected to occur over a six-month period.

c. Construction/operations period of a year where the construction of LNG train 2 and the operation of LNG train 1 will occur simultaneously. This phase is conservatively based on emissions from: the operation of LNG trains 1 and 2 (assuming a full year of operation), start-up flaring (LNG trains 1 and 2) and construction (assuming a full year of operation).

d. Construction Phase 2 involves the construction of LNG trains 3 and 4. Phase 2 is expected to commence in Year 6 and end in Year 9 (included). During this stage, construction of LNG trains 3 and 4, and operation of LNG trains 1 and 2 will occur simultaneously. This phase is based on emissions from the operation of LNG trains 1 and 2 and construction.

e. Construction/operations period of a year where the construction of LNG train 4 and the operation of LNG train 3 will occur simultaneously. In the assessment it has been conservatively assumed that during this year emissions occur from the operation of LNG trains 1 – 4 construction of the LNG trains 3 and 4 (full year) as the precise timing for commencement of operation for LNG trains 3 and 4 is unknown. This is consistent with the methodology used in the original assessment.

Start-up of LNG trains 3 & 4 in Year 9. This phase is based on emissions from the operation of LNG trains 1 to 4, start-up flaring (LNG Trains 3 and 4) and construction.

f. Consistent with the original assessment, the emissions from the operation of Arrow LNG are estimated to be similar for Year 10 to Year 25.

2.2.4 "Mechanical/Electrical Option" versus "All Mechanical Option"

A comparison between estimated emissions between the" mechanical/electrical option" and "all mechanical option" is presented in Table 2.8 for the construction phase and Table 2.9 for the operational phase.

The principal reasons for differences in estimated emissions between the two scenarios are summarised as follows:

CONSTRUCTION EMISSION ESTIMATES

Scope 1 emission sources:

- More diesel fuel is combusted under the "all mechanical option" to provide construction power and to generate electricity for the construction camp.

Scope 2 emission sources

- Additional electricity is required under the "mechanical/electrical option" to provide electricity for construction activities and for the construction camp. Both scenarios require electricity for the temporary workers accommodation camp (TWAF) on the mainland.

Scope 3 emission sources

- Consistent with the differences with scope 1 and scope 2 sources, more diesel fuel is combusted under the "all mechanical option" and more electricity is required under the "mechanical/electrical option".

OPERATIONAL EMISSION ESTIMATES

Scope 1 emission sources

- Slightly less CSG is combusted under the "mechanical/electrical option" as some of the power required for utilities during operation is sourced from the national electricity grid.

Scope 2 emission sources

- No electricity is required to be imported under the "all mechanical option".

Scope 3 emission sources

- Consistent with the differences in scope 1 and scope 2 sources, slightly less CSG is required under the "mechanical/electrical option" and electricity is not required under the "all mechanical option".

The comparison shows that lifecycle emissions (scope 1, scope 2 and scope 3 emissions) from the "all mechanical option" are essentially equivalent to emissions from the "mechanical/electrical option".

Table 2.8: Comparison of Forecast Greenhouse Gas Emissions Associated with Construction Activities - "Mechanical/Electrical Option" versus "All Mechanical Option"

Category	Activity	Emissions (tonnes CO_2-e/annum) "Mechanical/Electrical Option"	Emissions (tonnes CO_2-e/annum) "All Mechanical Option"	% Difference	Explanation for Difference in Emissions
CONSTRUCTION - SCOPE 1 EMISSIONS					
Fuel Combustion	Construction power - construction activities and construction camp (diesel)	8,863	35,301	298%	More diesel is combusted under the "all mechanical option" to provide construction power and to generate electricity for the construction camp.
	Dredging equipment (diesel)	1,076	1,076	0%	The same volume of material is required to be dredged under each scenario.
	Marine vessels - tug boats (diesel)	999	999	0%	The same activity for tugboats is required under each scenario.
	Passenger marine vessels - fast cats (fuel oil)	1,620	1,620	0%	The same activity for passenger marine vessels (fast cats) is required under each scenario.
	Passenger/vehicles marine vessels - Ro-Pax (fuel oil)	6,804	6,804	0%	The same activity for passenger /vehicle (Ro-Pax) vessels is required under each scenario.
Land clearing	Vegetation removal (only included in Year 1)	67,753	67,753	0%	The same vegetation removal during construction is required under each scenario.
CONSTRUCTION - SCOPE 2 EMISSIONS					
Energy Consumption	Electricity consumption at the TWAF and construction camp	80,506	16,894	-79%	Additional electricity is required under the "mechanical/electrical option" to provide electricity for construction activities and for the construction camp. Both scenarios require electricity for the temporary workers accommodation camp (TWAF) on the mainland.
CONSTRUCTION - SCOPE 3 EMISSIONS					
Energy Consumption/ Production	Full fuel cycle - diesel (marine vessels)	147	147	0%	The same activity for tugboats and dredging equipment is required under each scenario.
	Full fuel cycle - diesel (construction activities)	672	2,688	300%	More diesel is combusted under the "all mechanical option" to provide construction power and to generate electricity for the construction camp.
	Full fuel cycle - fuel oil (marine vessels)	607	607	0%	The same activity for passenger (fast cats) and passenger/vehicle (RoPax) vessels is required under each scenario.
	Full fuel cycle - electricity (TWAF)	11,233	2,357	-79%	Additional electricity is required under the "mechanical/electrical option" to provide electricity for construction activities and for the construction camp. Both scenarios require electricity for the temporary workers

Category	Activity	Emissions (tonnes CO_2-e/annum) "Mechanical/Electrical Option"	"All Mechanical Option"	% Difference	Explanation for Difference in Emissions
					accommodation camp (TWAF) on the mainland.
	Bulk construction materials - embodied energy	14,607	14,607	0%	The same amount of construction bulk material is assumed under both scenarios.
	Bulk construction materials - transportation	6,023	6,023	0%	The same amount of construction bulk material is assumed under both scenarios.
	Personnel transport	5,877	5,877	0%	The same amount of personnel transport is assumed for both scenarios.
	Waste transportation	14	14	0%	The same volume of waste is transported to landfill under both scenarios.
TOTAL SCOPE 1 EMISSIONS (excluding vegetation clearing)		**19,362**	**45,800**	**137%**	**Higher scope 1 emissions occur under the "all mechanical option" due to onsite generation of power using diesel generators.**
TOTAL SCOPE 2 EMISSIONS		**80,506**	**16,894**	**-79%**	**Higher scope 2 (indirect due to electricity usage) emissions occur under the "mechanical/electrical option" as bulk of the construction power is sourced from the national electricity grid.**
TOTAL SCOPE 3 EMISSIONS		**39,182**	**32,322**	**-18%**	**Higher scope 3 emissions occur under the "mechanical/electrical option" due to the additional electricity usage and associated upstream emissions from electricity generation in Queensland (e.g. coal mining/washery, coal rail transport).**
OVERALL		**139,050**	**95,017**	**-32%**	**Higher emissions occur under the "mechanical/electrical option". It is less emissions intensive to generate power onsite using diesel generators than importing electricity from the grid.**

Table 2.9: Comparison of Forecast Greenhouse Gas Emissions Associated with Operational Activities - "Mechanical/Electrical Option" versus "All Mechanical Option"

Category	Activity	Emissions (tonnes CO_2-e/annum) "Mechanical/Electrical Option"	"All Mechanical Option"	% Difference	Explanation for Difference in Emissions
OPERATION - SCOPE 1 EMISSIONS					
Fuel Combustion	Stationary engines - power generation for utilities and LNG trains (CSG) [a]	3,231,996	3,318,492	3%	Slightly less CSG is combusted under the "mechanical/electrical option" as some of the power required for utilities during operation is sourced from the national electricity grid.
	Marine vessels – tug boats for LNG movement (diesel)	1,184	1,184	0%	No difference in activity for tug boats assisting LNG tankers between the two scenarios.
	Marine vessels – tug boats for bulk material movement (diesel)	749	749	0%	No difference in activity for tug boats required for bulk material movements between the two scenarios.
	Personnel transport - vehicles (diesel)	161	161	0%	No difference in activity for personnel transport between the two scenarios.
	Passenger marine vessels –fast cats (fuel oil)	1,537	1,537	0%	No difference in activity for fast cat movements between the two scenarios.
	Passenger/vehicles marine vessels – Ro-Pax (fuel oil)	6,455	6,455	0%	No difference in passenger/vehicle marine vessel movements between the two scenarios.
Fugitive Emissions	Venting from acid gas removal unit (AGRU)	564,610	564,610	0%	No difference in venting emissions between the two scenarios.
	Start-up flaring (only included in Year 1 and Year 9)	43,384	43,879	1%	Slightly less CSG is required under the "mechanical/electrical option" as some power is imported from the electricity grid rather than generated onsite using CSG.
	Pilot flaring & maintenance flaring	157,103	158,818	1%	Slightly less CSG is required under the "mechanical/electrical option" as some power is imported from the electricity grid rather than generated onsite using CSG (slightly less maintenance flaring).
	Facility-level fugitives	625,572	632,713	1%	Slightly less CSG is required under the "mechanical/electrical option" as some power is imported from the electricity grid rather than generated onsite using CSG.
	Transmission	75	75	0%	No difference in transmission losses between the two scenarios.
OPERATION - SCOPE 2 EMISSIONS					
Energy Consumption	Electricity consumption (utility shortfall)	143,189	0	-100%	No electricity is required to be imported under the "all mechanical option".

Category	Activity	Emissions (tonnes CO_2-e/annum) "Mechanical/Electrical Option"	"All Mechanical Option"	% Difference	Explanation for Difference in Emissions
OPERATION - SCOPE 3 EMISSIONS					
Energy Consumption/ Production	End-use - LNG	47,406,779	47,406,779	0%	There is no difference in LNG production levels between the two scenarios.
	Full fuel cycle - CSG processed (upstream emissions associated with extraction and transport of CSG)	7,447,008	7,511,799	1%	Slightly less CSG is required under the "mechanical/electrical option" as some power is imported from the electricity grid rather than generated onsite using CSG.
	Full fuel cycle – diesel (marine vessels & vehicles)	160	160	0%	There is no difference in diesel usage between the two scenarios.
	Full fuel cycle - fuel oil (marine vessels)	576	576	0%	There is no difference in fuel oil usage between the two scenarios.
	Full fuel cycle - electricity (electricity shortfall)	19,980	0	-100%	No electricity is required to be imported under the "all mechanical option".
TOTAL SCOPE 1 EMISSIONS (excluding start-up flaring)		**4,589,442**	**4,684,793**	**2%**	Slightly less CSG is combusted under the "mechanical/electrical option" as some of the power required for utilities during operation is sourced from the national electricity grid.
TOTAL SCOPE 2 EMISSIONS		**143,189**	**0**	**NA**	**No electricity is required to be imported under the "all mechanical option".**
TOTAL SCOPE 1 & 2 EMISSIONS		**4,732,630**	**4,684,793**	**-1%**	**The "mechanical/electrical option" is slightly more emissions intensive in terms of scope 1 and scope 2 emissions as it is more energy efficient to generate power onsite than importing electricity from the grid.**
TOTAL SCOPE 3 EMISSIONS		**54,874,502**	**54,919,313**	**0%**	**Insignificant difference in scope 3 emissions between the two scenarios.**
OVERALL		**59,607,132**	**59,604,106**	**0%**	**Insignificant difference in total lifecycle emissions between the two scenarios considered.**

2.3 Comparison with Previous Assessment

A quantitative comparison of estimated emissions presented in this revised assessment and estimated emissions presented in the original assessment for the "all mechanical option" is presented in the section for cross reference purposes. A comparison for the "mechanical/electrical option" is not presented as this option was not considered in the original assessment.

Comparative emission estimates for the "all mechanical option" are presented in:

- Table 2.10 for construction emissions.
- Table 2.11 for operational emissions.

The principal causes for differences in estimated emissions for this assessment are summarised as follows:

CONSTRUCTION EMISSION ESTIMATES

Scope 1 emission sources:

- The assumptions regarding construction have been refined through front end engineering design, resulting in a lower estimate for the amount of diesel required for construction than previously assessed.
- The assumptions regarding dredging have been refined through front end engineering design resulting in increased dredging volumes (i.e. increased fuel required to power dredging equipment and subsequent emissions for dredging equipment) compared to the original assessment.
- Emissions from landing craft transport (LCT) vessels have been included in the assessment for the supplementary report (not specifically included in the original EIS).

Scope 2 emission sources:

- The Queensland emission factor for electricity usage has been recently updated from 0.89 kg CO_2/kWh to 0.86 kg/kWh (DCCEE, 2012b).

Scope 3 emission sources:

- Less diesel is required for construction power and more diesel is required for dredging than previously assessed (larger volumes of material is required to be dredged). This is consistent with the changes noted for scope 1 emission sources. Additional diesel has also been included in the supplementary assessment to account for LCT movements and transport of construction waste to Benaraby landfill.
- The Queensland scope 3 emission factor for electricity usage has reduced by 8% (from 0.13 kg CO_2/kWh to 0.12 kg CO_2/kWh) since the previous assessment (DCCEE, 2012a).
- Additional scope 3 emission sources have been included in the revised assessment including:
    - Upstream emissions from the use of bulk materials.
    - Transportation of bulk materials.
    - Transportation of personnel.

- Transportation of waste (as previously noted).

OPERATIONAL EMISSION ESTIMATES

Scope 1 emission sources:

- Estimates of CSG fuel consumption has been revised down after taking into account that the turbines are not fully loaded at all times and the turbines are not as efficient as stated by the manufacturer (Shell, 2012). Revised power requirements enabled a more realistic estimate of fuel consumption for each option to be made (see Appendix A for more detail).
- Start-up flaring is only considered when each train starts up following construction. In the supplementary report only two trains are required to flare at start-up after each construction period (i.e. trains 1 and 2 undergo start-up flaring after the phase 1 construction period and trains 3 and 4 undergo start-up flaring after the phase 2 construction period). In the original assessment it was assumed that all four trains undergo start-up flaring following the phase 2 construction period.
- The production rate of LNG has been revised down from 18 Mtpa to 16.2 Mtpa (Shell, 2012).

Scope 2 emission sources:

- No electricity is used in the "all mechanical option" as such there are no relevant changes in project design that affect greenhouse gas emissions for this option.

Scope 3 emission sources:

- The LNG production rate in the supplementary assessment has reduced by 10% when compared to the original assessment, in alignment with changes to the scope 1 emissions.

Table 2.10: Change in Annual Forecast Greenhouse Gas Emissions (Original EIS compared to Supplementary Report) Associated with Construction Activities – "All Mechanical Option"

Category	Activity	Emissions (tonnes CO_2-e/annum)		% Change	Reason for Difference in Estimated Emissions
		Original EIS	Supplementary Report		
CONSTRUCTION - SCOPE 1 EMISSIONS					
Fuel Combustion	Construction power - construction activities and construction camp (diesel)	48,959	35,301	-28%	The assumptions regarding construction have been refined through front end engineering design resulting in a lower estimate for the amount of diesel required for construction than previously assessed in the original EIS.
	Dredging equipment (diesel)	897	1,076	20%	The assumptions regarding dredging have been refined through front end engineering design resulting in increased dredging volumes (i.e. increased fuel required to power dredging equipment and subsequent emissions for dredging equipment) compared to the original assessment.
	Marine vessels - tug boats (diesel)	794	999	26%	Included emissions from LCT vessel movements in the supplementary report.
	Passenger marine vessels - fast cats (fuel oil)	1,620	1,620	0%	No change in activity data.
	Passenger/vehicles marine vessels - Ro-Pax (fuel oil)	6,804	6,804	0%	No change in activity data.
Land clearing	Vegetation removal (only included in Year 1)	64,032	67,753	6%	The area required to be cleared in the revised assessment has been refined.
CONSTRUCTION - SCOPE 2 EMISSIONS					
Energy Consumption	Electricity consumption at the TWAF	17,483	16,894	-3%	Difference is due to an updated emission factor in the NGER technical guidelines (DCCEE, 2012b).
CONSTRUCTION - SCOPE 3 EMISSIONS					
Energy Consumption/ Production	Full fuel cycle - diesel (marine vessels)	128	147	15%	As per scope 1 emission estimates, revised diesel volume estimates for marine vessels through the inclusion of LCT vessels and refined estimates for other marine vessels.
	Full fuel cycle - diesel (construction activities)	3,734	2,688	-28%	As per scope 1 emissions, the assumptions regarding construction have been refined through front end engineering design resulting in a lower estimate for the amount of diesel required for construction than previously assessed in the original EIS.

Category	Activity	Emissions (tonnes CO_2-e/annum)		% Change	Reason for Difference in Estimated Emissions
		Original EIS	Supplementary Report		
	Full fuel cycle - fuel oil (marine vessels)	607	607	0%	No change in activity data.
	Full fuel cycle - electricity (TWAF)	2,554	2,357	-8%	Change is due to an updated emission factor in the National Greenhouse Accounts (DCCEE, 2012a).
	Bulk construction materials - embodied energy	NA	14,607	NA	New source included in the supplementary report. Refined estimates on bulk material requirements for construction have been designed allowing an estimate to be made.
	Bulk construction materials - transportation	NA	6,023	NA	New source included in the supplementary report. Refined estimates on bulk material requirements for construction have been designed allowing an estimate to be made.
	Personnel transport	NA	5,877	NA	New source included in the supplementary report. Refined estimates on personnel requirements for construction been designed allowing an estimate to be made.
	Waste transportation	NA	14	NA	New source included in the supplementary report. Refined estimates on waste transportation have been designed allowing an estimate to be made.
TOTAL SCOPE 1 EMISSIONS (excluding vegetation clearing)		**59,074**	**45,800**	**-22%**	**Difference mainly due to the updated diesel requirement supplied for the supplementary report.**
TOTAL SCOPE 2 EMISSIONS		**17,483**	**16,894**	**-3%**	**Difference due to a change in emission factor for Queensland electricity usage (DCCEE, 2012a).**
TOTAL SCOPE 3 EMISSIONS		**7,022**	**32,322**	**360%**	**More detailed data were available allowing estimates for upstream emissions for embodied energy of bulk materials, transportation of bulk materials and personnel transport and downstream emissions for waste transportation to be made for the supplementary report.**
OVERALL		**83,580**	**95,017**	**14%**	**Difference mainly due to increased scope 3 emission estimates through the inclusion of upstream estimates for bulk materials and personnel transport in the supplementary report.**

Table 2.11: Change in Annual Forecast Greenhouse Gas Emissions (Original EIS compared to Supplementary Report) Associated with Operational Activities – "All Mechanical Option"

Category	Activity	Emissions (tonnes CO_2-e/annum) Original EIS	Supplementary Report	% Change	Reason for Difference in Estimated Emissions
OPERATION - SCOPE 1 EMISSIONS					
Fuel Combustion	Stationary engines - power generation for utilities and LNG trains (CSG) [a]	4,926,496	3,318,492	-33%	Revised power requirements enabled a more realistic estimate of fuel consumption for each option to be made that is less than previously estimated in the original EIS (Shell, 2012)
	Marine vessels – tug boats for LNG movement (diesel)	1,176	1,184	1%	Emission factors for diesel (transportation) have been updated.
	Marine vessels – tug boats for bulk material movement (diesel)	753	749	-1%	Revised emission factors for diesel (transportation) emission factors.
	Personnel transport - vehicles (diesel)	162	161	-1%	No change.
	Passenger marine vessels –fast cats (fuel oil)	1,537	1,537	0%	No change.
	Passenger/vehicles marine vessels – Ro-Pax (fuel oil)	6,455	6,455	0%	No change.
Fugitive Emissions	Venting from acid gas removal unit (AGRU)	564,610	564,610	0%	No change.
	Start-up flaring (only included in Year 1 and Year 9)	97,334	43,879	-55%	Revised flaring data provided.
	Pilot flaring & maintenance flaring	176,666	158,818	-10%	Updated production data available for the supplementary report.
	Facility-level fugitives	702,500	632,713	-10%	Updated production data available for the supplementary report.
	Transmission	75	75	0%	No change.
OPERATION - SCOPE 2 EMISSIONS					
Energy Consumption	Electricity consumption	0	0	NA	No electricity used in the "all mechanical option".
OPERATION - SCOPE 3 EMISSIONS					
Energy Consumption/ Production	End-use - LNG	52,778,452	47,406,779	-10%	Updated production data provided for the supplementary report.

Category	Activity	Emissions (tonnes CO_2-e/annum) Original EIS	Supplementary Report	% Change	Reason for Difference in Estimated Emissions
	Full fuel cycle - CSG processed (upstream emissions associated with extraction and transport of CSG)	8,338,679	7,511,799	-10%	Updated production data provided for the supplementary report.
	Full fuel cycle – diesel (marine vessels & vehicles)	159	160	0%	No change.
	Full fuel cycle - fuel oil (marine vessels)	576	576	0%	No change.
TOTAL SCOPE 1 EMISSIONS (excluding start-up flaring)		**6,380,431**	**4,684,793**	**-27%**	**Difference mainly due to the revised activity data provided for power generation requirements supplied for the supplementary report.**
TOTAL SCOPE 2 EMISSIONS		**0**	**0**	**NA**	**No electricity is required under the "all mechanical option".**
TOTAL SCOPE 3 EMISSIONS		**61,117,866**	**54,919,313**	**-10%**	**Updated production data provided for the supplementary report.**
OVERALL		**67,498,296**	**59,604,106**	**-12%**	**Updated production data provided for the supplementary report and revised activity data provided for power generation requirements supplied for the supplementary report.**

3 REVISED BENCHMARKING

The greenhouse emission intensity of Arrow LNG Plant associated with scope 1 and scope 2 emissions for the "mechanical/electrical option" and "all mechanical option" (in t CO_2-e/t LNG produced) has been benchmarked against the emission intensity of other LNG production facilities in Australia and overseas. It should be noted that only the emissions relevant to the production by the facility (i.e. scope 1 and scope 2 emission sources) are taken into account to estimate the greenhouse gas emission intensity.

The total scope 1 and scope 2 emissions for both options are estimated to be 4.7 Mt CO_2-e per annum (expressed to two significant figures). Therefore, Arrow LPG Plant is predicted to have an emission intensity of approximately 0.29 t CO_2e/ t LNG produced (based on 16.2 Mtpa LNG). The emissions intensity under the "mechanical/electrical option" is slightly more (0.293 t CO_2e/ t LNG produced) than under the "all mechanical option" (0.290 t CO_2e/ t LNG produced) as the energy efficiency of generating power onsite is slightly better than from importing electricity from the electricity grid. The emissions intensity of the Arrow LNG Plant, under both operating options, is shown in comparison to other facilities in Australia and abroad in Figure 3.1.

The revised operating scenarios of Arrow LNG have been shown to have a relatively low emissions intensity when compared to the previously assessed operating scenarios (0.35 – 0.45 t CO_2e/ t LNG) and with facilities in Australia and abroad. This indicates that both current design configurations are consistent with Best Available Technology (BAT) in relation to greenhouse gas emissions intensity for the industry.

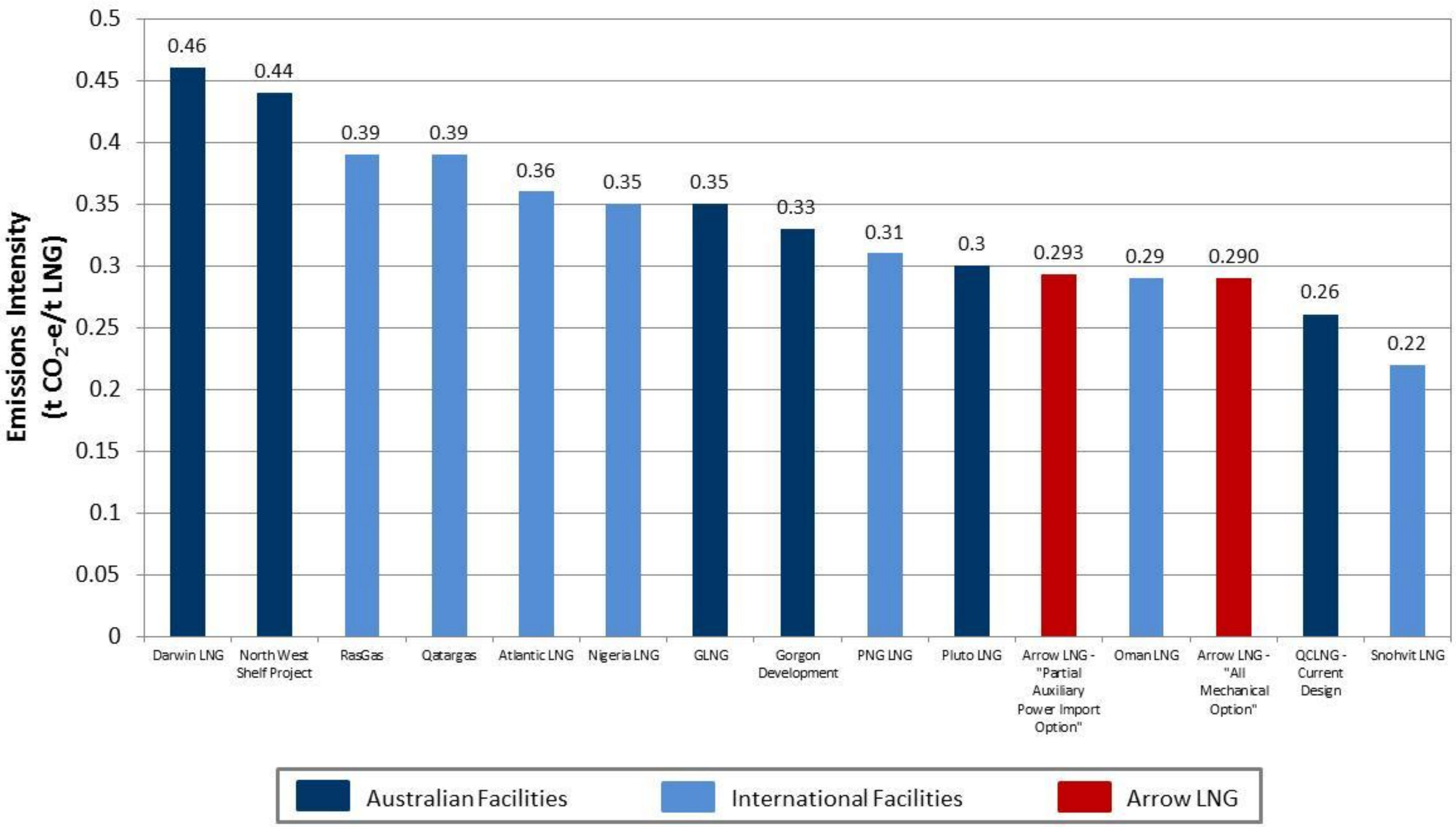

Figure 3.1: Revised Comparison of Arrow LNG to Greenhouse Gas Emission Intensities of other LNG Facilities

4 CONCLUSIONS

A greenhouse gas (GHG) assessment (PAEHolmes, 2011) was submitted that addressed the impact assessment of the estimated greenhouse gas emissions from the proposed Arrow LNG plant under the two following operating scenarios:

- an "all mechanical option" using gas turbine compressor drives and generators
- an "all electrical option" using electricity from the grid (mains power).

Following submission of the Environmental Impact Statement (EIS), further developments during the front end engineering design (FEED) of the Arrow LNG plant occurred and a number design changes are proposed.

This supplementary report addresses consequent relevant changes to the greenhouse gas assessment (PAEHolmes, 2011) due to the proposed project design changes.

The main change to the project description that has the potential to affect the greenhouse gas impact assessment involved the consideration of the following two options for power generation:

- **"All mechanical option"**. This is the base case that was assessed in the EIS, and was modelled as part of the EIS greenhouse gas impact assessment.
- **"Mechanical/electrical option".** This reflects the 'mechanical/electrical' case that was identified during the EIS. This case was not modelled in the original greenhouse gas assessment.

The "all electrical option", which was modelled as part of the EIS greenhouse gas impact assessment and is the most emissions intensive option considered, has been discontinued.

This assessment describes the greenhouse gas emissions from the construction and operation of Arrow LNG Plant under the two revised operating scenarios "mechanical/electrical option" and "all mechanical option" including changes to activity levels due to refined front end engineering design.

The estimated emissions are shown to be lower than previously assessed in the original EIS for the "all mechanical option" and "all electrical option" operating scenarios. However, there is no change in estimated impacts of GHG emissions from the Arrow LNG Plant compared with the assessment in the original EIS.

The revised direct (scope 1) and indirect (scope 2) greenhouse gas emissions from the operation of Arrow LNG Plant were estimated to be 4.7 Mt CO_2-e/annum (excluding start-up flaring) for both the "mechanical/electrical option" and the "all mechanical option" (excluding start-up flaring). The majority of emissions are associated with gas combustion for the facility's power requirements and start-up flaring. The aggregate operation emissions are insignificant in comparison with Global 2009 emissions (0.016%)[b]. However the project's emissions are more significant in Australian terms, considering Australia's 2009 emissions for the energy sector (i.e., 1.1%) or the Australian Government's 2020 emissions target (i.e., 0.9%), as can be seen in Table 4.1. However, Australia's total emission inventory in 2009 represents approximately

[b] The EIS compared emissions to Global 2007 emissions. Comparisons are made to Global 2009 emissions in the supplementary report as more recent Global greenhouse gas emission estimates are available (UNSD, 2012).

1.3% of global greenhouse emissions (UNSD, 2012). Therefore the potential impacts associated with climate change directly attributable to the Arrow LNG Plant on a global scale can be expected to be negligible.

Table 4.1: Estimates of greenhouse emissions

Geographic Coverage	Source Coverage	Timescale	Emissions (Mt CO_2-e)
Global [a]	Consumption of fossil fuels	2009	30,086
Australia [b]	Energy sector	2009	420.3
Australia [c]	All sectors	2020 (Australian Government's target)	530
Queensland [d]	Total GHG emissions including Land Use, Land Use Change and Forestry (LULUCF) activities	2009	155.1
Arrow LNG Plant [e]	**Scope 1 operational emissions**	**"Mechanical/electrical option"**	**4.7**
	Scope 2 operational emissions		**0**
	Total operational emissions		**4.7**
	Scope 1 operational emissions	**"All mechanical option"**	**4.6**
	Scope 2 operational emissions		**0.14**
	Total operational emissions		**4.7**

a. UNSD (2012)

b. DCCEE (2011) - Energy sector includes stationary energy, transport and fugitive emissions.

c. Based on 2000 Australian emissions levels for all sectors = 558 Mt CO_2-e (DCCEE, 2010). The Government has committed to reduce carbon pollution by 5 per cent from 2000 levels by 2020 (Australian Government, 2011).

d. DCCEE (2011) - Emissions including land use change.

e. Additional start-up emissions in first and ninth operational years due to flaring.

The aggregate (direct and indirect) greenhouse gas emissions from the Arrow LNG Plant are minor (i.e., 8.5 – 8.6%) in comparison with greenhouse gas emissions associated with the end-use of the product fuel. These end-use emissions will occur as a result of the combustion of LNG for heating and electricity. In comparison with other fossil fuels, particularly coal, combusting LNG for heating purposes emits less greenhouse gas emissions per unit of thermal energy produced. If LNG is combusted to produce electricity as opposed to direct heating use, the reductions in greenhouse gas emission intensity, when compared to other fossil fuels, are even greater per MWh of electricity generated.

Arrow LNG Plant is a significant project in the Gladstone region, regardless of which power option is adopted, and as a result, its activities will contribute significantly to the total greenhouse gas emissions of the region. Arrow LNG Plant's greenhouse gas emissions' contribution to climate change will however be in proportion with Arrow LNG Plant's contribution to global greenhouse gas emissions. As the Arrow LNG Plant's contribution to global greenhouse gas emissions are negligible (0.016%), the impacts of the project on climate change are also expected to be negligible.

Consistent with the commitments and mitigation measures presented in the original assessment, a number of measures have been included in the Arrow LNG Plant design, including high efficiency gas turbines for power generation for both operating scenarios. The estimated emissions intensity (t CO_2-e/t LNG) is amongst the lowest emission intensities of existing and proposed LNG facilities in Australia and abroad, demonstrating that the Arrow LNG Plant utilises Best Available Technology (BAT). In addition, Arrow Energy has committed to the ongoing measurement and monitoring of the LNG plant's emissions and energy consumption, through a range of schemes, including:

- the National Greenhouse and Energy Reporting (NGER) System

- the Energy Efficiency Opportunities Program (EEO).

While the Arrow LNG Plant utilises BAT and is producing a low emissions fossil fuel, it is recommended that Arrow continues to investigate GHG abatement measures. This includes both ongoing monitoring and proactive and preventative maintenance programs at the site-level, to reduce fugitive emissions from equipment leaks, and high-level investigations into new technologies as they become available.

Arrow Energy is a direct participant in the carbon price mechanism. This will mean that Arrow Energy must report their emissions annually and acquit their carbon liability by submitting carbon units equivalent to their liable emissions under the *Clean Energy Act 2011*.

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APPENDIX A

Estimation of Emissions

A.1 SCENARIOS ASSESSED

The two operational scenarios for consideration are now:

- **"All mechanical option"**. This is the base case that was assessed in the EIS, and was modelled as part of the EIS greenhouse gas impact assessment.
- **"Mechanical/electrical option"**. This reflects the 'mechanical/electrical' case which was identified during the EIS. This case was not assessed in the original greenhouse gas report.

A construction scenario will be linked to each operational scenario. That is, four scenarios will be considered in total.

A.2 EMISSION SOURCES

Emission sources considered in the revised assessment are summarised in Table A.1 for both the "mechanical/electrical option" and "all mechanical option".

Table A.1: Greenhouse gas emission sources

Scope 1 Emissions	Scope 2 Emissions	Scope 3 Emissions
CONSTRUCTION ■ Fuel combustion – diesel for stationary energy and construction vehicles ■ Fuel combustion – diesel for transport energy - Marine vessels – dredging equipment - Marine vessels – tug boats and landing craft transport vessels ■ Fuel combustion – fuel oil for transport energy - Passenger marine vessels (fast cats) - Passenger/vehicle marine vessels (Ro-Pax) ■ Vegetation clearing	■ Electricity usage	■ Emissions from the extraction (and processing and transport) of diesel ■ Emissions from the extraction (and processing and transport) of fuel oil ■ Emissions from the production and transport and distribution losses of electricity ■ Emissions from the extraction and production of bulk materials (concrete, marine rock, sand, cement and fill) ■ Emissions from the transport of bulk materials (concrete, marine rock, sand and fill) ■ Personnel transport – air and road transport
OPERATION ■ Fuel combustion – coal seam gas for stationary energy ■ Fuel combustion – diesel for transport energy - Marine vessels – tug boats - Vehicles ■ Fuel combustion – fuel oil for transport energy - Passenger marine vehicles (fast cats) - Passenger/vehicle marine vessels – (RoPax) ■ Fugitive emissions – venting from acid gas removal unit ■ Flares - Start up flaring - Pilot lights & maintenance flaring ■ Fugitive emissions - Facility level fugitives - Transmission	■ Electricity usage	■ Emissions from the extraction (and processing and transport) of CSG ■ Emissions from the extraction (and processing and transport) of diesel ■ Emissions from the extraction (and processing and transport) of fuel oil ■ End use of LNG

A.3 CONSTRUCTION - SCOPE 1 EMISSIONS

A.3.1 Fuel Combustion – Diesel for Stationary Energy and Construction Vehicles

"MECHANICAL/ELECTRICAL OPTION"

In this scenario, diesel consumption would gradually increase to 22 kL per day until the project's sixteenth month for power generation for the camp and fuel supply for on-site vehicles.

From the sixteenth month onwards, the power supply for construction will be imported from the grid.

Estimated diesel consumption required during phase 1 construction under the "mechanical/electrical option" is shown in Figure A.1.

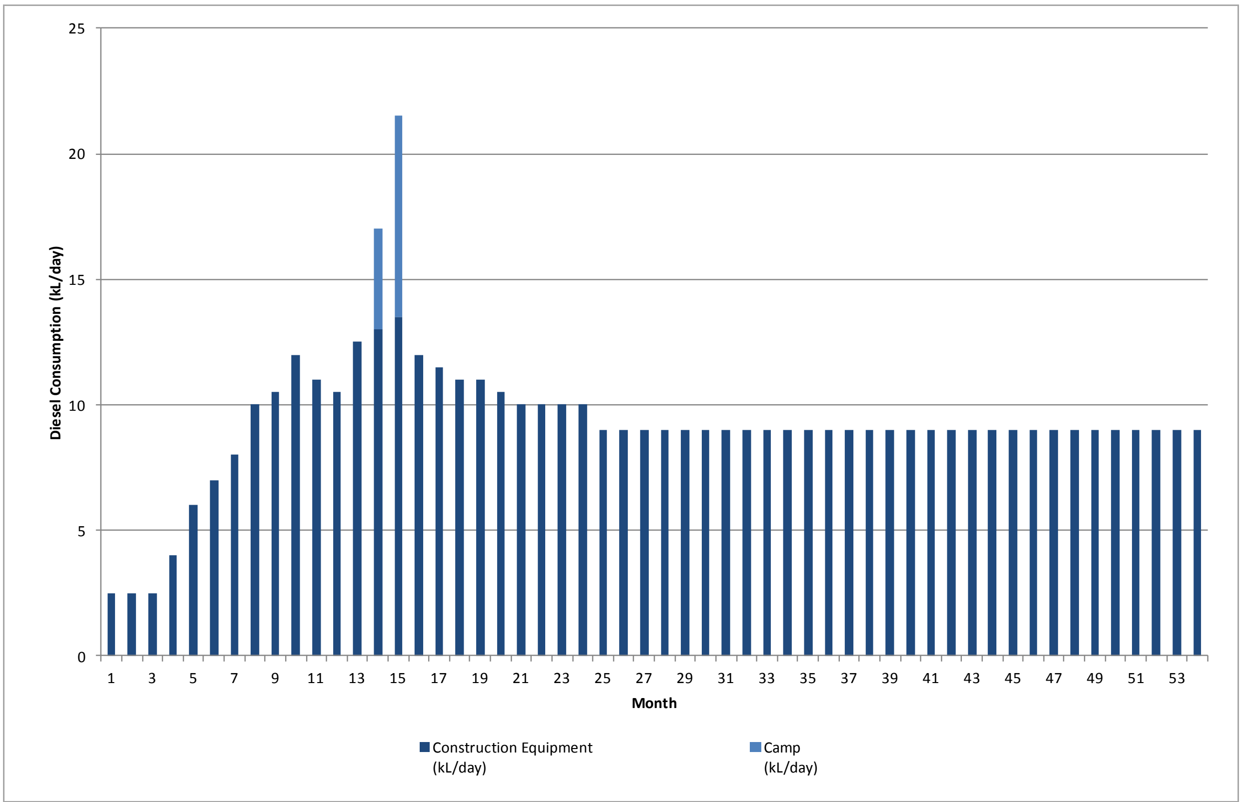

Figure A.1: Estimated diesel consumption during phase 1 construction ("mechanical/electrical option")

"ALL MECHANICAL OPTION"

Under the "all mechanical option", diesel will be combusted in construction equipment and in onsite power generators to power the camp.

Estimated diesel consumption required during phase 1 construction under the "all mechanical option" is shown in Figure A.2.

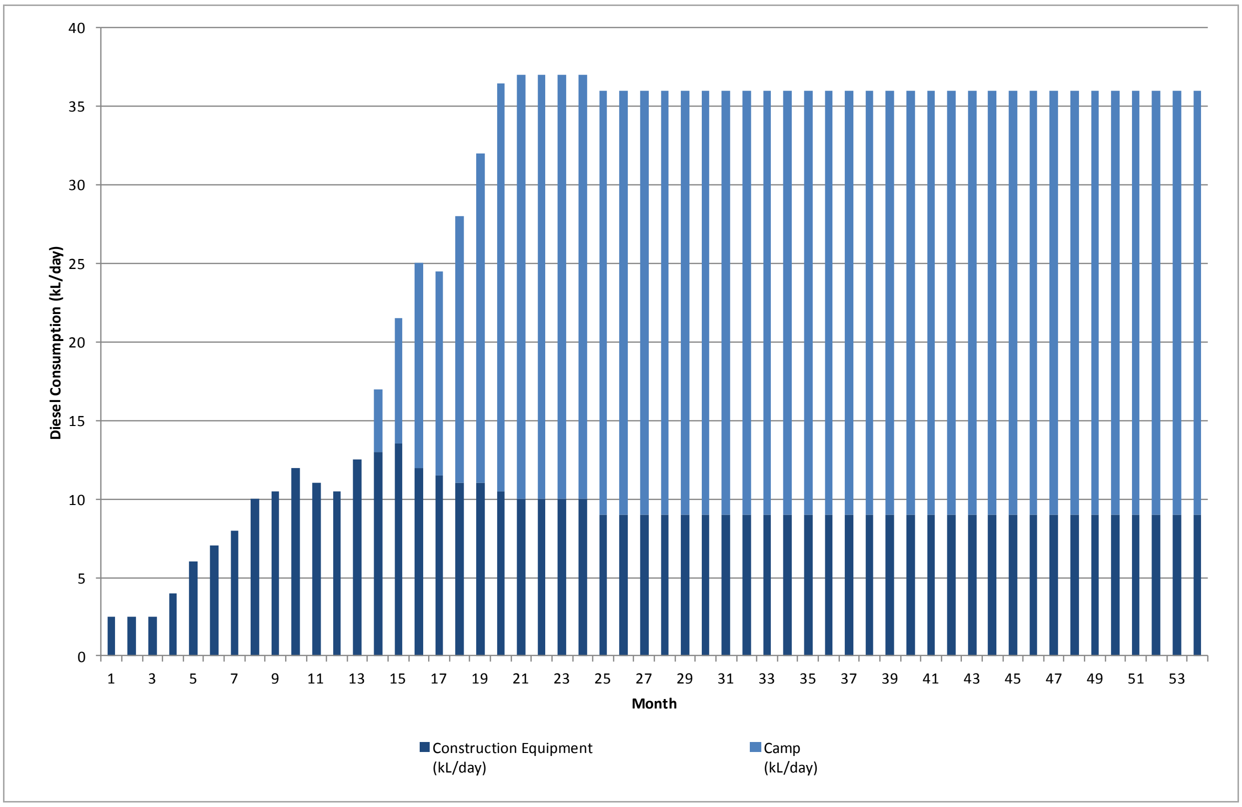

Figure A.2: Estimated diesel consumption during phase 1 construction ("all mechanical option")

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, 2012b)):

$$E_j = \frac{Q \times EC \times EF_{joxec}}{1000}$$

where:

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

The default energy content factor for diesel and the default emission factor for each gas were sourced from Table 2.4.2A (stationary energy) and Table 2.4.2B (transport energy), of the *Technical Guidelines* (DCCEE, 2012b) and are listed in Table A.2..

Table A.2: Factors associated with diesel combustion for construction activities

Method Used	Constant	Value	Units
-	Default energy content factor [a]	38.6	GJ/kL
Method 1	CO_2 emission factor (stationary energy)[a]	69.2	kg CO_2-e / GJ
Method 1	CH_4 emission factor (stationary energy)[a]	0.1	
Method 1	N_2O emission factor (stationary energy)[a]	0.2	
Method 1	CO_2 emission factor (transport energy)[b]	69.2	
Method 1	CH_4 emission factor (transport energy)[b]	0.2	
Method 1	N_2O emission factor (transport energy)[b]	0.5	

a. Table 2.4.2A, DCCEE (2012b)
b. Table 2.4.2B, DCCEE (2012b)

Estimated greenhouse gas emissions from diesel combustion for stationary energy and construction vehicles are presented in Table A.3 for the "mechanical/electrical option" and in Table A.4 for the "all mechanical option". 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 A.3: Estimated emissions from diesel combustion – stationary energy and construction vehicles ("mechanical/electrical option")

Project Phase	Phase Code	Actual Year	Emissions (tonnes/year)			
			CO_2	CH_4	N_2O	Total
Construction Phase 1 [a]	C1[b]	2014	1,991	6	14	2,011
	C2	2014-2015	11,984	33	82	12,099
	C3	2015-2016	9,384	27	68	9,479
	C4	2016-2017	8,775	25	63	8,863
Construction/ operations period 1[c]	1	2017-2018	8,775	25	63	8,863
Full operation of LNG trains 1 and 2	2	2018-2019	-	-	-	-
	3	2019-2020	-	-	-	-
	4	2020-2021	-	-	-	-
	5	2021-2022	-	-	-	-
Construction Phase 2[d]	6	2022-2023	8,775	25	63	8,863
	7	2023-2024	8,775	25	63	8,863
	8	2024-2025	8,775	25	63	8,863
Construction/operations period 2	9	2025-2026	8,775	25	63	8,863
Full operation of LNG trains 3 and 4	10-25	2026-2042	-	-	-	-

a. Construction Phase 1 involves the construction of LNG trains 1 and 2. Phase 1 is expected to commence in 2014 and occur for three and a half years.

b. Corresponds to a six month period

c. Construction/operations period of a year where the construction of LNG train 2 and the operation of LNG train 1 will occur simultaneously. Based on emissions from: the operation of LNG trains 1 and 2, start-up flaring (LNG Trains 1 and 2) and construction.

d. Construction Phase 2 involves the construction of LNG trains 3 and 4. Phase 2 is expected to commence in Year 6 and end in Year 9 (included). During this stage, construction of LNG trains 3 and 4, and operation of LNG trains 1 and 2 will occur simultaneously.

Table A.4: Estimated emissions from diesel combustion – stationary energy and construction vehicles ("all mechanical option")

Project Phase	Phase Code	Actual Year	Emissions (tonnes/year)			
			CO_2	CH_4	N_2O	Total
Construction Phase 1 [a]	C1 [b]	2014	1,991	6	14	2,011
	C2	2014-2015	15,477	38	92	15,608
	C3	2015-2016	35,139	64	142	35,346
	C4	2016-2017	35,099	63	139	35,301
Construction/ operations period 1[c]	1	2017-2018	35,099	63	139	35,301
Full operation of LNG trains 1 and 2	2	2018-2019	-	-	-	-
	3	2019-2020	-	-	-	-
	4	2020-2021	-	-	-	-
	5	2021-2022	-	-	-	-
Construction Phase 2[d]	6	2022-2023	35,099	63	139	35,301
	7	2023-2024	35,099	63	139	35,301
	8	2024-2025	35,099	63	139	35,301
Construction/operations period 2	9	2025-2026	35,099	63	139	35,301
Full operation of LNG trains 3 and 4	10-25	2026-2042	-	-	-	-

a. Construction Phase 1 involves the construction of LNG trains 1 and 2. Phase 1 is expected to commence in 2014 and occur for three and a half years.

b. Corresponds to a six month period

c. Construction/operations period of a year where the construction of LNG train 2 and the operation of LNG train 1 will occur simultaneously. Based on emissions from: the operation of LNG trains 1 and 2, start-up flaring (LNG Trains 1 and 2) and construction.

d. Construction Phase 2 involves the construction of LNG trains 3 and 4. Phase 2 is expected to commence in Year 6 and end in Year 9 (included). During this stage, construction of LNG trains 3 and 4, and operation of LNG trains 1 and 2 will occur simultaneously.

A.3.2 Fuel Combustion - Diesel for Transport Energy

A.3.2.1 Marine Vessels - Dredging Equipment

It was assumed that diesel oil will be used in dredging equipment to accommodate the construction and operation of the marine facility options during construction for both configuration options (i.e., "all mechanical option" and "mechanical/electrical option"). Five sites have been identified as requiring dredging, including:

- Boatshed point (Curtis Island) – the base case for Materials Offloading Facility (MOF) and personnel transfer facilities;
- Boatshed Point (Curtis Island) – access channel and swing basin
- LNG Jetty (Curtis Island) – construction dredging;
- Mainland Passenger Terminal Options:

- Launch Site 4N (Northern end of the proposed reclamation area for the Fishermans Landing Northern Expansion Project); and
- Launch Site 1 (north of Gladstone city near the mouth of the Calliope River).

Launch Site 1 option has been identified to be the worst case option for the dredging activity based on its more significant volume of material to be dredged (i.e., 900,000 m^3 vs. 2,500 m^3 for Launch Site 4N), which results in greater fuel consumption. Accordingly, emissions associated with dredging at Launch Site 4N were not assessed.

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, 2012b)):

$$E_j = \frac{Q \times EC \times EF_{joxec}}{1000}$$

where:

E_j	=	Estimated emissions of gas type (j) from diesel combustion	(t CO_2-e/a)
Q	=	Estimated quantity of diesel combusted in dredging equipments in a 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 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, 2012b) and are listed in Table A.5. The equation used to estimate the quantity of diesel combusted in dredging equipment is provided below and the associated activity data are presented in Table A.6. The resulting greenhouse gas emission estimates are presented in Table A.7. It is assumed that dredging emissions only occur in the first year of construction.

Table A.5: Factors associated with diesel combusted in dredging equipment

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	69.9	

a. Table 2.4.2B, DCCEE (2012b)

$$Q = \left(\frac{FC}{PC}\right) \times \sum_{1}^{4} V_{dm}$$

where:

Q	=	Estimated quantity of diesel combusted in dredging equipment in a year	(kL/a)
FC	=	Specific fuel consumption of dredger	(kL/hr)
PC	=	Nominal pump capacity of dredger	(m^3/hr)
V_{dm}	=	Volume of material to be dredged at sites 1 to 4	(m^3/a)

Table A.6: Data input associated with diesel combusted in dredging equipment

Data Required	Value	Units
Volume of Dredged Material - Boatshed Point MOF and integrated personnel jetty [a]	148,000	m^3
Volume of Dredged Material - Boatshed Point MOF access channel and swing basin [a]	165,000	
Volume of Dredged Material - LNG Product Jetty [a]	131,000	
Volume of Dredged Material - Launch 1 [a]	900,000	
Specific Fuel Consumption (7012 HP Dredger) [b, c]	0.0794	kL/hr
Nominal Pump Capacity (7012 HP Dredger) [b, c]	267.6	m^3/hr
Estimated quantity of diesel combusted in dredging equipment	332	kL/a

a. Coffey Environments (2012d)

b. IMS Dredges (2012)

c. This model was selected based on its suitability for port projects. The dredger is completely self-propelled. Maximum digging depth = 30 ft (about 9 m) (IMS Dredges, 2012)

Table A.7: GHG emissions associated with diesel combusted in dredging equipment

Option	Scope 1 Emissions (t CO_2-e/annum)			
	CO_2	CH_4	N_2O	Total CO_2-e
"all mechanical option" and "mechanical/electrical option"	1,065	3.1	7.7	1,076

A.3.2.2 Marine Vessels – Tug Boats & LCTs

Diesel will be used in tug boats (to propel barges) and landing craft transport (LCT) vessels for transport of bulk materials from the mainland to Curtis Island during construction for both configuration options (i.e., "mechanical/electrical option" and "All Mechanical Option").

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, 2012b)):

$$E_j = \frac{Q \times EC \times EF_{joxec}}{1000}$$

where:

E_j	=	Estimated emissions of gas type (j) from diesel combustion	(t CO_2-e/a)
Q	=	Estimated quantity of diesel combusted in tug boats in a 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 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, 2012b) and are listed in Table A.8.

Table A.8: Factors associated with diesel combusted in tug boats and LCTs for bulk material movement

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	69.9	

a. Table 2.4.2B, DCCEE (2012b)

The following equation was used to calculate the quantity of diesel combusted in tug boats:

$$Q_{TB} = \left(\frac{FC}{S_s}\right) \times N_{tb} \times n \times d \times \frac{365}{12}$$

where:

Q_{TB}	=	Estimated quantity of diesel combusted in tug boats in a year	(kL/month)
FC	=	Specific fuel consumption of tug boat (0.227 kL/hour, Source: Smit Marine Australia, 2011)	(kL/hour)
S_s	=	Service speed of tug boat (16.7 km/hour, Source: Smit Marine Australia, 2011)	(km/hour)
N_{tb}	=	Number of tug boats per barge (N_{TB} = 2)	(-)
n	=	Total number of barge trips in a month	(trips/month)
d	=	Trip distance (per return trip)	(km/trip)

Trip	Return distance (km)
Fishermans Landing to GLNG/GAWB (distance, including return)	16.8
MLS to MOF (distance, including return)	12.3

The following equation was used to calculate the quantity of diesel combusted in LCT vessels:

$$Q_{LCT} = \left(\frac{FC}{S_s}\right) \times n \times d \times \frac{365}{12}$$

where:

Q_{LCT}	=	Estimated quantity of diesel combusted in LCT vessels in a month	(kL/month)
FC	=	Specific fuel consumption of LCT vessel (FC = 0.15 kL/hour, typical fuel consumption rate for a 50 m LCT vessel)	(kL/hour)
S_s	=	Service speed of LCT vessel (S_S = 16 km/hour, based on a service speed of 8 knots)	(km/hour)
n	=	Number of return trips by LCT vessels per month	(trips/month)
d	=	Trip distance (per return trip)	(km/trip)

Trip	Return distance (km)
Fishermans Landing to GLNG/GAWB (distance, including return)	16.8
Marina to Pioneer MOF/GLNG/GAWB (distance, including return)	12.3
Marina to GLNG/GAWB (distance, including return)	12.3
MLS to MOF (distance, including return)	12.3

Estimated vessel movements required for transporting bulk materials for construction sourced from *Arrow LNG Plant Project Logistics Execution Plan* (Arrow Energy, 2012) are provided in Table A.9.

Table A.9: Estimated vessel movements required for transporting bulk materials for construction

Month	Return Movements Per day						Total
	50 m LCT Fishermans Landing to GLNG/GAWB	50 m LCT Marina to Pioneer MOF/GLNG /GAWB	50 m LCT Marina to GLNG/GAWB	70x20 Barge Fishermans Landing to GLNG/GAWB	70x20 Barge MLS to MOF	80 m ROPAX/LCT MLS to MOF	
1	2	0	2	0	0	0	4
2	2	0	2	0	0	0	4
3	2	0	2	0	0	0	4
4	0	4	0	1	0	0	5
5	0	4	0	1	0	0	5
6	0	4	0	1	0	0	5
7	0	4	0	1	0	0	5
8	0	4	0	1	0	0	5
9	0	4	0	1	0	0	5
10	0	4	0	0	2	0	6
11	0	4	0	0	2	0	6
12	0	4	0	0	2	0	6
13	0	0	0	0	2	3	5
14	0	0	0	0	2	3	5
15	0	0	0	0	2	3	5
16	0	0	0	0	2	3	5
17	0	0	0	0	2	3	5
18	0	0	0	0	2	3	5
19	0	0	0	0	2	3	5
20	0	0	0	0	2	3	5
21	0	0	0	0	2	3	5
22	0	0	0	0	2	3	5
23	0	0	0	0	2	3	5
24	0	0	0	0	2	3	5

[a] Source: Arrow Energy (2012)

Estimated greenhouse gas emissions associated with diesel combustion in tug boats and LCT vessels used for bulk materials transport during construction is provided in Table A.10.

Table A.10: GHG emissions from diesel combustion in tug boats and LCT vessels for bulk materials movement

Project Phase	Phase Code	Actual Year	Emissions (tonnes/year)			
			CO_2	CH_4	N_2O	Total
Construction Phase 1 [a]	C1[b]	2014	386	0.3	3	390
	C2	2014-2015	1,076	0.9	9	1,086
	C3	2015-2016	1,072	0.9	9	1,081
	C4	2016-2017	1,072	0.9	9	1,081
Construction/operations period 1 [c]	1	2017-2018	1,072	0.9	9	1,081
Full operation of LNG trains 1 and 2	2	2018-2019	-	-	-	-
	3	2019-2020	-	-	-	-
	4	2020-2021	-	-	-	-
	5	2021-2022	-	-	-	-
Construction Phase 2[d]	6	2022-2023	1,072	0.9	9	1,081
	7	2023-2024	1,072	0.9	9	1,081
	8	2024-2025	1,072	0.9	9	1,081
Construction/operations period 2	9	2025-2026	1,072	0.9	9	1,081
Full operation of LNG trains 3 and 4	10-25	2026-2042	-	-	-	-

a. Construction Phase 1 involves the construction of LNG trains 1 and 2. Phase 1 is expected to commence in 2014 and occur for three and a half years.
b. Corresponds to a six month period
c. Construction/operations period of a year where the construction of LNG train 2 and the operation of LNG train 1 will occur simultaneously. Based on emissions from: the operation of LNG trains 1 and 2, start-up flaring (LNG Trains 1 and 2) and construction.
d. Construction Phase 2 involves the construction of LNG trains 3 and 4. Phase 2 is expected to commence in Year 6 and end in Year 9 (included). During this stage, construction of LNG trains 3 and 4, and operation of LNG trains 1 and 2 will occur simultaneously.

A.3.3 Fuel Combustion - Fuel Oil for Transport Energy

A.3.3.1 Passenger Marine Vessels – Fast Cats

It was assumed that fuel oil will be consumed in Fast Cats for transport of passengers from the mainland to Curtis Island during construction for both configuration options (i.e., “mechanical/electrical option” and “all mechanical option”). Emissions from passenger marine vessels were assessed based on the Launch Site 4N option.

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, 2012b)):

$$E_j = \frac{Q \times EC \times EF_{joxec}}{1000}$$

where:

E_j	=	Estimated emissions of gas type (j) from fuel oil combustion	(t CO_2-e/a)
Q	=	Estimated quantity of fuel oil combusted in passenger marine vessels in a year	(kL/a)
EC	=	Energy content factor of fuel oil	(GJ/kL)
EF_{joxec}	=	Emission factor for each gas type (j)	(kg CO_2-e/GJ)

The default energy content factor for fuel oil and the default emission factor for each gas were sourced from Table 2.4.2B, of the *Technical Guidelines* (DCCEE, 2012b) and are listed in Table A.11.

Table A.11: Factors associated with fuel oil combusted in passenger marine vessels

Method Used	Constant	Value	Units
-	Default energy content factor [a]	39.7	GJ/kL
Method 1	Scope 1 default CO_2 emission factor [a]	72.9	kg CO_2-e/ GJ
Method 1	Scope 1 default CH_4 emission factor [a]	0.06	
Method 1	Scope 1 default N_2O emission factor [a]	0.6	
Method 1	Scope 1 overall emission factor	73.56	

a. Table 2.4.2B, DCCEE (2012b)

The following equation was used to calculate the quantity of fuel oil combusted in Fast Cats:

$$Q = FC \times T \times t$$

where:

Q	=	Estimated quantity of fuel oil combusted in passenger marine vessels in a year	(kL/a)
FC	=	Specific fuel consumption of passenger marine vessel	(kL/hr)
T	=	Total number of trips in a year	(trips/a)
t	=	Trip duration	(hr/trip)

Associated activity data for Fast Cat transportation is presented in Table A.12.

Table A.12: Data input associated with fuel oil combustion in passenger marine vessels

Data Required	Value	Units
Specific fuel consumption (Fast Cat 250 PAX) [a]	0.16	kL/hr
Total number of trips (including return trip) [b]	13,870	trips/a
Duration of trip from Launch 4N to Boatshed Point (one way) [c]	15 (0.25)	minutes/trip (hr/trip)
Estimated quantity of fuel oil combusted in passenger marine vessels [d]	555	kL/a

a. Estimated based on a fuel consumption rate of 80 L/hr per engine and 2 engines. Consistent with specifications for Calypso catamaran (Sea Speed Design, 2008)

b. Coffey Environments (2011b) – Based on 24 trips/day for Fast Cat 1, 14 trips/day for Fast Cat 2 and 365 days a year.

c. Coffey Environments (2011a) - Duration provided by Coffey Environments (between 15 & 20 minutes). Based on distance (Launch 4N to BSP) = 7.4 km and service speed = 37 km/hr (PAE's assumptions), the trip duration is below 15 minutes.

d. PAEHolmes' estimation

Estimated greenhouse gas emissions from fast cats are presented in Table A.13.

Table A.13: GHG emissions associated with fuel oil combustion in passenger marine vessels

Option	Scope 1 Emissions (t CO_2-e/annum)			
	CO_2	CH_4	N_2O	Total CO_2-e
"All Mechanical Option" or "Mechanical/Electrical Option"	1,606	1	13	1,620

A.3.3.2 Passenger/Vehicles Marine Vessels – Ro-Pax

It was assumed that fuel oil will be used in Ro-Pax[3] for transport of passengers and vehicles from the mainland to Curtis Island during construction for both configuration options (i.e., "mechanical/electrical option" and "All Mechanical Option"). Emissions from passenger/vehicle marine vessels were assessed based on the Launch Site 4N option.

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, 2012b)):

[3] Vessel with Roll-on, Roll-off and Passenger Capacity (Ro-Pax)

$$E_j = \frac{Q \times EC \times EF_{joxec}}{1000}$$

where:

E_j	=	Estimated emissions of gas type (j) from fuel oil combustion	(t CO_2-e/a)
Q	=	Estimated quantity of fuel oil combusted in passenger/vehicle marine vessels in a year	(kL/a)
EC	=	Energy content factor of fuel oil	(GJ/kL)
EF_{joxec}	=	Emission factor for each gas type (j)	(kg CO_2-e/GJ)

The default energy content factor for fuel oil and the default emission factor for each gas were sourced from Table 2.4.2B, of the *Technical Guidelines* (DCCEE, 2012b) and are listed in Table A.14.

Table A.14: Factors associated with fuel oil combustion in passenger/vehicle marine vessels

Method Used	Constant	Value	Units
-	Default energy content factor [a]	39.7	GJ/kL
Method 1	Scope 1 default CO_2 emission factor [a]	72.9	kg CO_2-e/ GJ
Method 1	Scope 1 default CH_4 emission factor [a]	0.06	
Method 1	Scope 1 default N_2O emission factor [a]	0.6	
Method 1	Scope 1 overall emission factor	73.56	

a. Table 2.4.2B, DCCEE (2012b)

The following equation as used to estimate the annual fuel consumption by Ro-Pax vessels:

$$Q = FC \times \frac{d}{60} \times n$$

where:

Q	=	Estimated quantity of fuel oil combusted in passenger/vehicle marine vessels in a year	(kL/a)
FC	=	Estimated fuel consumption rate (FC = 1.064 kL/hour, Source: Workboats International, 2011)	(kL/hour)
d	=	Estimated duration of one way trip (20 minutes, Coffey Environments, 2012)	(minutes/trip)
n	=	Number of one way trips per year (n = 6570 trips per year, based on 18 trips per day, 365 days per year (Arrow Energy, 2012)	(trips/year)

Estimated greenhouse gas emissions from Ro-Pax vessels is provided in Table A.15.

Table A.15: GHG emissions from fuel oil combustion in passenger/vehicle marine vessels

Option	Scope 1 Emissions (t CO_2-e/annum)			
	CO_2	CH_4	N_2O	Total CO_2-e
"All Mechanical Option" or "Mechanical/Electrical Option"	6,743	6	55	6,804

A.3.4 Vegetation Clearing

Clearing existing vegetation for the purposes of constructing project infrastructure will release an amount of stored carbon within the vegetation's biomass.

The FullCAM model from the National Carbon Accounting Toolbox can be used to determine vegetation clearing emission factors. This method was used for the GLNG project, yielding an emission factor of 201 t CO_2-e/ha (URS, 2009). This resulting emission factor is larger than the estimate PAEHolmes derived using FullCAM. As the projects are very close together, the emission factor determined by URS will be used as a conservative estimate of the vegetation clearing emissions.

The estimated emissions from land clearing associated with different project activities is summarised in Table A.16.

Table A.16: Vegetation clearance emission factors and areas cleared

Project Activity	Total Area Cleared per Activity [a] (ha)	Emission Factor [b] (t CO_2-e/ha)	Total Emission per Activity (t CO_2-e)
Vegetation clearing	336.7	201	67,753
Total			**67,753**

a. Coffey Environments (2012e).
b. URS (2009).

The estimated emissions of greenhouse gases over the life of the Arrow LNG Plant for vegetation clearing are approximately 64,032 t CO_2-e. These values do not take into account the planned rehabilitation of all areas cleared for project purposes and have been estimated conservatively.

A.4 SCOPE 1 EMISSIONS – OPERATION

A.4.1 Fuel Combustion – CSG for Stationary Energy

CSG is combusted in gas turbines to provide power during operation for the "mechanical/electrical option" and the "all mechanical option".

Emissions of CH_4 and N_2O were estimated using Method 1 (Division 2.3.2, *Method 1- emissions of carbon dioxide, methane and nitrous oxide,* of the *Technical Guidelines* (DCCEE, 2012b)):

$$E_j = \frac{Q \times EC \times EF_{joxec}}{1000}$$

where:

E_j	=	Estimated emissions of gas type (j) from CSG combustion	(t CO_2-e/a)
Q	=	CSG combusted in stationary engines in a year at standard conditions	(Sm^3/a)
EC	=	Energy content factor of CSG at standard conditions	(GJ/Sm^3)
EF_{joxec}	=	Emission factor for each gas type (j)	(kg CO_2-e/GJ)

The default energy content factor for CSG that is captured for combustion for stationary energy purposes and the default emission factor for each gas were sourced from Table 2.3.2A, of the *Technical Guidelines* (DCCEE, 2012b) and are listed in Table A.18.

Emissions of CO_2 were estimated using Method 2 presented below (Division 2.3.3, *Method 2-emissions of carbon dioxide from the combustion of gaseous fuels,* of the *Technical Guidelines* (DCCEE, 2012b)), which requires the composition of the CSG extracted (refer to Table A.17).

[1]
$$E_{CO_2} = \frac{Q \times EC \times EF_{CO2,ox,ec}}{1000}$$

[2]
$$EF_{CO2,ox,kg} = \sum_y \left[\left(\frac{mol_y\% \times \left(\frac{mw_y}{V}\right) \times 100}{d_{y,total}}\right) \times \left(\frac{44.010 \times f_y \times OF_g}{mw_y \times 100}\right)\right]$$

[3]
$$d_{y,total} = \sum_y mol_y\% \times \left(\frac{mw_y}{V}\right)$$

[4]
$$EF_{CO2,ox,ec} = EF_{CO2,ox,kg} \div \left(\frac{EC}{C}\right)$$

[5]
$$C = \frac{d_{y,total}}{100}$$

where:

E_{CO_2}	=	Estimated emissions of carbon dioxide from CSG combustion	(t CO_2-e/a)
Q	=	CSG combusted in stationary engines in a year at standard conditions	(Sm^3/a)
EC	=	Energy content factor of CSG at standard conditions	(GJ/Sm^3)
$EF_{CO2,ox,ec}$	=	Site-specific carbon dioxide emission factor for CSG combustion	(kg CO_2-e/GJ)
$EF_{CO2,ox,kg}$	=	Site-specific carbon dioxide emission factor for CSG combustion incorporating the effects of a default oxidation factor	(kg CO_2/kg CSG)
$mol_y\%$	=	Gas type *y*'s share of 1 mole of CSG; or gas type *y*'s share of the total volume of the CSG	(mol%)
mw_y	=	Molecular weight of gas type *y*	(kg/kmole)
V	=	Volume of 1 kilomole of the gas at standard conditions	(Sm^3/kmole)
$d_{y,total}$	=	Factor	(mol%.kg/kmole.Sm^3)
f_y	=	Number of carbon atoms in a molecule of gas type *y*	(-)
OF_g	=	Oxidation factor applicable to gaseous fuels	(-)
C	=	Density of CSG at standard conditions	(kg/Sm^3)

The additional constants required to estimate the emissions of carbon dioxide using equations [1-5] were sourced from the *Technical Guidelines* (DCCEE, 2012b) and are listed in Table A.17.

Table A.17: Additional constants required for CO_2 site-specific emission factor estimation

Constant	Value	Units
$mol\%_{CH4}$	98.01	mol%
$mol\%_{CO2}$	0.34	mol%
mw_{CH4} [a]	16.043	kg/kmole
mw_{CO2} [a]	44.01	kg/kmole
f_{CH4} [a]	1	Number of C atoms in CH_4
f_{CO2} [a]	1	Number of C atoms in CO_2
V [a]	23.6444	Sm^3/kmole
OF_g [a]	0.995	-

a. Division 2.3.3 DCCEE (2012b)

Table A.18: Factors associated with gas combusted in stationary engines

Method Used	Constant	Value	Units
-	Energy Content Factor [a]	0.0377	GJ/m^3
Method 2	Scope 1 Site-Specific CO_2 Emission Factor [b]	48.3	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	
-	Scope 1 Overall Emission Factor	48.54	

a. Table 2.3.2A, DCCEE (2012b).
b. PAEHolmes' estimation based on Section 2.22 (4) NGERS Measurement - Technical Guidelines (DCCEE, 2012b)

The equation used to estimate the amount of gas combusted for power generation during operation is provided below and the associated activity data are presented in Table A.19 and Table A.20.

$$Q = N_{GT} \times P \times \frac{A_{GT}}{100} \times 8760 \times LF$$

where:

Q	=	Estimated quantity of gas combusted in stationary turbines	(GJ/a)
N_{GT}	=	Number of gas turbines generators	(-)
P	=	Gas turbine shaft power	(MW)
A_{GT}	=	Gas turbines availability	(hrs/a)
HR_{GT}	=	Heat rate of the gas turbine	(GJ/MWh)
LF	=	Load factor	(-)

Table A.19: Activity data required to estimate gas usage ("mechanical/electrical option") – 4 train operation

Parameter	Value	Unit
Number of LNG trains [a]	4	-
Number of gas turbine generators to power LNG trains [a]	8	-
Load factor [b]	0.966	-
Gas turbine (LNG train) shaft power [c]	100.4	MW
Gas turbine thermal efficiency (LNG train) [c]	43.3	%
Gas turbine heat rate [d]	8.3	GJ/MWh
Gas turbine availability [a]	94.8	%
Number of gas turbine generators to power utilities [a]	6	-
Load factor [b]	0.98	-
Gas turbine (utilities) shaft power [c]	27.4	MW
Gas turbine (utilities) shaft power [c]	36.6	%
Gas turbine (utilities) heat rate [d]	9.8	GJ/MWh
Gas turbine (utilities) availability [a]	94.8	%

[a] Coffey Environments (2012b)

[b] Load factor to account for drop in performance efficiency and n+1 sparing (Derived from Shell, 2012)

[c] Coffey Environments (2012a)

[d] Calculated value

Table A.20: Activity data required to estimate gas usage ("all mechanical option") – 4 train operation

Parameter	Value	Unit
Number of LNG trains [a]	4	-
Number of gas turbine generators to power LNG trains [a]	8	-
Load factor [b]	0.966	-
Gas turbine (LNG train) shaft power [c]	100.4	MW
Gas turbine thermal efficiency (LNG train) [c]	43.3	%
Gas turbine heat rate [d]	8.3	GJ/MWh
Gas turbine availability [a]	94.8	%
Number of gas turbine generators to power utilities [a]	8	-
Load factor [b]	0.827	-
Gas turbine (utilities) shaft power [c]	27.4	MW
Gas turbine (utilities) shaft power [c]	36.6	%
Gas turbine (utilities) heat rate [d]	9.8	GJ/MWh
Gas turbine (utilities) availability [a]	94.8	%

[a] Coffey Environments (2012b)

[b] Load factor to account for drop in performance efficiency and n+1 sparing (Derived from Shell, 2012)

[c] Coffey Environments (2012a)

[d] Calculated value

The resulting greenhouse gas emission estimates are presented in Table A.21.

Table A.21: GHG emission associated with gas combusted in stationary engines

Mode	Description	CO_2	CH_4	N_2O	Total emissions
		(tonnes CO_2-e/year)			
"Mechanical/electrical option"	Gas turbines (LNG train)	2,587,260	10,715	1,607	2,599,583
	Gas turbines (utilities)	629,416	2,607	391	632,413
	Total emissions	**3,216,676**	**13,322**	**1,998**	**3,231,996**
"All mechanical option"	Gas turbines (LNG train)	2,587,260	10,715	1,607	2,599,583
	Gas turbines (utilities)	715,501	2,963	445	718,908
	Total emissions	**3,302,761**	**13,679**	**2,052**	**3,318,492**

A.4.2 Fuel Combustion - Diesel for Transport Energy

A.4.2.1 Marine Vessels - Tug Boats

Diesel oil is used in tug boats to propel dumb barges for transport of bulk materials from the mainland to Curtis Island and manoeuvre LNG carriers during operation for both configuration options (i.e., "mechanical/electrical option" and "all mechanical option"). Emissions from the transport of bulk materials were assessed based on the Launch Site 4N option.

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, 2012b)):

$$E_j = \frac{Q \times EC \times EF_{joxec}}{1000}$$

where:

E_j	=	Estimated emissions of gas type (j) from diesel combustion	(t CO_2-e/a)
Q	=	Estimated quantity of diesel combusted in tug boats in a 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 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, 2012b) and are listed in Table A.22. The equation used to calculate the quantity of diesel combusted in tug boats for bulk material and LNG movements are both provided below in the respective order. The associated activity data are presented in Table A.23. The resulting greenhouse gas emission estimates are presented in Table A.24.

Table A.22: Factors associated with diesel combustion in tug boats for bulk materials and LNG movement

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 (2012b).
b. PAEHolmes' estimation.

$$Q = \left(\frac{FC}{S_s}\right) \times N_{tb} \times T \times D$$

where:

Q	=	Estimated quantity of diesel combusted in tug boats associated with bulk materials movement in a year	(kL/a)
FC	=	Specific fuel consumption of tug boat	(kL/hr)
S_s	=	Service speed of tug boat	(km/hr)
N_{tb}	=	Number of tug boats per barge	(-)
T	=	Total number of trips in a year	(trips/a)
D	=	Trip distance	(km/trip)

$$Q = FC \times N_{tb} \times N_c \times D$$

where:

Q	=	Estimated quantity of diesel combusted in tug boats associated with LNG movement in a year	(kL/a)
FC	=	Specific fuel consumption of tug boat	(kL/hr)
N_{tb}	=	Number of tug boats per LNG carrier	(-)
N_c	=	Total number of LNG carriers in a year	(trips/a)
D	=	Trip duration (in and out of the harbour)	(hrs/trip)

Table A.23: Data inputs associated with diesel combustion in tug boats for bulk materials and LNG movements

Emission Source Description	Data Required	Value	Units
Bulk Materials and LNG Movements	Specific fuel consumption (Smit Leopard) [a]	0.227	kL/hr
	Service speed (Smit Leopard) [a]	16.7	km/hr
Bulk Materials Movement	Number of Smit Leopard tug boats per barge [b]	2	-
	Number of trips (including return) [b]	2	trips/day
	Number of operating days [b]	346.3	days/a
	Total number of trips (including return)	693	trips/a
	Distance between Launch 4N and Boatshed Point (including return) [b]	14.8	km/trip
	Estimated quantity of diesel combusted in tug boats associated with bulk materials movement	279	kL/a
LNG Movement	Number of tug boats per carrier [b]	2	-
	Total number of carriers [c]	243	trips/a
	Trip duration (in and out of the harbour) [b]	4	hrs/trip
	Estimated quantity of diesel combusted in tug boats associated with LNG movement	441	kL/a

a. Smit Marine Australia (2011).

b. Coffey Environments (2011b).

c. Coffey Environments (2011b) - Based on worst case: Option 1 - 15 ships per 1 Mtpa based on 145,000 m^3 ship capacity and a production rate of 16.168 Mtpa.

Table A.24: GHG emissions associated with diesel combustion in tug boats for bulk materials and LNG movements - "Mechanical/Electrical Option" and "All Mechanical Option"

Option	Emission Source Description	Scope 1 Emissions (t CO_2-e/annum)			
		CO_2	CH_4	N_2O	Total CO_2-e
"mechanical/electrical option" or "all mechanical option"	Bulk Materials Movement	746	2	5	753
	LNG Movement	1,179	2	3	1,184
	Bulk Materials & LNG Movements	1,925	4	8	1,937

A.4.2.2 Vehicles

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, 2012b)):

$$E_j = \frac{Q \times EC \times EF_{joxec}}{1000}$$

where:

E_j	=	Estimated emissions of gas type (j) from diesel combustion	(t CO_2-e/a)
Q	=	Estimated quantity of diesel combusted in vehicles in a 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 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, 2012b) and are listed in Table A.25. The activity data associated with diesel combustion in vehicles and the resulting greenhouse gas emission estimates are presented in Table A.26 and Table A.27 respectively.

Table A.25: Factors associated with diesel combustion in vehicles for personnel transport

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	69.9	

a. Table 2.4.2B, DCCEE (2012b)

Table A.26: Data input associated with diesel combustion in vehicles for personnel transport

Data Required	Value	Units
Estimated quantity of diesel combusted in vehicles [a]	60	kL/a

a. Coffey Environments (2012b) – Based on 8-10 trips/day and a distance of 5 km from the mainland workers camp to Launch Site 1.

Table A.27: GHG emissions associated with diesel combustion in vehicles for personnel transport

Option	Scope 1 Emissions (t CO_2-e/annum)			
	CO_2	CH_4	N_2O	Total CO_2-e
"mechanical/electrical option" or "all mechanical option"	160	0	1	162

A.4.3 Fuel Combustion - Fuel Oil for Transport Energy

A.4.3.1 Passenger Marine Vessels – Fast Cats

It was assumed that fuel oil will be used in Fast Cats for transport of passengers from the mainland to Curtis Island during operation for both configuration options (i.e., "mechanical/electrical option" and "all mechanical option").

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, 2012b)):

$$E_j = \frac{Q \times EC \times EF_{joxec}}{1000}$$

where:

E_j	=	Estimated emissions of gas type (j) from fuel oil combustion	(t CO_2-e/a)
Q	=	Estimated quantity of fuel oil combusted in passenger marine vessels in a year	(kL/a)
EC	=	Energy content factor of fuel oil	(GJ/kL)
EF_{joxec}	=	Emission factor for each gas type (j)	(kg CO_2-e/GJ)

The default energy content factor for fuel oil and the default emission factor for each gas were sourced from Table 2.4.2B, of the *Technical Guidelines* (DCCEE, 2012b) and are listed in Table A.28. The equation used to calculate the quantity of fuel oil combusted in Fast Cats is provided below and the associated activity data are presented in Table A.29. The resulting greenhouse gas emission estimates are presented in Table A.30.

Table A.28: Factors associated with fuel oil combustion in passenger marine vessels

Method Used	Constant	Value	Units
-	Default energy content factor [a]	39.7	GJ/kL
Method 1	Scope 1 default CO_2 emission factor [a]	72.9	kg CO_2-e/GJ
Method 1	Scope 1 default CH_4 emission factor [a]	0.06	
Method 1	Scope 1 default N_2O emission factor [a]	0.6	
Method 1	Scope 1 overall emission factor	73.56	

a. Table 2.4.2B, DCCEE (2012b).

$$Q = FC \times T \times t$$

where:

Q	=	Estimated quantity of fuel oil combusted in passenger marine vessels in a year	(kL/a)
FC	=	Specific fuel consumption of passenger marine vessel	(kL/hr)
T	=	Total number of trips in a year	(trips/a)
t	=	Trip duration	(hr/trip)

Table A.29: Data inputs associated with fuel oil combustion in passenger marine vessels

Data Required	Value	Units
Specific fuel consumption (Fast Cat 250 PAX (passengers)) [a]	0.16	kL/hour
Service speed [a]	37	km/hour
Number of trips (including return) [b]	38	trips/day
Number of operating days [c]	346.3	days/annum
Total number of trips (including return trips)	13,159	trips/annum
Duration of trip from Launch 4N to Boatshed Point (one way) [d]	15 (0.25)	minutes/trip (hour/trip)
Estimated quantity of fuel oil	526	kL/a

a. Estimated based on a fuel consumption rate of 80 L/hr per engine and 2 engines. Consistent with specifications for Calypso catamaran (Sea Speed Design, 2008)

b. Coffey Environments (2011b) – Based on 24 trips/day for Fast Cat 1, 14 trips/day for Fast Cat 2.

c. Coffey Environments (2012b).

d. Coffey Environments (2011a) - Duration provided by Coffey Environments (between 15 & 20 minutes). Based on distance (Launch 4N to BSP) = 7.4 km and service speed = 37 km/hr (PAE's assumptions), the trip duration is below 15 minutes.

Table A.30: GHG emissions associated with fuel oil combustion in passenger marine vessels

Option	Scope 1 Emissions (t CO_2-e/annum)			
	CO_2	CH_4	N_2O	Total CO_2-e
"mechanical/electrical option" or "all mechanical option"	1,523	1	13	1,537

A.4.3.2 Passenger/Vehicles Marine Vessels – Ro-Pax

It was assumed that fuel oil will be used in Ro-Pax for transport of passengers and vehicles from the mainland to Curtis Island during operation for both configuration options (i.e., "mechanical/electrical option" and "all mechanical option").

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, 2012b)):

$$E_j = \frac{Q \times EC \times EF_{joxec}}{1000}$$

where:

E_j	=	Estimated emissions of gas type (j) from fuel oil combustion	(t CO_2-e/a)
Q	=	Estimated quantity of fuel oil combusted in passenger/vehicle marine vessels in a year	(kL/a)
EC	=	Energy content factor of fuel oil	(GJ/kL)
EF_{joxec}	=	Emission factor for each gas type (j)	(kg CO_2-e/GJ)

The default energy content factor for fuel oil and the default emission factor for each gas were sourced from Table 2.4.2B, of the *Technical Guidelines* (DCCEE, 2012b) and are listed in Table A.31. The equation used to calculate the quantity of fuel oil combusted in Ro-Pax is provided below and the associated activity data are presented in Table A.32. The resulting greenhouse gas emission estimates are presented in Table A.33.

Table A.31: Factors associated with fuel oil combustion in passenger/marine vessels

Method Used	Constant	Value	Units
-	Default energy content factor [a]	39.7	GJ/kL
Method 1	Scope 1 default CO_2 emission factor [a]	72.9	kg CO_2-e/GJ
Method 1	Scope 1 default CH_4 emission factor [a]	0.06	
Method 1	Scope 1 default N_2O emission factor [a]	0.6	
Method 1	Scope 1 overall emission factor	73.56	

a. Table 2.4.2B, DCCEE (2012b)

Table A.32: Data inputs associated with fuel oil combustion in passenger/vehicle marine vessels

Data Required	Value	Units
Specific fuel consumption (Ro-Pax 300 PAX) [a]	1.064	kL/hr
Service Speed [b]	24	km/hr
Number of trips (including return trips) [c]	18	trips/day
Number of operating days [c]	346.3	days/a
Total number of trips (including return trips)	6,210	trips/a
Duration of trip from Launch 4N to Boatshed Point (one way) [d]	20 (0.33)	minutes/trip (hr/trip)
Estimated quantity of fuel oil	2,210	kL/a

a. Workboats International (2011) – Assumption based on 80 L/hr per engine (2 engines).

b. Workboats International (2011) – Based on 13 knots at economic speed.

c. Arrow Energy (2012)

d. Coffey Environments (2011a) - Duration provided by Coffey Environments (between 15 & 20 minutes). Based on distance (Launch 4N to BSP) = 7.4 km and service speed = 24.1 km/hr, the trip duration is closer to 20 minutes.

Table A.33: GHG emissions associated with fuel oil combusted in passenger/vehicle marine vessels

Option	Scope 1 Emissions (t CO_2-e/annum)			
	CO_2	CH_4	N_2O	Total CO_2-e
"mechanical/electrical option" or "all mechanical option"	6,397	5	53	6,455

A.4.4 Fugitive Emissions - Venting from the Acid Gas Removal Unit

CO_2 removed from the feed gas in the Acid Gas Removal Unit (AGRU) is vented to the atmosphere (based on process design information provided by Coffey Environments) during operation. Emissions of CO_2 and CH_4 for both configuration options (i.e., "mechanical/electrical option" and "all mechanical option") were estimated as follows:

$$E_{CO_2-e\,(CO_2)} = \frac{N_t \times \frac{VR}{MW_s} \times y_{CO_2} \times MW_{CO_2} \times 3600 \times 24 \times N_{op}}{1000}$$

where:

$E_{CO_2-e\,(CO_2)}$	=	Estimated emissions of CO_2-e from venting stream from the AGRU	(t CO_2-e/a)
N_t	=	Number of LNG trains	(trains)
VR	=	Vent rate of gas from the AGRU per LNG train	(kg/s/train)
MW_s	=	Molecular weight of the vent stream	(kg/kmole)
y_{CO_2}	=	Mol fraction of CO_2 in the vent stream	(-)
MW_{CO_2}	=	Molecular weight of CO_2	(kg/kmole)
N_{op}	=	Number of operating days	(days/a)

$$E_{CO_2-e\,(CH_4)} = \frac{N_t \times \frac{VR}{MW_s} \times y_{CO_2} \times MW_{CH_4} \times 3600 \times 24 \times N_{op} \times GWP_{CH_4}}{1000}$$

where:

$E_{CO_2-e\,(CH_4)}$	=	Estimated emissions of CO_2-e from venting stream from the AGRU	(t CO_2-e/a)
N_t	=	Number of LNG trains	(trains)
VR	=	Vent rate of gas from the AGRU per LNG train	(kg/s/train)
MW_s	=	Molecular weight of the vent stream	(kg/kmole)
y_{CH_4}	=	Mol fraction of CH_4 in the vent stream	(-)
MW_{CH_4}	=	Molecular weight of CH_4	(kg/kmole)
GWP_{CH_4}	=	Global warming potential of CH_4	(t CO_2-e/ t CH_4)
N_{op}	=	Number of operating days	(days/a)

The activity data for venting are presented in Table A.34 and the resulting greenhouse gas emission estimates are presented in Table A.35.

Table A.34: Data input associated with venting from the AGRU (4 trains)

Data Required	Value	Units
Number of LNG trains	4	trains
Vent rate per LNG train [a]	4.608	kg/s
Molecular weight of the vent stream [a]	42.43	kg/kmole
Mol fraction of CO_2 in vent stream [a]	0.940	-
Mol fraction of CH_4 in vent stream [a]	0.006	-
Molecular weight of CO_2 [b]	44.01	kg/kmole
Molecular weight of CH_4 [b]	16.043	kg/kmole
Global warming potential of CH_4 [c]	21	t CO_2-e/ t CH_4
Number of operating days [a]	346.3	days/a

a. Coffey Environments (2012b).

b. Division 2.3.3, DCCEE (2012b).

c. Appendix C, DCCEE (2012b).

Table A.35: GHG emissions associated with venting from the AGRU

Option	Scope 1 Emissions (t CO_2-e/annum)			
	CO_2	CH_4	N_2O	Total CO_2-e
"mechanical/electrical option" or "all mechanical option"	537,487	27,123	Not applicable	564,610

A.4.5 Fugitive Emissions – Process Flaring

A.4.5.1 Fugitive Emissions - Start-Up Flaring

During the start-up of the plant, untreated gas must be flared for safety reasons. Using the estimated amount of gas flared during this period for both configuration options (i.e., "mechanical/electrical option" and "all mechanical option"), emissions of CO_2, CH_4 and N_2O were estimated using Method 1 (Division 3.85, *Method 1- gas flared from natural gas production and processing,* of the *Technical Guidelines* (DCCEE, 2012b)):

$$E_j = Q \times EF_j$$

where:

E_j	=	Emissions of gas type (j) from CSG flared in the CSG production and processing during the year	(t CO_2-e/a)
Q	=	Quantity of CSG flared during 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 default energy content factor for *processed gas flared* and the default emission factor for each gas were sourced from Table 2.3.2A and Section 3.85 (2) respectively (*Technical Guidelines* (DCCEE, 2012b)) and are listed in Table A.36. The equation used to calculate the quantity of CSG flared is provided below and the associated activity data are presented in Table A.37. The resulting greenhouse gas emission estimates are presented in Table A.38.

Table A.36: Factors associated with start-up flaring

Method Used	Constant	Value	Units
-	Energy content factor [a]	0.0377	GJ/m^3
Method 1	Scope 1 default CO_2 emission factor [b]	2.7	t CO_2-e/t CSG flared
Method 1	Scope 1 default CH_4 emission factor [b]	0.1	
Method 1	Scope 1 default N_2O emission factor [b]	0.03	
Method 1	Scope 1 overall emission factor	2.83	

a. Table 2.3.2A, DCCEE (2012b).
b. Section 3.85, DCCEE (2012b).

$$Q = \%F \times Q_T \times D$$

where:

Q	=	Quantity of CSG flared in the reporting year	(t CSG flared/a)
$\%F$	=	Maximum percentage of total quantity of CSG produced for all trains being flared	(%CSG flared)
Q_T	=	Total quantity of CSG produced from all trains	(t CSG/hour)
D	=	Duration of flaring event under start-up conditions	(hours)

Table A.37: Data input associated with CSG start up flaring

Data Required	Value	Units
Maximum percentage of total quantity of CSG produced for all trains being flared [a]	30	%CSG flared
Total quantity of CSG produced from all trains ("mechanical/electrical option") [b]	2,129	t CSG/hour
Total quantity of CSG produced from all trains ("all mechanical option") [b]	2,153	t CSG/hour
Duration of flaring event under start-up conditions [c]	24	hours
Quantity of CSG flared ("mechanical/electrical option")[e]	15,330	t/a
Quantity of CSG flared ("all mechanical option")[e]	15,550	t/a

a. Coffey Environments (2012b).
b. Coffey Environments (2012b) – "Mechanical/electrical option" production of 51,100 tonnes CSG per day; "all mechanical option" production of 51,684 tonnes CSG per day.
c. Coffey Environments (2012b) - start-up should take about 12 hours (per train) – only 2 trains start up at any time (i.e. 2 x 12 hours = 24 hours).

Table A.38: GHG emissions associated with CSG start up flaring

Option	Scope 1 Emissions (t CO_2-e/annum)			
	CO_2	CH_4	N_2O	Total CO_2-e
"mechanical/electrical option"	41,391	1,533	460	43,384
"all mechanical option"	41,864	1,551	465	43,879

A.4.5.2 Fugitive Emissions - Pilot Lights Flaring & Maintenance Flaring

Flaring will not be used at Arrow LNG Plant for continuous disposal of process gas; however it will be required for the following events:

- pilot lights flaring - under normal operating conditions the pilot flares will be continuously lit to ensure its readiness state should there be an emergency event;
- unscheduled trips associated with equipment malfunction and/or process upsets and/or emergency; 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, 2012b)) for both configuration options (i.e., "mechanical/electrical option" and "all mechanical option"):

$$E_j = Q \times EF_j$$

where:

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

The default energy content factor for CSG and the default emission factor for each gas were sourced from Table 2.3.2A and Section 3.85 (2) respectively, of the *Technical Guidelines* (DCCEE, 2012b) and are listed in Table A.39. The equations used to calculate the quantity of CSG flared for pilot lights flaring and maintenance, and emergency flaring are provided below. The associated activity data and the resulting greenhouse gas emission estimates are presented Table A.40 and Table A.41, respectively.

Table A.39: Factors associated with process CSG flaring

Method Used	Variable	Value	Units
-	Default energy content factor [a]	0.0377	GJ/m^3
Method 1	Scope 1 default CO_2 emission factor [b]	2.7	t CO_2-e/ t CSG flared
Method 1	Scope 1 default CH_4 emission factor [b]	0.1	
Method 1	Scope 1 default N_2O emission factor [b]	0.03	
Method 1	Scope 1 overall emission factor	2.83	

a. Table 2.3.2A, DCCEE (2012b).
b. Division 3.85 (2), DCCEE (2012b).

$$Q = \frac{R \times N_{fs} \times D \times 24 \times \rho_{CSG}}{1000}$$

where:

Q	=	Quantity of CSG flared (associated with pilot lights flaring) in the reporting year	(t CSG flared/a)
R	=	Pilot gas burner release rate at standard conditions	(Sm³ CSG/hr/stack)
N_{fs}	=	Number of flare stacks with pilot gas burner	(stacks)
D	=	Duration of pilot lights flaring	(days/a)
ρ_{CSG}	=	CSG density at standard conditions	(kg CSG/Sm^3 CSG)

$$Q = \%F \times Q_T$$

where:

Q	=	Quantity of CSG flared (associated with maintenance and emergency flaring) in the reporting year	(t CSG flared/a)
$\%F$	=	Percentage of total quantity of CSG produced for all trains being flared from maintenance and emergency trips	(%CSG flared)
Q_T	=	Total quantity of CSG produced from all trains	(t CSG/day)

Table A.40: Data input associated with process CSG flaring

Data Required	Value	Units
Pilot gas burner release rate at standard conditions [a]	100	Sm^3 CSG/hr/stack
Number of flare stacks with pilot gas burner (4 trains development) [b]	4	stacks
Duration of pilot flaring [c]	365	days/a
CSG density at standard conditions [d]	0.692	kg CSG/Sm^3 CSG
Total quantity of CSG flared (associated with pilot flaring)	2,425	t CSG flared/a
Percentage of total quantity of CSG produced for all trains being flared from maintenance and emergency trips [e]	0.3	%CSG flared
Total quantity of CSG produced from all trains ("mechanical/electrical option")[f]	51,100	t CSG/day
Total quantity of CSG produced from all trains ("all mechanical option")[f]	51,684	t CSG/day
Total quantity of CSG flared (associated with maintenance and emergency flaring) [d] ("mechanical/electrical option")	53,088	t CSG flared/a
Total quantity of CSG flared (associated with maintenance and emergency flaring) [d] ("all mechanical option")	53,694	t CSG flared/a

a. Coffey Environments (2012b) – assuming continuous release at maximum rate.
b. Coffey Environments (2012b)
c. It is assumed that pilot lights would operate even in times of plant shutdown for safety purposes
d. Coffey Environments (2012b) - Based on CSG composition
e. Shell (2012)
f. Shell (2012) Based on 51,100 t CSG/day ("mechanical/electrical option") and 51,684 t CSG/day ("all mechanical option")

Table A.41: GHG emissions from process CSG flaring

Option	Activity Description	Scope 1 Emissions (t CO_2-e/annum)			
		CO_2	CH_4	N_2O	Total CO_2-e
"mechanical/electrical option"	Pilot flaring	6,548	243	73	6,864
	Emergency and maintenance flaring	143,338	5,309	1,593	150,239
	Total	**149,886**	**5,551**	**1,665**	**157,103**
"all mechanical option"	Pilot flaring	6,548	243	73	6,864
	Emergency and maintenance flaring	144,974	5,369	1,611	151,954
	Total	**151,522**	**5,612**	**1,684**	**158,818**

A.4.6 Fugitive Emissions – Facility-Level Fugitives & Transmission

A.4.6.1 Facility-Level Fugitives

Methane is the primary GHG in fugitive leak emissions from processing and compression. Two 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 CSG processed) for methane from general leaks in the natural gas production and processing sourced from the *Technical Guidelines* (DCCEE, 2012b); and
- 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* (API) *Compendium of Greenhouse Gas Emissions Methodologies for the Oil and Natural Gas Industry* (API, 2009) – this default emission factor was derived by combining component emission measurements and activity factors for a "typical" facility.
- The equation to convert the default facility-level average fugitive emission factor to a site-specific emission factor is provided below. The associated input data are presented in Table A.42. The comparison of the two available emission factors associated with general leaks is presented in Table A.43.

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

where:

$EF_{ss(CH_4)}$	=	Site-specific CH_4 emission factor for general leaks	(t CO_2-e /t CSG processed)
$EF_{d(CH_4)}$	=	Default CH_4 emission factor for general leaks	(t CH_4/Sm^3 CSG processed)
$mol\%_{ss\ (CH_4)}$	=	Site-specific CH_4 mole percentage of CSG processed	(mol%)
$mol\%_{d\ (CH_4)}$	=	Default CH_4 mole percentage of CSG processed	(mol%)
GWP_{CH_4}	=	Global warming potential of CH_4	(t CO_2-e/ t CH_4)
ρ_{CSG}	=	CSG density at standard conditions	(kg CSG/ Sm^3 CSG)

Table A.42: Data inputs for general leaks – site specific emission factor estimation (API, 2009)

Data Description	Value	Units
Default CH_4 emission factor for general leaks associated with gas processing plants (at standard conditions) [a]	1.03×10^{-6}	t CH_4/ Sm^3 CSG processed
CH_4 mole percentage of CSG processed [b]	98.01	mol%
Global warming potential of CH_4 [c]	21	t CO_2-e/ t CH_4
CSG density at standard conditions [d]	0.692	kg/ Sm^3 CSG

a. Table 6-2, API (2009).
b. Shell (2012)
c. Appendix C, DCCEE (2012b).
d. Shell (2012) - Based on CSG composition.

Table A.43: General leaks estimation methods - 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]	0.0354	

a. Section 3.72 (1) of the *Technical Guidelines*, DCCEE (2012b).
b. PAEHolmes' estimation based on the emission factor sourced from the API Compendium (2009).

According to the API, applying average facility-level emission factors is the simplest method for estimating CH_4 emissions from oil and natural gas operation (API, 2009). While this emission factor is not directly related to the coal seam gas or LNG industries, it is the best available method for forecasting emissions for this project. It is assumed that this selected emission factor covers all fugitive emissions from gas processing and compression. Table A.43 shows that the site-specific emission factor sourced from the API Compendium is also more conservative as it will result in higher emissions and will thus be used to estimate emissions associated with facility-level leaks.

Emissions of CH_4 were estimated using the equation provided below for both configuration options (i.e., "mechanical/electrical option" and "all mechanical option"). The associated activity data are presented in Table A.44 and the resulting greenhouse gas emission estimates are presented in Table A.45.

$$E_{CO_2-e\,(CH4)} = Q \times EF_{ss(CH_4)}$$

where:

$E_{CO_2-e\,(CH4)}$	=	Emissions of CO_2-e from facility-level leaks of CH_4	(t CO_2-e/a)
Q	=	Quantity of uncompressed CSG processed at standard conditions	(t CSG/a)
$EF_{ss(CH_4)}$	=	Site-specific facility-level average emission factor for CH_4	(t CH_4/ t CSG)

Table A.44: Data input associated with facility-level leaks from gas processing plants

Data Required	Value	Units
Quantity of uncompressed CSG processed at standard conditions ("mechanical/electrical option")[a]	17,696,000	t CSG/ a
Quantity of uncompressed CSG processed at standard conditions ("all mechanical option")[a]	17,898,000	t CSG/ a

a. Shell (2012).

Table A.45: GHG emissions associated with facility-level leaks from gas processing plant

Option	Scope 1 Emissions (t CO_2-e/annum)			
	CO_2	CH_4	N_2O	Total CO_2-e
"mechanical/electrical option"	Not occurring	625,572	Not occurring	625,572
"all mechanical option"	Not occurring	632,713	Not occurring	632,713

A.4.6.2 Transmission

According to the *Technical Guidelines* (DCCEE, 2012b), additional potential emissions of methane can be a result of:

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

Emissions of CO_2 and CH_4 were estimated using Method 1 for both configuration options (i.e., "mechanical/electrical option" and "all mechanical option") (Division 3.3.7, *Method 1- natural gas transmission,* of the *Technical Guidelines* (DCCEE, 2012b)):

$$E_j = Q \times EF_j$$

where:

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

The default emission factor for each gas were sourced from Section 3.76, of the *Technical Guidelines* (DCCEE, 2012b) and are listed in Table A.46. The associated activity data and the resulting greenhouse gas emission estimates are presented in Table A.47 and Table A.48, respectively.

Table A.46: Emission factors associated with CSG 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	8.72	

a. Section 3.76, DCCEE (2012b)

Table A.47: Data input associated with CSG transmission

Data Required	Value	Units
Total length of pipeline system relevant to the study [a]	8.6	km

a. Coffey Environments (2012b).

Table A.48: GHG emissions associated with CSG transmission

Option	Scope 1 Emissions (t CO_2-e/annum)			
	CO_2	CH_4	N_2O	Total CO_2-e
"mechanical/electrical option" or "all mechanical option"	0	75	Not occurring	75

A.5 SCOPE 2 EMISSIONS

A.5.1 Construction

Electricity usage during the construction phases of the project are described as follows:

"MECHANICAL/ELECTRICAL OPTION"

Diesel engine powered generators will be installed on site to supply construction power of approximately 5 MW during the initial phase of the construction work (first 16 months). After completion of the connection to the electricity grid, the power supply for construction will be taken from the grid and the on-site generation by diesel generators will be discontinued.

Electricity is required to power the temporary workers accommodation facility (TWAF) located on the mainland. The TWAF will be decommissioned on completion of the Phase 1 works.

"ALL MECHANICAL OPTION"

The 10-20 MW of power required during the construction phase (site construction activities and camp) will be generated on the construction site by means of diesel engine driven generators.

Electricity is required to power the TWAF located on the mainland. The TWAF will be decommissioned on completion of the Phase 1 works.

Scope 2 emissions were estimated using the method outlined in Chapter 7 of the *Technical Guidelines* (DCCEE, 2012b) and is consistent with the method used in the previous assessment. The scope 2 emission factor for Queensland electricity consumption has decreased slightly since the initial greenhouse gas assessment.

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, 2012b)):

$$Y = Q \times \frac{EF_{S2}}{1000}$$

where:

Y	=	Scope 2 GHG emissions	(t CO_2-e/a)
Q	=	Quantity of electricity purchased from the grid	(kWh/a)
EF_{S2}	=	Default Scope 2 emission factor for Queensland (EF_{S2} = 0.86 kg CO_{2-e}/kWh Source: DCCEE, 2012b)	(kg CO_2-e/kWh)

The amount of diesel required under the "all mechanical option" to provide electricity to the camp is 27 kL per day (Arrow Energy, 2012). Assuming an engine efficiency of 70% and a diesel heat value of 38.6 GJ/kL (DCCEE, 2012b) provides an average power requirement for the camp of

8.44 MW. Therefore, it is estimated that on average, 8.44 MW is required to power the construction camp. It is noted that the peak electricity requirement for the construction camp may be up to 20 MW.

Estimated electricity base power requirements for the construction phases are provided in Table A.49.

Table A.49: Base power requirement factors for the construction phase ("mechanical/electrical option")

Variables	Value	Units
Peak electricity requirement for construction activities ("mechanical/electrical option")	15	MW
Average electricity requirement for construction activities ("mechanical/electrical option")	8.44	MW
Electricity requirement to supply TWAF ("partial auxiliary power option" and "all mechanical option")	2,243	kW

Annual scope 2 greenhouse gas emissions associated with construction for the life of the project are detailed in Table A.50.

Table A.50: Scope 2 emissions associated with construction

Project Phase	Phase Code	Actual Year	"Mechanical/Electrical Option" Power Factor for construction	Power Factor for TWAF	Power Requirement for construction (MWh)	Power Requirement for TWAF (MWh)	Annual Emissions (t CO2e/year)	"All Mechanical Option" Annual Emissions (t CO2e/year)
Construction Phase 1 [a]	C1 [b]	2014	0	0.5	0	0	8,447	8,447
	C2	2014-2015	0.167[c]	1	12,328	3,274	27,496	16,894
	C3	2015-2016	1	1	73,967	19,644	80,506	16,894
	C4	2016-2017	1	1	73,967	19,644	80,506	16,894
Construction/ operations period 1[d]	1	2017-2018	1	1	73,967	19,644	80,506	16,894
Full operation of LNG trains 1 and 2	2	2018-2019	0	0	0	0	0	0
	3	2019-2020	0	0	0	0	0	0
	4	2020-2021	0	0	0	0	0	0
	5	2021-2022	0	0	0	0	0	0
Construction Phase 2[e]	6	2022-2023	1	0	73,967	0	63,612	0
	7	2023-2024	1	0	73,967	0	63,612	0
	8	2024-2025	1	0	73,967	0	63,612	0
Construction/operations period 2	9	2025-2026	1	0	73,967	0	63,612	0
Full operation of LNG trains 3 and 4	10-25	2026-2042	0	0	0	0	0	0

a. Construction Phase 1 involves the construction of LNG trains 1 and 2. Phase 1 is expected to commence in 2014 and occur for three and a half years.
b. Corresponds to a six-month period.
c. A factor to adjust the power requirement as the connection to the grid is only available for 2 out of the 12 months in the year (2/12 = 0.167)
d. Construction/operations period of a year where the construction of LNG train 2 and the operation of LNG train 1 will occur simultaneously.
e. Construction Phase 2 involves the construction of LNG trains 3 and 4. Phase 2 is expected to commence in Year 6 and end in Year 9 (included). Based on emissions from: the operation of LNG trains 1 and 2 and construction.
f. Construction/operations period of a year where the construction of LNG train 4 and the operation of LNG train 3 will occur simultaneously.

A.5.2 Operation

Under the "mechanical/electrical option", the additional power required to power utilities will come from the power grid. The associated activity data and the resulting greenhouse gas emission estimates are presented in Table A.51.

Table A.51: Scope 2 emissions associated with electricity purchased from the grid in Queensland during operation ("mechanical/electrical option")

Parameter	Value	Unit
Total electricity provided by generators [a] ("all mechanical option")	3,554,531	MWh/year
Total electricity provided by generators [a] ("mechanical/electrical option")	3,388,033	MWh/year
External power requirement (shortfall) ("mechanical/electrical option")	166,498	MWh/year
Estimated scope 2 greenhouse gas emissions [b] ("mechanical/electrical option")	143,189	tonnes CO_2-e/year

[a] Calculated using the parameters provided in Section A.4.1
[b] Estimated using the technique provided in Section A.5.1

A.6 SCOPE 3 EMISSIONS

A.6.1 Construction

A.6.1.1 Upstream Emissions from the use of Fuels

Fuels used by Arrow LNG Plant, such as diesel and fuel oil, which are not produced directly by Arrow LNG Plant, have associated indirect emissions due to exploration, processing and transport of these fuels. 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 T&D network.

In order to estimate the greenhouse gas emissions from full fuel cycles, the total amount of fuel combusted or processed is required. The equations used to calculate the scope 3 emissions from fuel combustion or processing, and electricity consumption by end-users for both configuration options (i.e., "mechanical/electrical option" and "all mechanical option") are as follows:

$$E_{CO_2-e} = \frac{Q \times EC_i \times EF_{S3}}{1000}$$

where:

E_{CO_2-e}	=	Scope 3 emissions of GHGs from fuel combustion or processing	(t CO_2-e/a)
Q	=	Quantity of fuel combusted or processed	(kL/a)
EC_i	=	Energy content of fuel type (i)	(GJ/kL)
EF_{S3}	=	Scope 3 emission factor	(kg CO_2-e/GJ)

$$E_{CO_2-e} = \frac{Q \times EF_{S3}}{1000}$$

where:

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

Default fuel energy content factors and associated scope 3 emission factors are presented in Table A.52.

Table A.52: Factors associated with upstream emissions from the use of fuels

Variable	Value	Units
Energy content factor of diesel [a]	38.6	GJ/kL
Energy content factor of fuel oil [a]	39.7	
Scope 3 emission factor of diesel [c]	5.3	kg CO_2–e/GJ
Scope 3 emission factor of fuel oil [c]	5.3	
Scope 3 emission factor of electricity (Qld) [d]	0.12	kg CO_2–e/kWh

a. Table 2.4.2B, DCCEE (2012b).
b. Table 2.3.2A, DCCEE (2012b)
c. Table 39, *NGA Factors* DCCEE (2012a).
d. Table 40, *NGA Factors* DCCEE (2012a) – latest estimate for Queensland.

The estimated annual quantity of diesel, fuel oil and electricity consumed during construction periods is provided in Table A.53.

Table A.53: Activity data for fuel usage

Project Phase		Year	Both Options - Diesel Consumed (kL/year)		Diesel Consumed (kL/year)		Both Options - Fuel Oil Consumed (kL/year)	Electricity consumed (MWh/year)	
			Marine Vessels		"All Mechan-ical Option"	"Mechan-ical/ Electrical Option"	Marine Vessels	"All Mechan-ical Option"	"Mechan-ical/ Electrical Option"
			Dredg-ing	LCT + Tugboats	Construction		Fast Cats + RoPax	TWAF	Construction + TWAF
Construction Phase 1 [a]	C1[b]	2014	355	134	745	745	277	9,822	9,822
	C2	2014 - 2015	-	372	5,794	4,487	555	19,644	41,544
	C3	2015 - 2016	-	370	13,155	3,513	555	19,644	151,044
	C4	2016 - 2017	-	370	13,140	3,285	555	19,644	151,044
Construction / operations period 1 [c]	1	2017 - 2018	-	370	13,140	3,285	555	19,644	151,044
Full operation of LNG trains 1 and 2	2	2018 - 2019	-	-	-	-	-	-	-
	3	2019 - 2020	-	-	-	-	-	-	-
	4	2020 - 2021	-	-	-	-	-	-	-

Project Phase		Year	Both Options - Diesel Consumed (kL/year)		Diesel Consumed (kL/year)		Both Options - Fuel Oil Consumed (kL/year)	Electricity consumed (MWh/year)	
			Marine Vessels		"All Mechan-ical Option"	"Mechan-ical/ Electrical Option"	Marine Vessels	"All Mechan-ical Option"	"Mechan-ical/ Electrical Option"
			Dredg-ing	LCT + Tugboats	Construction		Fast Cats + RoPax	TWAF	Construction + TWAF
	5	2021 - 2022	-	-	-	-	-	-	-
Construction Phase [d]	6	2022 - 2023	-	370	13,140	3,285	555	-	131,400
	7	2023 - 2024	-	370	13,140	3,285	555	-	131,400
	8	2024 - 2025	-	370	13,140	3,285	555	-	131,400
Construction / operations period 2	9	2025 - 2026	-	370	13,140	3,285	555	-	131,400
Full operation of LNG trains 3 and 4	10-25	2026 - 2042	-	-	-		-	-	-

a. Construction Phase 1 involves the construction of LNG trains 1 and 2. Phase 1 is expected to commence in 2014 and occur for three and a half years.

b. Corresponds to a six month period

c. Construction/operations period of a year where the construction of LNG train 2 and the operation of LNG train 1 will occur simultaneously. Based on emissions from: the operation of LNG trains 1 and 2, start-up flaring (LNG Trains 1 and 2) and construction.

d. Construction Phase 2 involves the construction of LNG trains 3 and 4. Phase 2 is expected to commence in Year 6 and end in Year 9 (included). During this stage, construction of LNG trains 3 and 4, and operation of LNG trains 1 and 2 will occur simultaneously.

Estimated scope 3 emissions associated with full fuel cycles of diesel, fuel oil and electricity consumption are provided in Table A.54 for the "mechanical/electrical option" and in Table A.55 for the "all mechanical option".

Table A.54: Scope 3 emissions associated with fuel usage (upstream emissions) during construction ("mechanical/electrical option")

Project Phase		Emissions (tonnes CO_2-e/year) Marine Vessels - Diesel: Dredging	Marine Vessels - Diesel: LCT + Tugboats	Marine Vessels - Fuel Oil: Fast Cats + RoPax	Construction Activities	Electricity Consumed
Construction Phase 1 [a]	C1 [b]	73	27	58	152	1,179
	C2	-	76	117	918	4,985
	C3	-	76	117	719	18,125
	C4	-	76	117	672	18,125
Construction/ operations period 1[c]	1	-	76	117	672	18,125
Full operation of LNG trains 1 and 2	2	-	-	-	-	-
	3	-	-	-	-	-
	4	-	-	-	-	-
	5	-	-	-	-	-
Construction Phase 2[d]	6	-	76	117	672	15,768
	7	-	76	117	672	15,768
	8	-	76	117	672	15,768
Construction/operations period 2	9	-	76	117	672	15,768
Full operation of LNG trains 3 and 4	10-25	-	-	-	-	-

a. Construction Phase 1 involves the construction of LNG trains 1 and 2. Phase 1 is expected to commence in 2014 and occur for three and a half years.

b. Corresponds to a six month period

c. Construction/operations period of a year where the construction of LNG train 2 and the operation of LNG train 1 will occur simultaneously. Based on emissions from: the operation of LNG trains 1 and 2, start-up flaring (LNG Trains 1 and 2) and construction.

d. Construction Phase 2 involves the construction of LNG trains 3 and 4. Phase 2 is expected to commence in Year 6 and end in Year 9 (included). During this stage, construction of LNG trains 3 and 4, and operation of LNG trains 1 and 2 will occur simultaneously.

Table A.55: Scope 3 emissions associated with fuel usage (upstream emissions) during construction ("all mechanical option")

Project Phase		Emissions (tonnes CO_2-e/year) Marine Vessels - Diesel		Marine Vessels - Fuel Oil	Construction Activities	Electricity Consumed
		Dredging	LCT + Tugboats	Fast Cats + RoPax		
Construction Phase 1 [a]	C1 [b]	73	27	58	152	1,179
	C2	-	76	117	918	2,357
	C3	-	76	117	719	2,357
	C4	-	76	117	672	2,357
Construction/operations period 1[c]	1	-	76	117	672	2,357
Full operation of LNG trains 1 and 2	2	-	-	-	-	-
	3	-	-	-	-	-
	4	-	-	-	-	-
	5	-	-	-	-	-
Construction Phase 2[d]	6	-	76	117	672	-
	7	-	76	117	672	-
	8	-	76	117	672	-
Construction/operations period 2	9	-	76	117	672	-
Full operation of LNG trains 3 and 4	10-25	-	-	-	-	-

a. Construction Phase 1 involves the construction of LNG trains 1 and 2. Phase 1 is expected to commence in 2014 and occur for three and a half years.

b. Corresponds to a six month period

c. Construction/operations period of a year where the construction of LNG train 2 and the operation of LNG train 1 will occur simultaneously. Based on emissions from: the operation of LNG trains 1 and 2, start-up flaring (LNG Trains 1 and 2) and construction.

d. Construction Phase 2 involves the construction of LNG trains 3 and 4. Phase 2 is expected to commence in Year 6 and end in Year 9 (included). During this stage, construction of LNG trains 3 and 4, and operation of LNG trains 1 and 2 will occur simultaneously.

A.6.1.2 Upstream Emissions from the use of Bulk Materials

Bulk materials used by Arrow LNG Plant for construction such as concrete aggregate, marine rock, sand, cement and fill have associated indirect emissions due to the extraction and processing of these materials.

Scope 3 emissions from the extraction and processing of bulk construction materials were estimated using the following technique:

$$E_{CO_2-e,i} = Q_i \times EF_{S3,i}$$

where:

$E_{CO_2-,ie}$	=	Scope 3 emissions of GHGs from extraction and processing of bulk material i	(t CO_2-e)
Q	=	Quantity of construction material i used	(tonnes)
$EF_{S3,i}$	=	Scope 3 emission factor for construction material i	(t CO_2-e/tonne)

Estimated greenhouse gas emissions were allocated to years by assuming the rate of construction activity was equivalent to the amount rate of bulk materials delivered to the site (see Section A.6.1.3). It was assumed that similar levels of construction materials would be required for phase 2 with the exception of material for the construction of the MLS.

The total amount of construction materials required for the Arrow LNG Plant phase 1 construction were sourced from the *Arrow LNG Plant Project Logistics Execution Plan* (Arrow Energy, 2012). Scope 3 emission factors for construction bulk materials were sourced from Hammond and Jones (2008). Bulk materials and scope 3 emission factors are provided in Table A.56.

Table A.56: Bulk materials required for phase 1 construction

Bulk materials	Scope 3 Emission Factor [a] (t CO_{2-e}/tonne)	Mass Required [b] (tonnes)
Concrete aggregate	0.017	160,000
Marine rock	0.017	31,600
Sand for backfill	0.005	192,000
Cement for concrete	0.83	60,000
Sand for concrete	0.006	120,000
Fill for MLS	0.017	245,000

a Hammond and Jones (2008)

b Arrow Energy, 2012

Estimated scope 3 emissions associated with extraction and processing of construction bulk materials are provided in Table A.57 for both options.

Table A.57: Scope 3 emissions associated with extraction and processing of construction bulk materials

Project Phase	Phase Code	Actual Year	Emissions (tonnes/year)			
			CO_2	CH_4	N_2O	Total
Construction Phase 1	C1	2014	353	-	-	353
	C2	2014-2015	21,592	-	-	21,592
	C3	2015-2016	26,198	-	-	26,198
	C4	2016-2017	5,320	-	-	5,320
Construction/operations period 1	1	2017-2018	5,320	-	-	5,320
Full operation of LNG trains 1 and 2	2	2018-2019	-	-	-	-
	3	2019-2020	-	-	-	-
	4	2020-2021	-	-	-	-
	5	2021-2022	-	-	-	-
Construction Phase 2	6	2022-2023	4,856	-	-	4,856
	7	2023-2024	4,856	-	-	4,856
	8	2024-2025	4,856	-	-	4,856
Construction/operations period 2	9	2025-2026	4,856	-	-	4,856
Full operation of LNG trains 3 and 4	10-25	2026-2042	-	---	--	-

A.6.1.3 Transportation of Bulk Materials

Transportation of bulk materials used by Arrow LNG Plant for construction such as concrete aggregate, marine rock, sand, cement and fill have associated indirect emissions due to the transportation of the bulk material to the site.

Materials required to be transported to the facility include bulk materials for construction (concrete aggregate, marine rock, sand, cement, fill) from local sources and unitised materials and construction equipment from Brisbane. All bulk material is assumed to be transported to the site using articulated diesel trucks. Emissions for a return trip are included for transportation of materials from the Gladstone region, considering that one trip with a laden truck is required to transport equipment to the site and one return trip to the bulk material facility empty is required. A one way trip for articulated trucks from Brisbane is included in the assessment, as it is assumed that the transportation facility will be able to pick up other materials and transport to any location in Australia following delivery of either construction or unitised materials to the site.

Scope 3 emissions associated with transportation of bulk materials to the site are estimated using the following technique:

$$E_{i,j} = \frac{T_j \times d_j \times \frac{FE}{100} \times EC \times EF_i}{1{,}000{,}000}$$

where:

$E_{i,j}$	=	Estimated emissions of greenhouse gas i from transportation of bulk material j	(t CO_2-e/annum)
T_j	=	Estimated number of trips per year required to transport material j	(trips/annum)
d	=	Estimated transportation distance for trip j	(km/trip)
FE	=	Estimated diesel fuel efficiency for articulated truck	(L/km)
EC	=	Diesel energy content	(GJ/kL)
EF_i	=	Emission factor for substance i for diesel transportation	(kg/GJ)

The number of trips for each material type was derived from *Arrow LNG Plant Project Logistics Execution Plan* (Arrow Energy, 2012) and is summarised in Table A.58.

It is assumed that concrete aggregate, marine rock, sand fill for the MLS is sourced from Yarwun Quarries, Unimen Quarry or Earth Commodities in the Gladstone region (Arrow Energy, 2012). For the greenhouse gas assessment, it was conservatively assumed that all quarry material will be sourced from Unimen Quarry as it is furthest from the MLS. The one-way distance is estimated to be 65.1 kilometres.

Sand is sourced from the Boral facility at Tannum Sands (Arrow Energy, 2012). The estimated one way distance to the MLS is 31 kilometres.

Cement is sourced from Cement Australia's facility at Fisherman's Landing (Arrow Energy, 2012). The estimated one way distance is 14 kilometres.

Parameters required to estimate the amount of diesel consumed to transport bulk materials to the site are provided in Table A.59.

Table A.58: Estimated number of trips required to transport bulk materials for construction

Project Phase	Phase Code	Trips per year			
		Fill for MLS	Unitised Materials ex. Brisbane	Construction Equipment ex Brisbane	Bulk Materials ex Gladstone
Construction Phase 1	C1	152	61	30	0
	C2	7574	5,870	624	1,734
	C3	0	7,057	207	11,293
	C4	0	6,935	73	2,293
Construction/operations period 1	1	0	6,935	73	2,293
Full operation of LNG trains 1 and 2	2	-	-	-	-
	3	-	-	-	-
	4	-	-	-	-
	5	-	-	-	-
Construction Phase 2	6	0	6,935	73	2,293
	7	0	6,935	73	2,293
	8	0	6,935	73	2,293
Construction/operations period 2	9	0	6,935	73	2,293
Full operation of LNG trains 3 and 4	10-25	-	-	-	-

Source: Arrow Energy (2012)

Table A.59: Parameters required to estimated the amount of fuel combusted for transporting bulk materials to the site

Parameter	Value
Average travel distance (return)– Fill for MLS	130.2 km
Average travel distance (one way) – Unitised material from Brisbane	540 km
Average travel distance (one way) – construction equipment from Brisbane	540 km
Average travel distance (return) – bulk materials from Gladstone area [a]	81.6 km
Diesel fuel efficiency (articulated truck) [b]	55.7 L/100 km

a Weighted average distance based on the volume of material required and the travel distance for each material type

b Average fuel efficiency for a diesel articulated truck (Queensland) (ABS, 2011)

Factors required to greenhouse gas emissions for transportation of bulk materials using diesel trucks are provided in Table A.60.

Table A.60: Factors associated with diesel combusted for the transportation of bulk materials

Method Used	Constant	Value	Units
-	Default Energy Content Factor [a]	38.6	GJ/kL
Method 1	Default CO_2 Emission Factor [a]	69.2	kg CO_2-e/ GJ
Method 1	Default CH_4 Emission Factor [a]	0.2	
Method 1	Default N_2O Emission Factor [a]	0.5	
Method 1	Overall Emission Factor	69.9	

a. Table 2.4.2B, DCCEE (2012b)

Estimated scope 3 emissions from the transportation of bulk materials to the Arrow LNL plant for construction are provided in Table A.61.

Table A.61: GHG emissions from the transportation of bulk materials for construction

Project Phase	Phase Code	Actual Year	Emissions (tonnes/year)			
			CO_2	CH_4	N_2O	Total
Construction Phase 1	C1	2014	103	0.3	0.7	104
	C2	2014-2015	6,691	19	48	6,759
	C3	2015-2016	5,881	17	42	5,940
	C4	2016-2017	5,640	16	41	5,697
Construction/operations period 1	1	2017-2018	5,640	16	41	5,697
Full operation of LNG trains 1 and 2	2	2018-2019	-	-	-	-
	3	2019-2020	-	-	-	-
	4	2020-2021	-	-	-	-
	5	2021-2022	-	-	-	-
Construction Phase 2	6	2022-2023	5,640	16	41	5,697
	7	2023-2024	5,640	16	41	5,697
	8	2024-2025	5,640	16	41	5,697
Construction/operations period 2	9	2025-2026	5,640	16	41	5,697
Full operation of LNG trains 3 and 4	10-25	2026-2042	-	-	-	-

A.6.1.4 Transportation of Personnel

Scope 3 emissions from personnel transport have been included in the greenhouse gas assessment for the following personnel transportation routes:

- Fly-in fly-out (FIFO) workers
- Road transport - Local to MLS
- Road transport - Mainland Workers Camp to MLS
- Road transport - Gladstone residential to MLS
- Road transport – drive in – drive out (DIDO) workers
- Road transport - FIFO to airport

AIR TRANSPORT

Scope 3 emissions from air transport of personnel for FIFO workers have been estimated using the following technique:

$$E_{CO_2-e} = d \times p \times RFI \times EF \times 2$$

where:

E_{CO2-e}	=	Emissions of greenhouse gases from fuel combustion in planes	(t CO_2-e/annum)
d	=	Distance travelled per trip (one way) (540 km estimated distance from Brisbane to Gladstone)	(km/trip)
p	=	Total number of passengers travelling	(passengers/annum)
RFI	=	Radiative forcing index (RFI = 2.7 Source: Calculating Your Greenhouse Gas Emissions from Flights, Environmental Protection Authroity Victoria (EPAV, 2009))	(-)
EF	=	Emission factor for plane flights (EF = 0.00012 t CO_2-e/km/passenger Source: Calculating Your Greenhouse Gas Emissions from Flights, Environmental Protection Authroity Victoria (EPAV, 2009)	(t CO_2-e/km/passenger)

The total number of personnel in return flights per week was sourced from *Arrow LNG Plant Project Logistics Execution Plan* (Arrow Energy, 2012) and is summarised Table A.62. For the purposes of the greenhouse gas assessment, scope 3 emissions from flights to Brisbane to Gladstone and vice versa have been taken into account. It is expected that the majority of FIFO workers will travel this route, although some personnel may continue to other destinations. It is not possible to accurately assess emissions from further personnel air travel.

Table A.62: Estimated number of personnel in return flights per week

Project phase [a]	Number of personnel in return flights per week
Early	80
Ramp-up	255
Peak	522
Ramp-down	80

a Assumed to cover the following periods:

Early: Month 1 – 6

Ramp-up: Month 7 – 24

Peak: Month 25 – 36

Ramp-down: Month 37 – 54

It was estimated that the number of personnel required for phase 2 construction was equivalent to the requirements for phase 1 construction without the early period (i.e. from ramp-up onwards).

The estimated number of flights and the number of personnel using air transport for the construction activities is provided in Table A.63.

Table A.63: Estimated number of flights and personnel transported by air transport for construction activities

Project Phase	Phase Code	Actual Year	Number of return flights	Number of personnel in return flights
Construction Phase 1	C1	2014	21	2,080
	C2	2014-2015	133	13,260
	C3	2015-2016	202	20,202
	C4	2016-2017	157	15,652
Construction/operations period 1	1	2017-2018	42	4,160
Full operation of LNG trains 1 and 2	2	2018-2019	-	-
	3	2019-2020	-	-
	4	2020-2021	-	-
	5	2021-2022	-	-
Construction Phase 2	6	2022-2023	133	13,260
	7	2023-2024	202	20,202
	8	2024-2025	157	15,652
Construction/operations period 2	9	2025-2026	42	4,160
Full operation of LNG trains 3 and 4	10-25	2026-2042	-	-

Estimated scope 3 GHG emissions from air transport of personnel for construction activities are provided in Table A.64.

Table A.64: Estimated scope 3 GHG emissions from personnel transport – construction activities

Project Phase	Phase Code	Actual Year	Emissions (tonnes/year)			
			CO_2	CH_4	N_2O	Total
Construction Phase 1	C1	2014	728	-		728
	C2	2014-2015	4,640	-		4,640
	C3	2015-2016	7,069	-		7,069
	C4	2016-2017	5,477	-		5,477
Construction/operations period 1	1	2017-2018	1,456	-		1,456
Full operation of LNG trains 1 and 2	2	2018-2019	-	-		-
	3	2019-2020	-	-		-
	4	2020-2021	-	-		-
	5	2021-2022	-	-		-
Construction Phase 2	6	2022-2023	4,640	-		4,640
	7	2023-2024	7,069	-		7,069
	8	2024-2025	5,477	-		5,477
Construction/operations period 2	9	2025-2026	1,456	-		1,456
Full operation of LNG trains 3 and 4	10-25	2026-2042	-	-		-

ROAD TRANSPORT

Scope 3 emissions from road transport of construction workers have been estimated in the assessment using data provided in the *Arrow LNG Plant Project Logistics Execution Plan* (Arrow Energy, 2012) as summarised in Table A.65.

Table A.65: Road transport activity data

Trip	Estimated Number of Personnel Making Return Journeys per Day [a, b]				One Way Travel Distance[c] (km)	Vehicle Type [d]	Number of passengers per vehicle type [a]
	Early	Ramp-up	Peak	Ramp-down			
Local to MLS	500	700	500	500	7	Petrol car	1
Mainland Workers Camp to MLS	450	100	250	0	30	Diesel bus	55
Gladstone Residential to MLS	50	200	250	100	7	Petrol car	1
DIDO	9	13	17	9	110	Petrol car	1
FIFO to airport	27	85	174	27	7	Diesel bus	55

a Arrow Energy (2012)

b Assumed to cover the following periods:

Early: Month 1 – 6

Ramp-up: Month 7 – 24

Peak: Month 25 – 36

Ramp-down: Month 37 – 54

c Estimated as follows: Local to MLS estimated as the distance from Telina to MLS; Mainland Workers Camp to MLS estimated to be 30 km (Arrow Energy, 2012), Gladstone residential to MLS assumed to be 7 km (equivalent as the distance for local to MLS; DIDO workers were assumed to live in Rockhampton, thus a distance of 100 km was assumed; the distance from the airport to the MLS was estimated to be 7 km.

d Assumed

Based on the data provided in Table A.65 the total distance travelled in petrol and diesel vehicles to transport personnel for construction is provided is Table A.66.

Table A.66: Estimated distance travelled in petrol and diesel vehicles transporting personnel for construction

Project Phase	Phase Code	Actual Year	Estimated Distance travelled (km)	
			Petrol vehicles	Diesel vehicles
Construction Phase 1	C1	2014	1,761,760	90,596
	C2	2014-2015	5,627,440	47,585
	C3	2015-2016	5,405,400	81,490
	C4	2016-2017	4,480,840	58,948
Construction/operations period 1	1	2017-2018	3,778,320	2,502
Full operation of LNG trains 1 and 2	2	2018-2019	-	-
	3	2019-2020	-	-
	4	2020-2021	-	-
	5	2021-2022	-	-
Construction Phase 2	6	2022-2023	5,627,440	47,585
	7	2023-2024	5,405,400	81,490
	8	2024-2025	4,480,840	58,948
Construction/operations period 2	9	2025-2026	3,778,320	2,502
Full operation of LNG trains 3 and 4	10-25	2026-2042	-	-

Scope 3 emissions from personnel road transport in petrol and diesel vehicles were estimated using the following technique

$$E_i = \frac{d_p \times \frac{FE_p}{100} \times EC_p \times EF_{i,p} + d_d \times \frac{FE_d}{100} \times EC_d \times EF_{i,d}}{1{,}000{,}000}$$

where:

E_i	=	Emissions of greenhouse gases from fuel combustion in planes	(t CO_2-e/annum)
d_p	=	Estimated distance travelled in petrol vehicles to transport personnel	(km/annum)
FE_p	=	Fuel efficiency for petrol vehicles	(L/100 km)
EC_p	=	Energy content for petrol	(GJ/kL)
$EF_{i,p}$	=	Emission factor for greenhouse substance i from petrol combustion for transport purposes	(kg $CO_{2\text{-}e}$/GJ)
d_d	=	Estimated distance travelled in diesel buses to transport personnel	(km/annum)
FE_d	=	Fuel efficiency for a diesel bus	(L/100 km)
EC_d	=	Energy content for diesel	(GJ/kL)
$EF_{i,d}$	=	Emission factor for greenhouse substance i from diesel combustion for transport purposes	(kg $CO_{2\text{-}e}$/GJ)

Parameters required to estimate emissions from the transportation of personnel during the construction phases are provided in Table A.60.

Table A.67: Factors associated with fuel combusted for the transportation of personnel

Vehicle Type	Constant	Value	Units
Petrol vehicle	Default Energy Content Factor [a]	34.2	GJ/kL
	Default CO_2 Emission Factor [a]	66.7	kg CO_2-e/ GJ
	Default CH_4 Emission Factor [a]	0.6	
	Default N_2O Emission Factor [a]	2.3	
	Overall Emission Factor	34.2	
	Fuel efficiency [b]	10.3	L/100 km
Diesel bus	Default Energy Content Factor [a]	38.6	GJ/kL
	Default CO_2 Emission Factor [a]	69.2	kg CO_2-e/ GJ
	Default CH_4 Emission Factor [a]	0.2	
	Default N_2O Emission Factor [a]	0.5	
	Overall Emission Factor	69.9	
	Fuel efficiency [b]	26.9	L/100 km

a. Table 2.4.2B, DCCEE (2012b)
b. ABS (2011)

Estimated scope 3 GHG emissions from the transportation of personnel for the construction phases are provided in Table A.68.

Table A.68: GHG emissions from the transportation of personnel for construction

Project Phase	Phase Code	Actual Year	Emissions (tonnes/year)			
			CO_2	CH_4	N_2O	Total
Construction Phase 1	C1	2014	479	4	15	498
	C2	2014-2015	1,356	12	46	1,414
	C3	2015-2016	1,329	12	44	1,384
	C4	2016-2017	1,095	10	37	1,141
Construction/operations period 1	1	2017-2018	890	8	31	928
Full operation of LNG trains 1 and 2	2	2018-2019	-	-	-	-
	3	2019-2020	-	-	-	-
	4	2020-2021	-	-	-	-
	5	2021-2022	-	-	-	-
Construction Phase 2	6	2022-2023	1,356	12	46	1,414
	7	2023-2024	1,329	12	44	1,384
	8	2024-2025	1,095	10	37	1,141
Construction/operations period 2	9	2025-2026	890	8	31	928
Full operation of LNG trains 3 and 4	10-25	2026-2042	-	-	-	-

A.6.1.5 Transportation of Waste

Solid waste will be sorted on site and/or the MLS then disposed of in the existing Benaraby landfill, approximately 28 kilometres drive from the MLS by a licensed service provider (Arrow Energy, 2012). It is estimated that 20 semi-trailer loads of solid waste are expected to be handled per month at peak (Arrow Energy, 2012).

Emissions of CO_2, CH_4 and N_2O were estimated using the following method from the *Technical Guidelines* (DCCEE, 2012b)):

$$E_j = \frac{Q \times EC \times EF_{joxec}}{1000}$$

where:

E_j	=	Estimated emissions of greenhouse gas from transportation of waste	(t CO_2-e/a)
Q	=	Estimated quantity of diesel used to transport waste in a year	(kL/a)

$$Q_i = \sum_{month=i} \left(n_{month} \times L_{peak} \times d \times 2 \times FE\right)$$

where

Q_i	=	Estimated quantity of diesel used to transport waste	(kL/year)
n_{month}	=	Estimated ratio of waste movement based on construction activities in month i	(kL month/peak kL month)
L_{peak}	=	Number of semitrailer loads soil waste at peak	(loads per month)
D	=	Estimated distance from the MLS to Benaraby landfill (d = 28 kilometres)	(km/one way trip)
FE	=	Estimated fuel efficiency of articulated trucks (FE = 0.557 L/km Source: ABS, 2010)	(L/km)

EC	=	Energy content factor of diesel	(GJ/kL)
EF_{joxec}	=	Full fuel cycle greenhouse gas emission factor (i.e. sum of scope 1 and scope diesel emission factors) EF_{joxec} = 75.2 kg CO_2-e/GJ, Source: Table 39, NGA Factors, July 2012 & Table 2.4.2B, NGER Technical Guidelines, June 2012	(kg CO_2-e/GJ)

Estimated scope 3 greenhouse gas emissions from the transportation of construction waste are provided in Table A.69.

Table A.69: GHG emissions from the transportation of construction waste

Project Phase	Phase Code	Actual Year	Estimated Fuel Usage (kL/year)	Emissions (tonnes CO_2e/year)			
				CO_2	CH_4	N_2O	Total
Construction Phase 1 [a]	C1 [b]	2014	1.1	3			3
	C2	2014-2015	6.3	18			18
	C3	2015-2016	5.3	15			15
	C4	2016-2017	5.0	14			14
Construction/operations period 1 [c]	1	2017-2018	5.0	14			14
Full operation of LNG trains 1 and 2	2	2018-2019	-	-	-	-	-
	3	2019-2020	-	-	-	-	-
	4	2020-2021	-	-	-	-	-
	5	2021-2022	-	-	-	-	-
Construction Phase 2[d]	6	2022-2023	5.0	14			14
	7	2023-2024	5.0	14			14
	8	2024-2025	5.0	14			14
Construction/operations period 2	9	2025-2026	5.0	14			14
Full operation of LNG trains 3 and 4	10-25	2026-2042	-	-	-	-	-

a. Construction Phase 1 involves the construction of LNG trains 1 and 2. Phase 1 is expected to commence in 2014 and occur for three and a half years.
b. Corresponds to a six month period
c. Construction/operations period of a year where the construction of LNG train 2 and the operation of LNG train 1 will occur simultaneously. Based on emissions from: the operation of LNG trains 1 and 2, start-up flaring (LNG Trains 1 and 2) and construction.
d. Construction Phase 2 involves the construction of LNG trains 3 and 4. Phase 2 is expected to commence in Year 6 and end in Year 9 (included). During this stage, construction of LNG trains 3 and 4, and operation of LNG trains 1 and 2 will occur simultaneously.

A.6.2 Operation

A.6.2.1 Upstream Emissions from the use of Fuels

Fuels used by Arrow LNG Plant, such as diesel and fuel oil, which are not produced directly by Arrow LNG Plant, have associated indirect emissions due to exploration, processing and transport of these fuels. 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 T&D network.

The site-specific scope 3 emission factor associated with the extraction and processing of CSG was sourced from the Surat Gas Greenhouse Assessment (PAEHolmes, 2011), and corresponds to the average scope 1 emission intensities (in kg CO_2-e/GJ of CSG produced) associated with the time period 2017-2042 of the Surat Gas project's life.

The site-specific scope 3 upstream emission factors for fuels used during operation are presented in Table A.70.

Table A.70: Factors associated with upstream emissions from the use of fuels

Variable	Value	Units
Energy content factor of diesel [a]	38.6	GJ/kL
Energy content factor of fuel oil [a]	39.7	
Energy content factor of CSG [b]	0.0377	GJ/m^3
Scope 3 emission factor of diesel [c]	5.3	kg CO_2–e/GJ
Scope 3 emission factor of fuel oil [c]	5.3	
Average scope 3 emission factor of CSG (upstream emissions associated with extraction and transport of CSG) [d]	7.70	
Scope 3 emission factor of electricity (Qld) [e]	0.12	kg CO_2–e/kWh

a. Table 2.4.2B, DCCEE (2012b).
b. Table 2.3.2A, DCCEE (2012b).
c. Table 39, *NGA* Factors DCCEE (2012a).
d. Based on Surat Gas Project average scope 1 emission intensities for upstream activities for the time period 2017-2042 (PAEHolmes, 2011). The average scope 1 emission intensity was estimated based on the average scope 1 emissions (associated with the base case; i.e. integrated power generation) and average CGS production (Table 19, (PAEHolmes, 2011) for year 2017–2042.
e. Table 40, *NGA Factors* DCCEE (2012a) – latest estimate for Queensland.

Estimated scope 3 emissions from diesel and fuel oil usage were estimated using the methodologies presented in Section A.6.1.1.

Table A.71: Data input associated with fuel use

Phase	Data Required	"Mechanical/ electrical option"	"All mechanical option"	Unit
Operation	Total amount of diesel consumed in marine vessels and vehicles [a]	775	775	kL/a
	Total amount of fuel oil consumed in passenger marine vessels [b]	2,737	2,737	kL/a
	Total amount of CSG processed [c]	25,566,527,729	25,858,369,874	Sm^3/a
	Total amount of electricity purchased from the grid for operation power and accommodations [d]	166,498,452	0	kWh/a

a. Refer to Section A.4.2
b. Refer to Section A.4.3
c. Shell (2012) – 4 trains in operation
d. Refer to Section A.5.2

Table A.72: Scope 3 emissions associated with fuel usage (upstream emissions) during operation

Phase	Activity Description	Scope 3 Emissions ($t\ CO_2$-e/annum)	
		"Mechanical/ electrical option"	"All mechanical option"
Operation	Diesel combusted in marine vessels and vehicles	159	159
	Fuel oil combusted in passenger marine vessels	576	576
	CSG processed	7,447,007	7,511,798
	Electricity purchased from the grid for operation power and accommodations	19,980	NA
	Total scope 3 emissions	7,467,721	7,512,532

A.6.2.2 End use of LNG

Scope 3 emissions associated with the end use of LNG refer to the combustion of product LNG. End use of the product LNG will be the most significant scope 3 emission associated with Arrow LNG Plant.

In order to estimate the greenhouse gas emissions from the end use of LNG, it has been assumed that no fugitive losses will occur after the product LNG leaves the Arrow LNG Plant. The emissions will therefore be based on the combustion of the LNG delivered to end-users. The equation used to calculate the scope 3 emissions associated with the end use of LNG is as follows:

$$E_{CO_2-e} = \frac{Q \times EF_{S1}}{1000}$$

where:

E_{CO_2-e}	=	Emissions of GHGs from end use of LNG	(t CO_2-e/a)
Q	=	Quantity of LNG combusted	(GJ/a)
EF_{S1}	=	GHG scope 1 emission factor for LNG combustion	(kg CO_2-e/GJ)

The default energy content factor and the scope 3 emission factors of LNG were sourced from Table 2.3.2A*,* of the *Technical Guidelines* (DCCEE, 2012b) and are listed in Table A.73. The associated activity data are presented in Table A.74. The resulting greenhouse gas emission estimates are presented in Table A.75.

Table A.73: Factors associated with end use of LNG

Method Used	Variable	Value	Units
-	Default energy content factor of LNG [a]	25.3	GJ/m^3
Method 1	Scope 1 default CO_2 emission factor [a]	51.2	kg CO_2–e/GJ
Method 1	Scope 1 default CH_4 emission factor [a]	0.1	
Method 1	Scope 1 default N_2O emission factor [a]	0.03	
Method 1	Scope 1 overall emission factor	51.33	

a. Table 2.3.2A, DCCEE (2012b)

Table A.74: Data input associated with end use of LNG

Phase	Data Required	Value	Unit
Operation	Total amount of LNG produced [a]	16,168,000	t/a

a. Shell (2012) – Assuming total plant capacity as the worst case scenario

Table A.75: Scope 3 GHG emissions associated with end-use of LNG

Phase	Option	CO_2	CH_4	N_2O	Total Scope 3 CO_2-e
		(t CO_2-e/annum)			
Operation	"mechanical/electrical option" or "all mechanical option"	47,281,658	96,247	28,874	47,406,779

A.6.3 Emissions Summary

A summary of the revised annual greenhouse gas emissions estimated to be generated from the construction and operational activities of the Arrow LNG Plant for both the "mechanical/electrical option" and the "all mechanical option" are presented in Table A.76.

The following are key aspects in relation to when emissions are projected to occur (as per the original EIS):

- Vegetation clearing is estimated to occur in the first year of Construction Phase 1.
- Start-up flaring emissions were only included for Year 1 and Year 9, when the LNG trains are brought on-line. It is estimated that two trains are brought on line in Year 1 and two trains are brought online in Year 9 (following respective construction periods).
- Operational emissions are estimated based on the number of trains in operation for a given year.
- Emissions associated with construction activities are estimated to be similar for both construction phases.
- Scope 3 emissions associated with upstream activities (i.e., extraction and processing of CSG) were estimated using scope 1 emission intensities in kg CO_2-e/GJ (based on the average scope 1 emissions and the average CSG throughput), sourced from the Surat Gas Greenhouse Assessment (PAEHolmes, 2011).

A detailed comparison of emission estimates for the "mechanical/electrical option" and "all mechanical option" to estimated emissions presented in the original EIS is presented in Section 2.2.4.

Table A.76: Revised greenhouse gas emissions by scope associated with Arrow LNG Plant - "Mechanical/Electrical Option" and "All Mechanical Option"

Phase	Operational Year		Scope 1 and Scope 2 "Mechanical/Electrical Option"	Scope 1 and Scope 2 "All Mechanical Option"	Scope 3 (Including End-Use of LNG) "Mechanical/Electrical Option"	Scope 3 (Including End-Use of LNG) "All Mechanical Option"
			Emissions [t CO_2-e/annum]			
Construction Phase 1 [a]	C1 [b]	2014	83,321	83,254	3,419	3,419
	C2	2014-2015	50,099	43,006	39,861	38,649
	C3	2015-2016	100,484	62,739	53,242	46,339
	C4	2016-2017	99,868	62,694	30,237	23,377
Construction/operations period 1 (includes start-up flaring of LNG Trains 1 and 2) [c]	1	2017-2018	2,509,648	2,449,050	29,626,475	29,676,822
Full operation of LNG trains 1 and 2	2	2018-2019	2,366,396	2,342,477	27,426,893	27,459,289
	3	2019-2020	2,366,396	2,342,477	27,426,893	27,459,289
	4	2020-2021	2,366,396	2,342,477	27,426,893	27,459,289
	5	2021-2022	2,366,396	2,342,477	27,426,893	27,459,289
TOTAL – Construction Phase 1	**C1 -1**	**2014-2022**	**433,640**	**314,454**	**152,762**	**130,927**
TOTAL – Operation Phase 1	**1 - 5**	**2017-2022**	**11,875,362**	**11,756,263**	**139,308,046**	**139,494,836**
Construction Phase 2 [d]	6	2022-2023	2,449,370	2,388,277	27,453,745	27,479,281
	7	2023-2024	2,449,370	2,388,277	27,456,144	27,481,680
	8	2024-2025	2,449,370	2,388,277	27,454,309	27,479,845
Construction/operations period 2 (includes start-up flaring of LNG Trains 3 and 4) [f]	9	2025-2026	4,859,150	4,774,633	54,876,968	54,934,899
Full operation of LNG trains 3 and 4 [f]	10 - 25	2026-2042	4,732,791	4,684,954	54,853,786	54,918,578
TOTAL – Construction Phase 2	**6 - 9**	**2022-2026**	**331,896**	**183,201**	**106,700**	**79,260**
TOTAL – Operation Phase 2	**6 - 25**	**2022-2042**	**87,600,024**	**86,715,520**	**1,014,795,050**	**1,015,993,690**

a. Construction Phase 1 involves the construction of LNG trains 1 and 2. Phase 1 is expected to commence in 2014 and occur for three and a half years.

b. All the emissions associated with vegetation clearing were included in Year C1, which corresponds to a six-month period.

c. Construction/operations period of a year where the construction of LNG train 2 and the operation of LNG train 1 will occur simultaneously. Based on emissions from: the operation of LNG trains 1 and 2, start-up flaring (LNG Trains 1 and 2) and construction.

d. Construction Phase 2 involves the construction of LNG trains 3 and 4. Phase 2 is expected to commence in Year 6 and end in Year 9 (included). During this stage, construction of LNG trains 3 and 4, and operation of LNG trains 1 and 2 will occur simultaneously. Based on emissions from the operation of LNG trains 1 and 2 and construction.

e. Construction/operations period of a year where the construction of LNG train 4 and the operation of LNG train 3 will occur simultaneously.

Start-up of LNG trains 3 & 4 in Year 9. Based on emissions from the operation of LNG trains 1 to 4, start-up flaring (LNG Trains 3 and 4) and construction.

f. The emissions from the operation of Arrow LNG are estimated to be similar for Year 10 to Year 25.