Appendix X

Appendix X

Climate change and greenhouse gas calculations

January 2020

Roads and Maritime Services

Western Harbour Tunnel and Warringah Freeway Upgrade

Technical working paper: Climate change and greenhouse gas calculations

January 2020

Prepared for

Roads and Maritime

Prepared by

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Contents

Definitions

Acronym	Definition
AR5	Intergovernmental Panel on Climate Change's Fifth Assessment Report
BCC	Beijing Climate Center
CCIA	Climate Change in Australia
CFT	Climate Futures Tool
CH_4	Methane
CO_2	Carbon dioxide
CO_{2e}	CO_2 equivalents
ECF	energy content factor
EPA	Environment Protection Authority
GCM	General Circulation Model
GHG Protocol	Greenhouse Gas Protocol
ISCA	Infrastructure Sustainability Council Australia
ISMC	Infrastructure Sustainability Materials Calculator
N_2O	Nitrous oxide
NCAR	National Center for Atmospheric Research
NGA	National Greenhouse Accounts
RCP	Representative Concentration Pathway
SMPM	Sydney Motorway Project Model
TAGG	Transport Authorities Greenhouse Gas
TRAQ	Tools for Roadside Air Quality
VKT	Vehicle kilometres travelled

Executive Summary

The project

NSW Roads and Maritime Services (Roads and Maritime) is seeking approval under Division 5.2, Part 5 of the Environmental Planning and Assessment Act 1979 (EP&A Act) to construct and operate the Western Harbour Tunnel and Warringah Freeway Upgrade (the project), which would comprise two main components:

- A new crossing of Sydney Harbour involving twin tolled motorway tunnels connecting the WestConnex M4-M5 Link at Rozelle and the existing Warringah Freeway at North Sydney (the Western Harbour Tunnel)
- Upgrade and integration works along the existing Warringah Freeway, including allowance for connections to the Beaches Link and Gore Hill Freeway Connection project (the Warringah Freeway Upgrade).

This report has been prepared to support the environmental impact statement for the project and presents an assessment of climate change projections and greenhouse gas calculations.

Climate change projections

Climate change projections are useful tools to guide decision-making about climate risks. They indicate the expected trend in climate variables under various future scenarios and the likely quantum of change.

Climate change projections included in this assessment are based on Representative Concentration Pathway (RCP) 8.5, which reflects the highest of the emissions (or radiative forcing) scenarios considered in the Intergovernmental Panel on Climate Change's Fifth Assessment Report (AR5, IPCC (2013)). They follow the projections for this scenario through time from 2030 to 2090.

Climate change projections were developed for three periods, which broadly reflect the operating lives of different elements being constructed as part of the project. These were compared against a baseline (1986–2005) for some climate variables where relevant, as this relates to the period from which the changes to those variables are projected. For each period, the projection show increases in mean minimum and maximum temperatures.

Greenhouse gas calculations

'Greenhouse gases' is a collective term for a range of gases that are known to trap radiation in the upper atmosphere, where they have the potential to contribute to the greenhouse effect (global warming). Creating an inventory of the likely greenhouse gas emissions associated with a project has the benefit of determining the scale of the emissions and providing a baseline from which to develop and deliver greenhouse gas reduction options.

The greenhouse gas inventory in this document is calculated in accordance with the principles of the Greenhouse Gas Protocol (GHG Protocol) and emissions that form the inventory which can be split into three categories known as 'Scopes'. Scopes 1, 2 and 3 are defined by the GHG Protocol and can be summarised as follows:

- Scope 1 – Direct emissions from sources that are owned or operated by a reporting organisation (examples – combustion of diesel in company owned vehicles or used in on-site generators)
- Scope 2 – Indirect emissions associated with the import of energy from another source (examples – importation of electricity or heat)

- Scope 3 – Other indirect emissions (other than Scope 2 energy imports) which are a direct result of the operations of the organisation but from sources not owned or operated by them (examples include business travel (by air or rail) and manufacture of construction materials).

An estimate of greenhouse gas emissions associated with construction of the project has been calculated for:

- Fuel combustion from construction plant and equipment, including barge movements
- Fuel combustion by generators during harbour construction activities
- Construction materials
- Fuel combustion from the transport of materials
- Fuel combustion from the transport of waste and spoil
- Electricity consumption
- Vegetation removal.

An estimate of greenhouse gas emissions associated with construction of the project has been calculated for:

- Operational electricity consumption
- Maintenance activities
- Fuel consumption by vehicles using the road network.

Table E-1 provides a summary of the emissions associated with construction and operation of the project.

Table E-1 Construction and operation greenhouse gas summary

Source	Greenhouse gas emissions ($ktCO_2e$)	
	Project only	Cumulative
Construction	809	1477
Operation 2027	59	116
Operation 2037	72	143

Construction emissions are expected to be much higher than the increase in operational emissions over the network as a result of the project facilitating additional transport across Sydney. The efficiency of this transport is expected to improve for the project through the removal of congestion and the creation of freer-flowing routes.

Project related construction and operation emissions would contribute to national and State greenhouse gas inventories. The percentage contributions have been calculated and are presented in Section 3.2.3 of this report.

1. Introduction

This section provides an overview of the Western Harbour Tunnel and Warringah Freeway Upgrade (the project), including its key features and location. It also outlines the Secretary's environmental assessment requirements addressed in this technical working paper.

1.1 Overview

The Greater Sydney Commission's *Greater Sydney Region Plan – A Metropolis of Three Cities* (Greater Sydney Commission, 2018) proposes a vision of three cities where most residents have convenient and easy access to jobs, education and health facilities and services. In addition to this plan, and to accommodate for Sydney's future growth the NSW Government is implementing the *Future Transport Strategy 2056* (Transport for NSW, 2018), a plan that sets the 40 year vision, directions and outcomes framework for customer mobility in NSW. The Western Harbour Tunnel and Beaches Link program of works is proposed to provide additional road network capacity across Sydney Harbour and to improve transport connectivity with Sydney's northern beaches. The Western Harbour Tunnel and Beaches Link program of works include:

- The Western Harbour Tunnel and Warringah Freeway Upgrade project which comprises a new tolled motorway tunnel connection across Sydney Harbour, and an upgrade of the Warringah Freeway to integrate the new motorway infrastructure with the existing road network and to connect to the Beaches Link and Gore Hill Freeway Connection project
- The Beaches Link and Gore Hill Freeway Connection project which comprises a new tolled motorway tunnel connection across Middle Harbour from the Warringah Freeway and Gore Hill Freeway to Balgowlah and Killarney Heights and including the surface upgrade of Wakehurst Parkway from Seaforth to Frenchs Forest and upgrade and integration works to connect to the Gore Hill Freeway at Artarmon.

A combined delivery of the Western Harbour Tunnel and Beaches Link program of works would unlock a range of benefits for freight, public transport and private vehicle users. It would support faster travel times for journeys between the Northern Beaches and south, west and north-west of Sydney Harbour. Delivering the program of works would also improve the resilience of the motorway network, given that each project provides an alternative to heavily congested harbour crossings.

1.2 The project

Roads and Maritime Services (Roads and Maritime) is seeking approval under Division 5.2, Part 5 of the *Environmental Planning and Assessment Act 1979* to construct and operate the Western Harbour Tunnel and Warringah Freeway Upgrade, which would comprise two main components:

- A new crossing of Sydney Harbour involving twin tolled motorway tunnels connecting the M4-M5 Link at Rozelle and the existing Warringah Freeway at North Sydney (the Western Harbour Tunnel)
- Upgrade and integration works along the existing Warringah Freeway, including infrastructure required for connections to the Beaches Link and Gore Hill Freeway Connection project (the Warringah Freeway Upgrade).

Key features of the Western Harbour Tunnel component of the project are shown in Figure 1-1 and would include:

- Twin mainline tunnels about 6.5 kilometres long and each accommodating three lanes of traffic in each direction, connecting the stub tunnels from the M4-M5 Link at Rozelle to the Warringah Freeway and to the Beaches Link mainline tunnels at Cammeray. The crossing of Sydney Harbour between Birchgrove and Waverton would involve a dual, three lane, immersed tube tunnel

- Connections to the stub tunnels at the M4-M5 Link project in Rozelle and to the mainline tunnels at Cammeray (for a future connection to the Beaches Link and Gore Hill Freeway Connection project)
- Surface connections at Rozelle, North Sydney and Cammeray, including direct connections to and from the Warringah Freeway (including integration with the Warringah Freeway Upgrade), an off ramp to Falcon Street and an on ramp from Berry Street at North Sydney
- A ventilation outlet and motorway facilities (fitout and commissioning only) at the Rozelle Interchange
- A ventilation outlet and motorway facilities at the Warringah Freeway in Cammeray
- Operational facilities including a motorway control centre at Waltham Street, within the Artarmon industrial area and tunnel support facilities at the Warringah Freeway in Cammeray
- Other operational infrastructure including groundwater and tunnel drainage management and treatment systems, signage, tolling infrastructure, fire and life safety systems, lighting, emergency evacuation and emergency smoke extraction infrastructure, CCTV and other traffic management systems.

Key features of the Warringah Freeway Upgrade component of the project are shown in Figure 1-2 and would include:

- Upgrade and reconfiguration of the Warringah Freeway from immediately north of the Sydney Harbour Bridge through to Willoughby Road at Naremburn
- Upgrades to interchanges at Falcon Street in Cammeray and High Street in North Sydney
- New and upgraded pedestrian and cyclist infrastructure
- New, modified and relocated road and shared user bridges across the Warringah Freeway
- Connection of the Warringah Freeway to the portals for the Western Harbour Tunnel mainline tunnels and the Beaches Link tunnels via on and off ramps, which would consist of a combination of trough and cut and cover structures
- Upgrades to existing roads around the Warringah Freeway to integrate the project with the surrounding road network
- Upgrades and modifications to bus infrastructure, including relocation of the existing bus layover along the Warringah Freeway
- Other operational infrastructure, including surface drainage and utility infrastructure, signage, tolling, lighting, CCTV and other traffic management systems.

A detailed description of the project is provided in Chapter 5 (Project description) and construction of the project is described in Chapter 6 (Construction work) of the environmental impact statement. The project alignment at the Rozelle Interchange shown in Figure 1-1 and Figure 1-3 reflects the arrangement presented in the environmental impact statement for the M4-M5 Link, and as amended by the proposed modifications. The project would be constructed in accordance with the now finalised M4-M5 Link detailed design (refer to Section 2.1.1 of Chapter 2 (Assessment process) of the environmental impact statement for further details).

The project does not include ongoing motorway maintenance activities during operation or future use of residual land occupied or affected by project construction activities, but not required for operational infrastructure. These would be subject to separate planning and approval processes at the relevant times.

Subject to the project obtaining planning approval, construction is anticipated to commence in 2020 and is expected to take around six years to complete.

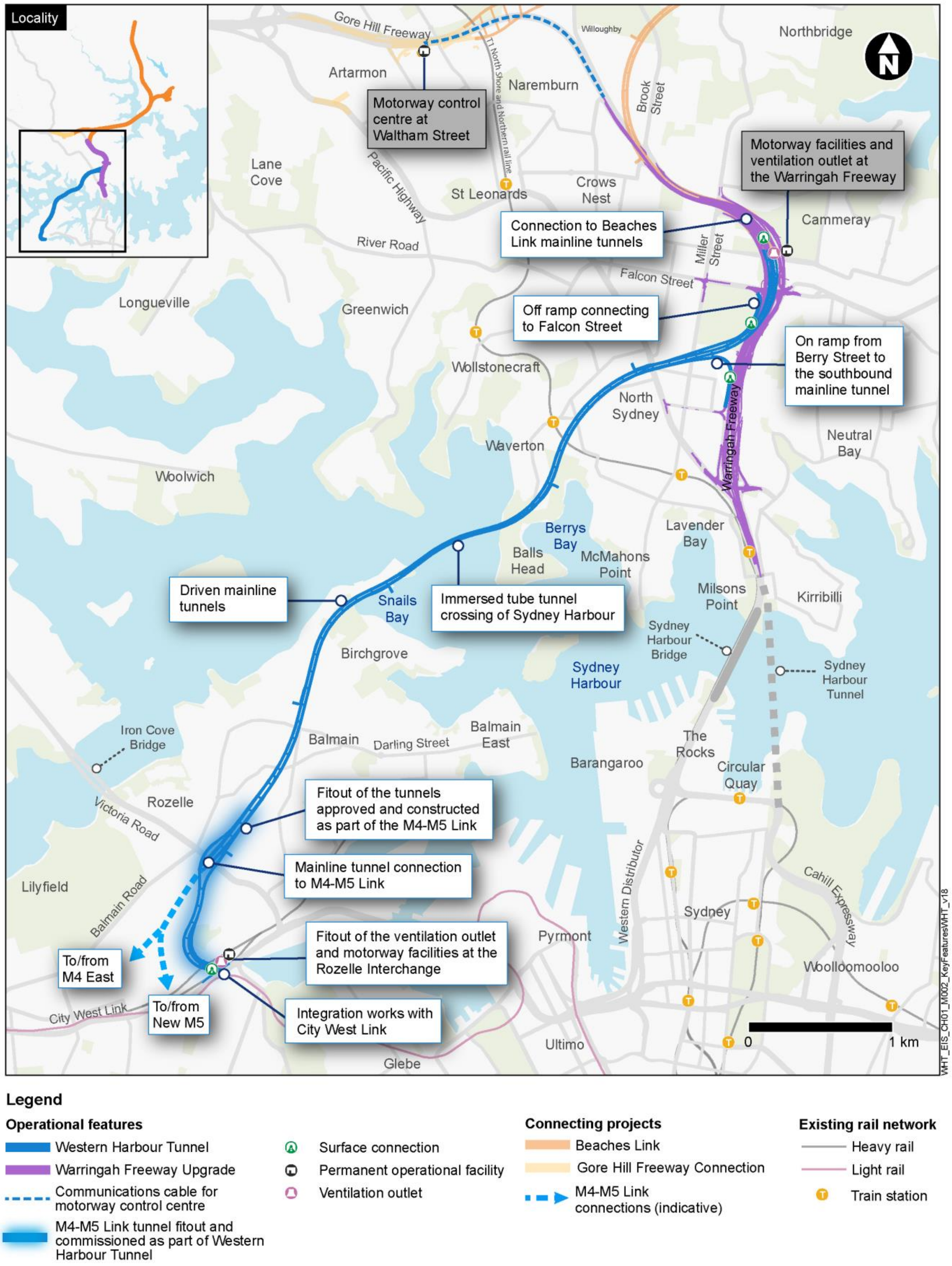

Figure 1-1 Key features of the Western Harbour Tunnel component of the project

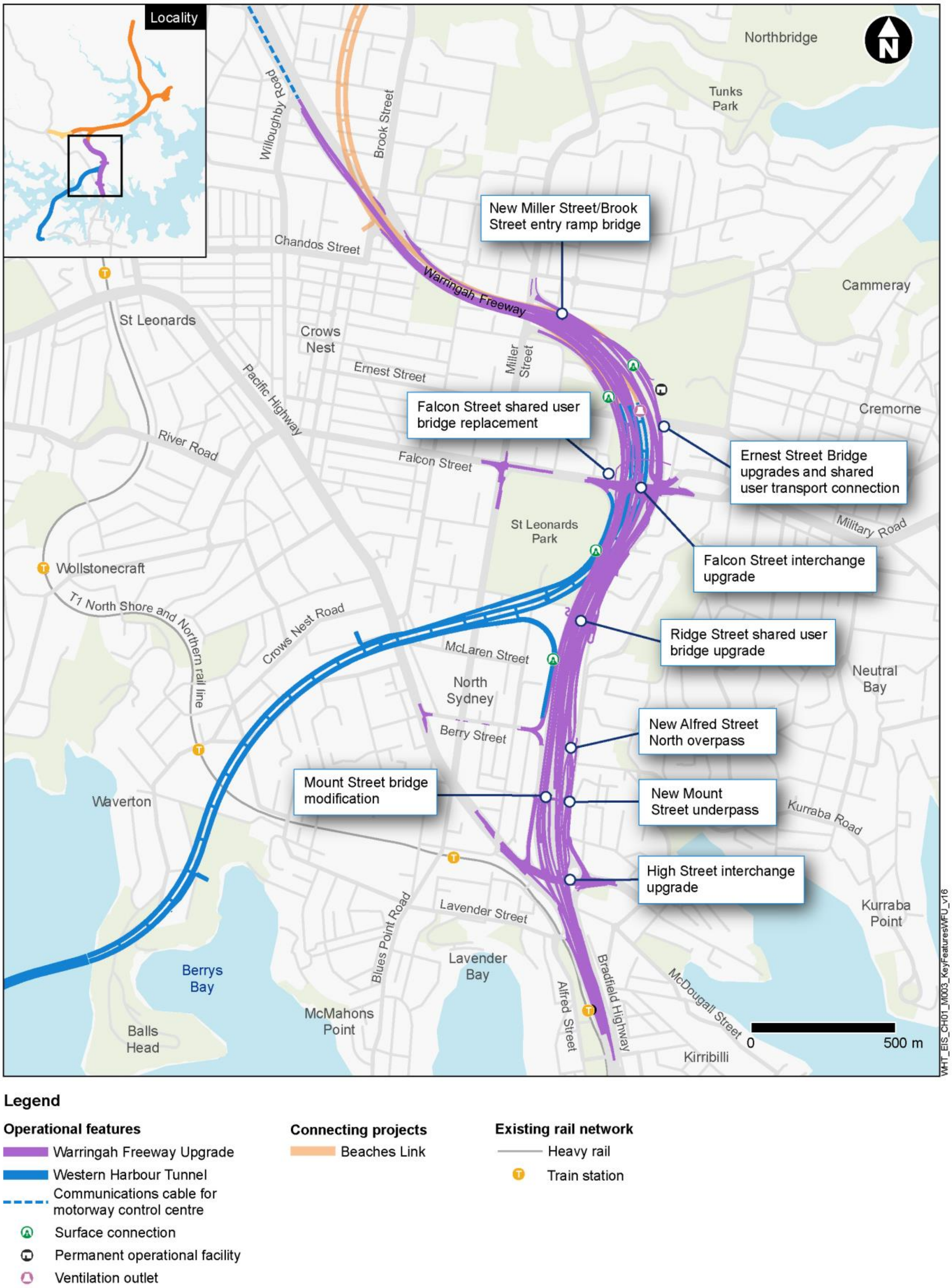

Figure 1-2 Key features of the Warringah Freeway Upgrade component of the project

1.3 Key construction activities

The area required to construct the project is referred to as the construction footprint. The majority of the construction footprint would be located underground within the mainline tunnels. However, surface areas would be required to support tunnelling activities and to construct the tunnel connections, tunnel portals and operational ancillary facilities.

Key construction activities would include:

- Early works and site establishment, with typical activities being property acquisition and condition surveys, utilities installation, protection, adjustments and relocations, installation of site fencing, environmental controls (including noise attenuation and erosion and sediment control) and traffic management controls, vegetation clearing, earthworks and demolition of structures, establishment of construction support sites including acoustic sheds and associated access decline acoustic enclosures (where required), construction of minor access roads and the provision of property access, temporary relocation of pedestrian and cycle paths and bus stops, temporary relocation of swing moorings within Berrys Bay and relocation of the historic vessels
- Construction of Western Harbour Tunnel, with typical activities being excavation of tunnel construction accesses, construction of driven tunnels, cut and cover and trough structures and construction of cofferdams, dredging activities in preparation for the installation of immersed tube tunnels, casting and installation of immersed tube tunnels and civil finishing and tunnel fitout
- Construction of operational facilities comprising of a motorway control centre at Waltham Street in Artarmon, motorway and tunnel support facilities and ventilation outlets at the Warringah Freeway in Cammeray, construction and fitout of the project operational facilities that form part of the M4-M5 Link Rozelle East Motorway Operations Complex, a wastewater treatment plant at Rozelle and the installation of motorway tolling infrastructure
- Construction of the Warringah Freeway Upgrade, with typical activities being earthworks, bridgeworks, construction of retaining walls, stormwater drainage, pavement works and linemarking and the installation of road furniture, lighting, signage and noise barriers
- Testing of plant and equipment, and commissioning of the project, backfill of access declines, removal of construction support sites, landscaping and rehabilitation of disturbed areas and removal of environmental and traffic controls.

Temporary construction support sites would be required as part of the project (refer to Figure 1-3), and would include tunnelling and tunnel support sites, civil surface sites, cofferdams, mooring sites, wharf and berthing facilities, laydown areas, parking and workforce amenities. Construction support sites for Western Harbour Tunnel would include:

- Rozelle Rail Yards (WHT1)
- Victoria Road (WHT2)
- White Bay (WHT3)
- Yurulbin Point (WHT4)
- Sydney Harbour south cofferdam (WHT5)
- Sydney Harbour north cofferdam (WHT6)
- Berrys Bay (WHT7)
- Berry Street north (WHT8)
- Ridge Street north (WHT9)
- Cammeray Golf Course (WHT10)
- Waltham Street (WHT11).

During the construction of the Warringah Freeway Upgrade, smaller construction support sites would be required to support the construction works (as shown on Figure 1-3). These include:

- Blue Street (WFU1)
- High Street south (WFU2)
- High Street north (WFU3)
- Arthur Street east (WFU4)
- Berry Street east (WFU5)
- Ridge Street east (WFU6)
- Merlin Street (WFU7)
- Cammeray Golf Course (WFU8)
- Rosalind Street east (WFU9).

A detailed description of construction works for the project is provided in Chapter 6 (Construction work) of the environmental impact statement.

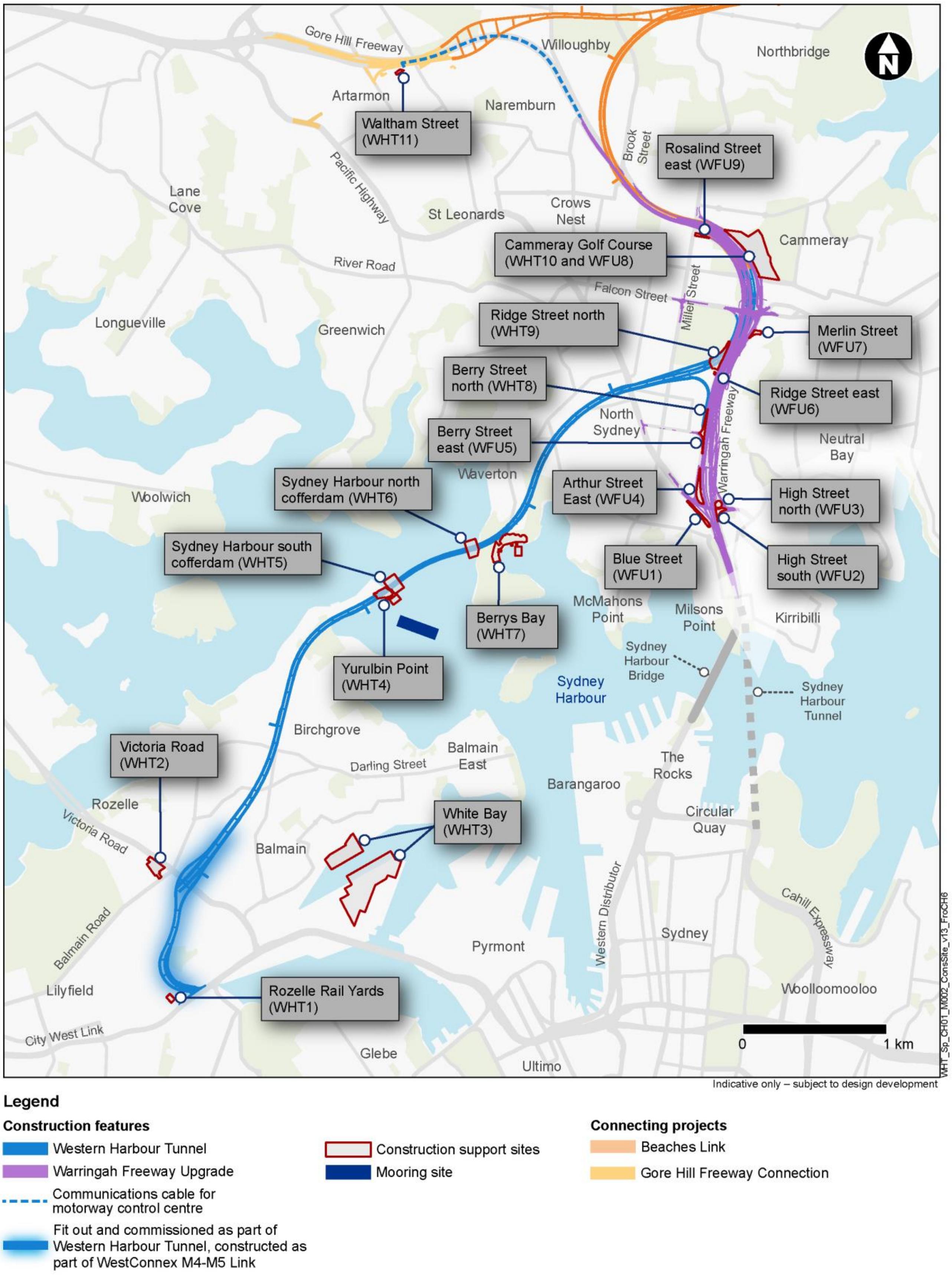

Figure 1-3 Overview of construction support sites

1.4 Project location

The project would be located within the Inner West, North Sydney and Willoughby local government areas, connecting Rozelle in the south with Naremburn in the north.

Commencing at the Rozelle Interchange, the mainline tunnels would pass under Balmain and Birchgrove, then cross Sydney Harbour between Birchgrove and Balls Head. The tunnels would then continue under Waverton and North Sydney, linking directly to the Warringah Freeway to the north of the existing Ernest Street bridge.

The motorway control centre would be located at Waltham Street, Artarmon, with a trenched communications cable connecting the motorway control centre to the Western Harbour tunnel along the Gore Hill Freeway and Warringah Freeway road reserves.

The Warringah Freeway Upgrade would be carried out on the Warringah Freeway from around Fitzroy Street at Milsons Point to around Willoughby Road at Naremburn. Upgrade works would include improvements to bridges across the Warringah Freeway, and upgrades to surrounding roads.

1.5 Purpose of this report

This report has been prepared to support the environmental impact statement for the project, its decision-making process in respect to climate change projections and associated climate risks and to address the environmental assessment requirements of the Secretary of the Department of Planning, Industry and Environment (formerly Department of Planning and Environment) ('the Secretary's environmental assessment requirements').

This report includes:

- A review of existing climate change projections and the climate change risk assessment approach
- Assessment of construction greenhouse gas emissions
- Assessment of operational greenhouse gas emission

1.6 Secretary's environmental assessment requirements

The Secretary's environmental assessment requirements relating to greenhouse gas, and where these requirements are addressed in this report are outlined in Table 1-1.

Table 1-1 Secretary's environmental assessment requirements – greenhouse gases

Secretary's environmental assessment requirements	Where addressed
1. The Proponent must assess the risk and vulnerability of the project to climate change in accordance with the current guidelines.	Section 3.2 Chapter 26 of the EIS
2. The Proponent must quantify specific climate change risks with reference to either the NSW Government's climate projections at 10 km resolution (or lesser resolution if 10 km projections are not available) or equivalent projection tool (such as the Climate Futures Tool from CSIRO and BoM (attenuated for project region)) and incorporate specific adaptation actions in the design.	Section 2 Chapter 26 of the EIS

2. Climate change projections

2.1 Overview

The Intergovernmental Panel on Climate Change's Fifth Assessment Report (AR5, IPCC (2013)) provides a synthesis of climate change modelling carried out by leading international climate research organisations. Outputs from this work for Australia are published on the Climate Change in Australia (CCIA) website (www.climatechangeinaustralia.gov.au), and specifically using its Climate Futures Tool (CFT). They consolidate projections from General Circulation Model (GCM or global climate model) runs for the 21st Century under a range of greenhouse gas emissions and Representative Concentration Pathway (RCP) scenarios and include data for a wide range of climate parameters, including rainfall, temperature and wind speed.

Climate change projections are useful tools to guide decision-making about climate risks. They indicate the expected trend in climate variables under various future scenarios and the likely quantum of change. While probabilities may be provided for GCM projections for given RCP or emissions scenarios, no probabilities can be attached to the scenarios themselves. Confidence in climate change projections is greater for temperature and related climate attributes and much lower for rainfall, particularly extreme rainfall events.

Climate change projections included in this assessment are based on RCP8.5, which reflects the highest emissions (or radiative forcing) scenario considered in AR5. They follow the projections for this scenario from 2030 to 2090.

2.2 Source of projections

The CFT collates the distribution of GCM change factors for each projection period and classifies models according to changes in average annual temperature and rainfall. The central tendency (see Figure 2-1) for the set of models which reliably reflect key climate drivers for south-eastern Australia is for warmer conditions, with little change in rainfall relative to 1986–2005, by 2030. By 2050, the central tendency in GCM projections is for the climate to be warmer and drier than the reference period. A large number of models project a hotter and drier climate or a warmer climate with little change in rainfall. In 2090, the most common projection is for climate to be much hotter and drier than during the 1986–2005 climate change reference period.

An initial filtering of GCMs was carried out to only include AR5 models and models which the website advised were suitable for the east coast of Australia. As noted above, the CFT was then used to identify the general pattern of climate change projections for 2030 and RCP8.5, with respect to changes in rainfall and temperature. Three GCMs which were considered by the CFT to best represent this pattern were then selected to provide the climate change factors for this period and for 2050 and 2090 under the RCP8.5 scenario. This ensures that climate change projections over each timeframe and for various climate characteristics are internally consistent.

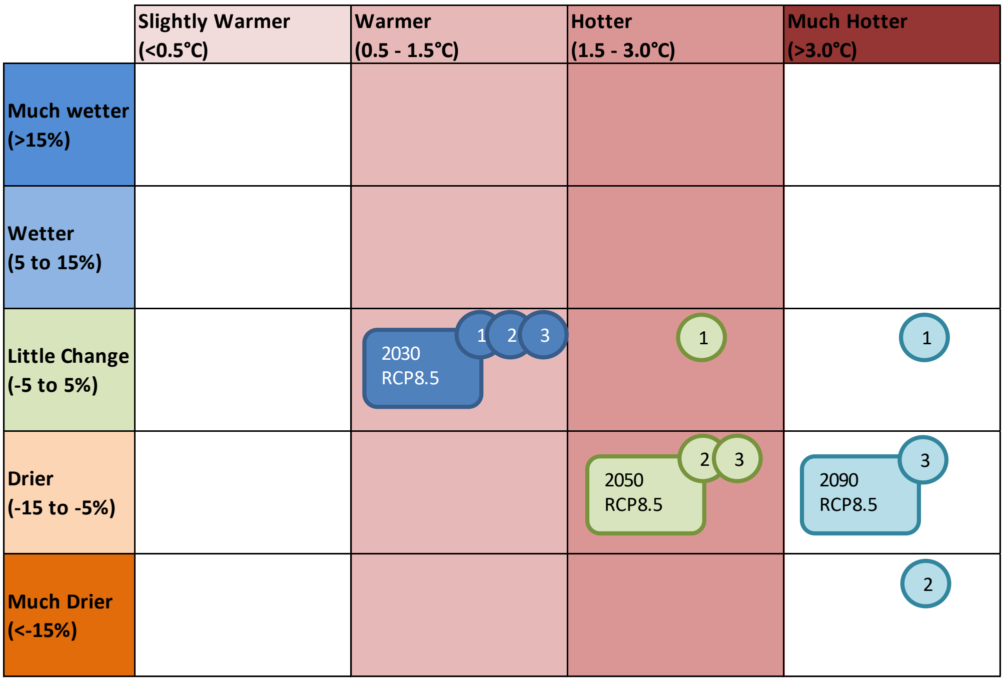

Figure 2-1 Central tendency in projected annual average rainfall and temperature for climate models used in AR5: 2030–2090. Projected changes in annual rainfall and average temperature for the climate models used in this analysis

Source: data derived from CCIA web site www.climatechangeinaustralia.gov.au . The full ensemble of GCM used for AR5 and CMIP5 (Coupled Model Intercomparison Project Phase 5), on average, project that climate will be warmer, with little change in rainfall in 2030, warmer and drier in 2050 and much hotter and drier in 2090. The three models used to develop climate change projections (1 – CESM1-CAM5, 2 – bcc-csm1-1, 3 – MPI-ESM-LR) broadly follow this trajectory. They were selected from the set of models which satisfactorily represent key processes influencing the climate of Eastern Australia.

The three GCMs used in this assessment were:

- CESM1-CAM5 – Version 5.0 of the Community Atmosphere Model (CAM) – the latest in a series of global atmosphere models developed primarily at the National Center for Atmospheric Research (NCAR) – United States of America
- BCC-CSM1-1 – version 1.1 of the Beijing Climate Center Climate System Model (BCC_CSM1.1) developed at the Beijing Climate Center (BCC), China Meteorological Administration (CMA), based on NCAR CCSM2.0.1. It is a fully coupled global climate–carbon model including interactive vegetation and global carbon cycle, in which the atmospheric component BCC_AGCM2.1, ocean component MOM4-L40, land component BCC_AVIM1.0, and sea ice component SIS are fully coupled and interact with each other through fluxes of momentum, energy, water and carbon at their interfaces – China
- MPI-ESM-LR – Max Planck Institute Earth System Model (MPI-ESM) on low resolution (LR) grid. MPI-ESM is a comprehensive Earth-System Model, in the sense that it consists of component models for the ocean, the atmosphere and the land surface. These components are coupled through the exchange of energy, momentum, water and important trace gases such as carbon dioxide (CO_2) – Germany.

2.3 Projections

A summary of the projections identified in this section are presented below. Climate change projections were developed for three periods, which broadly reflect the operating lives of different elements being constructed as part of the project:

- 2030: Assets and systems with short operating lives, such as communications and other electronic systems and landscaping, as well as road surfaces
- 2050: Assets and systems with long operating lives, such as drainage structures and barriers/rails
- 2090: 'Permanent' assets, which would become fixed and ongoing features of project, such as tunnel civil structures (including rock bolts), bridges, embankment culverts (and other inaccessible drainage), and buildings.

A baseline of 1986–2005 has been presented for some climate variables where relevant, as this relates to the period from which the changes to those variables are projected.

Table 2-1 Climate change projections

Project Category	Baseline (1986 - 2005)	2030 (RCP8.5)	2050 (RCP8.5)	2090 (RCP8.5)
Temperature				
Mean minimum temperatures (°C) – Annual	14.4	15.5	16.3	18.4
Mean minimum temperatures (°C) – Summer	19.1	20.2	22.12	23.0
Mean minimum temperatures (°C) – Autumn	15.3	16.4	18.31	19.2
Mean minimum temperatures (°C) – Winter	9.4	10.5	12.44	13.3
Mean minimum temperatures (°C) – Spring	14.1	15.2	17.08	18.0
Mean minimum temperatures (°C) – Annual	22.4	24.3	24.4	26.5
Mean minimum temperatures (°C) – Summer	26.2	27.4	29.4	30.1
Mean minimum temperatures (°C) – Autumn	23.1	24.3	26.3	27.0
Mean minimum temperatures (°C) – Winter	18.2	19.4	21.4	22.1
Mean minimum temperatures (°C) – Spring	22.6	23.8	25.8	26.5
Days over 35°C – Annual	3.5	5.6	5.9	11.3
Days over 40°C – Annual	0.2	0.8	0.9	2.0
Days over 45°C – Annual	0	0	0	0
Nights below 2°C – Annual	0	0	0	0
Rainfall				
Mean precipitation (mm) – Annual	1238	1206	1151	1049
Mean precipitation (mm) – Summer	333	346	322	351
Mean precipitation (mm) – Autumn	380	369	364	349
Mean precipitation (mm) – Winter	287	257	277	208
Mean precipitation (mm) – Spring	238	236	218	203
Extreme rainfall events – Max 1 Day Rainfall	Projected to increase 2 – 22%			
Extreme rainfall events – 20 year return level of max. 1 day rainfall	Projected to increase 5 – 42%			
Annual runoff % change	-	-	-	-70% to 15%

Project Category	Baseline (1986 - 2005)	2030 (RCP8.5)	2050 (RCP8.5)	2090 (RCP8.5)
Evapotranspiration				
Annual change in potential evapotranspiration (% change)	375mm (1961 – 1990)	4.2	No data	14.3
Summer change in potential evapotranspiration (% change)	495mm (1961 – 1990)	4.4	No data	13
Autumn change in potential evapotranspiration (% change)	308mm (1961 – 1990)	5.2	No data	19.3
Winter change in potential evapotranspiration (% change)	165mm (1961 – 1990)	5.7	No data	20.6
Spring change in potential evapotranspiration (% change)	1350mm (1961 – 1990)	3	No data	11.4
Fire Regimes				
Change in annual mean forest fire danger index (% change)	2158	2-7%	5-19%	No data
The number of days where the fire danger rating is 'very high' or 'extreme'	8.7	9.2 - 11.1	9.8-15.2	No data
Severe Wind				
Average maximum daily wind speed (% change)	120 kph	-0.2 to 1.9	1.8 to 3.2	0.3 to 5.7
Sea Conditions				
Sea level rise (m)	0	0.14	-	0.66
Sea surface temperature (°C)	-	1.0	-	3.1
Ocean pH	-	-	-	-0.3
Atmospheric CO_2				
Atmospheric CO_2 concentration	401 ppm	-	-	940ppm (2100)

2.4 Climate change risk assessment approach

The hazard-receiver pathway model was applied to identify and analyse climate change risks. This model considers the following:

- Hazard – climate or climate influenced attributes with potential to influence the operation and maintenance of the project
- Receiver – the component of the operation and/or maintenance of the project that would be impacted by the hazard. This may also include users of the project and affected elements of the surrounding environment
- Risk rating – utilising the likelihood (Table 2-2) and consequence (Table 2-3) rating system, an assessment of the way hazards influence the project receivers is carried out and a risk rating awarded (Table 2-4).

Table 2-2 Likelihood descriptions

Likelihood Rating	Description	Probability	Lifecycle
Almost Certain	The event is expected to occur in most circumstances	>90% probability	>1 in one year
Likely	The event would probably occur in most circumstances	51% to 90% probability	1 in 10 years
Moderate	The event should occur at some time	21% to 50% probability	1 in 50 years
Unlikely	The event could occur at some time	10% to 20% probability	1 in 100 years
Rare	The event might occur in exceptional circumstances	<10% probability	1 in 1000 years

Table 2-3 Consequence descriptions

Consequence Rating	Time		Cost		Safety		Environment Delivery Operation	Traffic Flow Peak Hour	Local Traffic	Community Attitude	Fit for purpose defects/ Accidents/ Maintenance Costs
	Develop-ment	Delivery	Develop-ment	Delivery	Delivery	Operation					
Critical	Year	Months	$(25% overall construction cost)	$(10% overall construction cost)	Workers Compensation Liability >$250,000 Death/ perm. loss of physical/mental amenity.	Multiple Workers Compensation Liability >$250,000 Death/ perm. loss of physical/mental amenity.	Major environmental damage and/ or delay due to legal finding in Land and Environment	No improve-ment	Severe disruption	Severe community protests	Functional failure
Major	Months	Months	$(15% overall construction cost)	$(7% overall construction cost)	Workers Compensation Liability $10,001 - $250,000 Lost time >=5 days	Workers Compensation Liability >$250,000 Death, permanent loss of physical or mental amenity.	Serious environmental damage and/or delay due to Public Enquiry. Environment Protection Authority (EPA) Major Notice	Marginal improve-ment	Disruption	Community protests	Serious functional failure
Moderate	Months	Months	$(7.5% overall	$(4% overall construction	Workers Compensation	Workers Compensation	Environmental damage and/or	N/A	N/A	Daily	Minor functional

Consequence Rating	**Time**		**Cost**		**Safety**		**Environment Delivery Operation**	**Traffic Flow Peak Hour**	**Local Traffic**	**Community Attitude**	**Fit for purpose defects/ Accidents/ Maintenance Costs**
	Develop-ment	**Delivery**	**Develop-ment**	**Delivery**	**Delivery**	**Operation**					
			construction cost)	cost)	Liability $1001 - $10,000 Lost time 1-4 days	Liability $10,001 - $250,000 Lost time >=5 days	EPA Infringement Notice			Complaints	failure
Minor	Months	Weeks	$(1% overall construction cost)	$(1% overall construction cost)	Workers Compensation Liability $251 - $1000 Lost time >=1 days	Workers Compensation Liability $1001 - $10,000 Lost time 1-4 days	Minor environmental damage and/or minor EPA infringement notices. Written Community comments	N/A	N/A	Complaints	N/A
Insignificant	Weeks	Nil	$(0.1% overall construction cost)	$(0.1% overall construction cost)	Workers Compensation Liability $1 - $250 First aid treatment (no lost time)	Workers Compensation Liability $251 - $1000 Lost time >=1 days	Minor repairable environmental damage. Verbal Community comment	N/A	N/A	Negligible Complaints	N/A

Table 2-4 Risk matrix

Likelihood Rating	Consequence				
	Insignificant	Minor	Moderate	Major	Critical
Almost certain	Medium	High	Extreme	Extreme	Extreme
Likely	Low	Medium	High	Extreme	Extreme
Moderate	Negligible	Low	Medium	High	Extreme
Unlikely	Negligible	Negligible	Low	Medium	High
Rare	Negligible	Negligible	Negligible	Low	Medium

3. Greenhouse gas calculations

3.1 Assessment methodology

This section describes the methodology used to estimate the greenhouse gas emissions that would be generated during construction and operation of the project. This report has been informed by information outlined within the environmental impact statement for the project as well as information provided by Roads and Maritime.

3.1.1 Greenhouse gas accounting

'Greenhouse gases' is a collective term for a range of gases that are known to trap radiation in the upper atmosphere, where they have the potential to contribute to the greenhouse effect (global warming). Creating an inventory of the likely greenhouse gas emissions associated with a project has the benefit of determining the scale of the emissions and providing a baseline from which to develop and deliver greenhouse gas reduction options. Greenhouse gases include:

- Carbon dioxide (CO_2) – by far the most abundant, primarily released during fuel combustion
- Methane (CH_4) – from the anaerobic decomposition of carbon based material (including emissions produced during digestion in some livestock and waste disposal in landfills)
- Nitrous oxide (N_2O) – from industrial activity, fertiliser use and production
- Hydrofluorocarbons (HFCs) – commonly used as refrigerant gases in cooling systems
- Perfluorocarbons (PFCs) – used in a range of applications including solvents, medical treatments and insulators
- Sulphur hexafluoride (SF_6) – used as a cover gas in magnesium smelting and as an insulator in heavy duty switch gear.

It is common practice to aggregate the emissions of these gases to the equivalent emission of CO_2. This provides a simple figure for comparison of emissions against targets. Aggregation is based on the potential of each gas to contribute to global warming relative to CO_2 and is known as the global warming potential. The resulting number is expressed as CO_2 equivalents (or CO_2e).

The greenhouse gas inventory in this document is calculated in accordance with the principles of the Greenhouse Gas Protocol (GHG Protocol)[1]. The greenhouse gas emissions that form the inventory can be split into three categories known as 'Scopes'. Scopes 1, 2 and 3 are defined by the GHG Protocol and can be summarised as follows:

- Scope 1 – Direct emissions from sources that are owned or operated by a reporting organisation (examples – combustion of diesel in company owned vehicles or used in on-site generators)
- Scope 2 – Indirect emissions associated with the import of energy from another source (examples – importation of electricity or heat)
- Scope 3 – Other indirect emissions (other than Scope 2 energy imports) which are a direct result of the operations of the organisation but from sources not owned or operated by them (examples include business travel (by air or rail) and product usage).

[1] The Greenhouse Gas Protocol is collaboration between the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD). The Protocol provides guidance on the calculation and reporting of carbon footprints.

The results of this assessment are presented in terms of the above listed 'scopes' to help understand the direct and indirect sources of the greenhouse gas emissions generated by the project.

The GHG Protocol (and similar reporting schemes) dictates that reporting Scope 1 and 2 sources is mandatory, whilst reporting Scope 3 sources is optional. Reporting significant Scope 3 sources is recommended. For this project, all 'scopes' have been assessed.

The initial action for a greenhouse gas inventory is to determine the potential sources of greenhouse gas emissions, assess their likely significance and set a provisional boundary for the assessment. Following this, data is collected to represent the activities being carried out for the project and converted to greenhouse gas emissions typically using emissions factors – a published figure for the particular activity representing the aggregated greenhouse gas emissions per unit of the activity. These have been aggregated for the whole project.

3.1.2 Greenhouse gas assessment boundary

The assessment boundary defines the scope of greenhouse gas emissions and the activities to be included in the assessment. Table 3-1 and Table 3-2 summarise the key emission sources and activities considered within the project's assessment boundary for construction and operation, according to scope. Note that some emissions sources are split into more than one scope. This is typically the case where there are direct emissions (eg combustion of fuel in a vehicle operated as part of the project) as well as indirect emissions (extraction and processing of the fuel before it is used).

Adopting the guidance provided by the Infrastructure Sustainability Council Australia (ISCA (2016)), any source of energy use, or greenhouse gas emissions that is likely to account for more than five per cent of the infrastructure lifecycle footprint is considered significant and has been included in this assessment.

Further, the assessment has also considered greenhouse gas emissions generated by ongoing maintenance activities in accordance with ISCA guidance. It is noted that maintenance activities would not be included in the project approval and would be subject to separate assessment and approval processes.

Table 3-1 Construction greenhouse gas emission sources

Emission Source	Scope 1	Scope 2	Scope 3
Fuel use – diesel consumption in plant and equipment during construction	✓		✓
Fuel use – diesel consumption by generators associated with harbour construction activities	✓		✓
Construction materials			✓
Fuel use – transport of construction materials			✓
Fuel use – transport of construction waste, spoil or dredged material			✓
Electricity consumption – construction support sites and roadheaders		✓	✓
Vegetation removal	✓		

Table 3-2 Operational greenhouse gas emission sources

Emission Source	Scope 1	Scope 2	Scope 3
Road use by vehicles (difference between 'Do minimum' and 'Do something' scenarios)			✓
Electricity consumption – lighting		✓	✓
Electricity consumption – hydraulics and water treatment		✓	✓
Electricity consumption – substation for air conditioning		✓	✓
Electricity consumption – motorway control centre		✓	✓
Electricity consumption – tunnel ventilation		✓	✓
Maintenance activities – fuel	✓		✓
Maintenance activities – materials			✓

3.1.3 Tools for assessment of greenhouse gas emissions

The calculation of greenhouse gas emissions for this assessment was facilitated through the use of a number of different tools. These are presented in Table 3-3. The tools were used to determine the emissions associated with discrete components of the assessment, but do not represent the whole assessment.

In addition to the tools, bespoke calculations were carried out for a large proportion of this assessment due to its complexity. All tools source a variety of emissions factors, but preference was taken for the National Greenhouse Accounts (NGA) factors (2017) where required.

Table 3-3 Tools for assessment of greenhouse gas emissions

Greenhouse Gas Assessment Tool	Description	Application
Carbon Gauge	• Framework for assessing greenhouse gas emissions from road construction projects • Automates calculations, assumptions and greenhouse gas emission factors presented in Greenhouse Gas Assessment Workbook for Road Projects • The greenhouse gas emission profile is built through the selection of a number of defined inputs, such as of road pavement lengths and areas, areas of vegetation, road features, cost of construction and other accessible data.	• Some elements of greenhouse gas emissions within construction (vegetation removal) • Fuel use/materials during maintenance • Review calculations conducted using different methods.
Infrastructure Sustainability Materials Calculator (ISMC)	• Developed by ISCA, to evaluate environmental impacts in relation to the use of materials on infrastructure projects, including the transport of materials to and from project sites • Emissions profile is built by inserting material quantities, concrete strengths, aggregate, plastic and steel types, as well as transport types into the model.	• Materials assessment • Transport of materials to and from project sites.
Tools for Roadside Air Quality (TRAQ)	• Tool for modelling emissions to air from vehicles using roads • Input data include traffic numbers and type, speed, lane numbers and standard emission factors.	• Greenhouse gas emissions associated with current and future road use, with and without the project.

3.1.4 Greenhouse gas emissions estimation – construction

This section presents the methodology used to estimate greenhouse gas emissions associated with construction of the project. Various assumptions have been made, including the use of the marine environment to transport spoil via barge instead of utilising trucks.

Fuel combustion from construction plant and equipment, including barge movements

The method to calculate the greenhouse gas emissions resulting from fuel combustion by construction equipment and plant involved the following:

- Identification of the plant and equipment to be used for each construction stage (as detailed in the environmental impact statement)
- Determination of hourly fuel consumption rates and duration of use for each plant and equipment, as well as total construction stage durations. Fuel consumption data were sourced from the equipment manufacturer specification sheets
- Daily operational hours of each equipment and plant (percentage of maximum hours) were assumed as either 100 per cent, 80 per cent, 50 per cent or 25 per cent in each construction stage, and the fuel consumption was calculated according to this assumed usage rate for each equipment and plant.

The following formula was used to calculate the Scope 1 greenhouse gas emissions from the combustion of fuel by construction equipment and plant (sourced from the NGA Factors, 2017). This formula was applied to each relevant equipment and plant identified in the construction plan, with usage rates and fuel consumption applied as above, accordingly.

Greenhouse Gas Emissions (t CO_2e) = ((Q x ECF)/1000) x ($EFCO_2$ + EFCH4 + EFN2O)

Where:

- Q is quantity of fuel (kL)
- ECF is the relevant energy content factor (in GJ/kL)
- $EFCO_2$ is the relevant carbon dioxide emission factor (kg CO_2e/GJ)
- EFCH4 is the relevant methane emission factor (kg CO_2e/GJ)
- EFN2O is the relevant nitrous oxide emission factor (kg CO_2e/GJ).

The following formula was used to calculate the Scope 3 greenhouse gas emissions from the combustion of fuel by construction equipment and plant, as per NGA Factors 2017. As with Scope 1 calculations, this formula was applied to each equipment and plant identified in the construction plan, with usage rates and fuel consumption applied as above, accordingly:

Greenhouse Gas Emissions (t CO_2e) = (Q x ECF x EFScope 3)/1000

Where:

- Q is the quantity of fuel (kL)
- ECF is the relevant energy content factor (GJ/kL)
- EFScope 3 is the relevant emission factor (kg CO_2e/GJ).

Table 3-4 presents the ECF and the emission factor which applies to the above equations.

Table 3-4 Diesel fuel emissions factor (NGA, 2017)

Fuel	Energy content factor (GJ per kL)	Scope 1 emission factor (kg CO_2e/GJ)			Scope 3 emission factor (kg CO_2e/GJ)	Emissions per unit quantity (t CO_2e per kL)	
		CO_2	CH4	N2O		Scope 1	Scope 3
Diesel	38.6	69.9	0.01	0.6	3.6	2.7217	0.1390

The above equations were applied assuming that all equipment and plant (including barges) to be used would operate on diesel fuel and are 'post 2004' vehicles.

Barges associated with the transport of personnel, equipment and construction materials between construction support sites have been classified as construction equipment for this assessment and are considered in the assessment of greenhouse gas emissions from the combustion of fuel from construction plant and equipment.

Greenhouse gas emissions generated by barges transporting dredged material, spoil and waste removal has been captured under emissions resulting from the transport of spoil and waste.

Fuel combustion by generators during harbour construction activities

Harbour construction activities (including dredging) would consume electricity from diesel generators. The inputs for calculating the greenhouse gas emissions from these harbour construction activities are presented in Table 3-5, including the total fuel consumption per equipment and plant. This includes the equipment and plant that would be used for trench dredging and excavation in cofferdams.

For equipment, electrical power consumption and time in use data were available. Fuel efficiency data from a 1.25 MW generator (assumed to be operating at 75 per cent capacity) was used to determine the total fuel consumption by the generators powering each equipment and plant as detailed in Table 3-5.

The equations in the previous section were then applied to then calculate the Scope 1 and Scope 3 greenhouse gas emissions.

Table 3-5 Construction equipment and assumed diesel consumption

Equipment	No. of units	Total average power (kW)	No. of weeks of operation	Total power use (MW)	Total diesel fuel consumption (kL)
Site offices	1	200	175	2100	455
Survey boats	1	100	165	578	125
Trailing suction hopper dredge	1	15,000	13	7500	1624
Backhoe dredger	1	2000	98	8820	1910
Hopper barges	3	450	98	2205	477
Cutter suction dredge	1	20,000	28	22,400	4850
Multi cat tug	1	250	126	1575	341
Tug and sweep bar	1	200	16	32	7
Crane barge	1	300	36	32	7
Flat-top	2	100	36	11	2
Wheel loader	1	75	36	8	2
Tug (curtain mount)	1	75	162	729	158
Cofferdam dry-excavation with disposal of spoil offshore					
Site offices	1	40	35	84	18
Survey boat	1	100	30	120	26
Excavators Large Small	 2 2	 150 400	 25 25	 169 450	 37 97
Hopper barge	1	25	25	16	3
Tug	1	100	25	75	16

Equipment	No. of units	Total average power (kW)	No. of weeks of operation	Total power use (MW)	Total diesel fuel consumption (kL)
Crane barge	1	400	25	450	97

Construction materials

Greenhouse gas emissions associated with construction materials have been determined using the emission factors provided by the ISMC, developed by the ISCA. This calculator evaluates environmental impacts in relation to the use of materials on infrastructure projects and assets. To determine the greenhouse gas emissions from construction materials, the following steps were carried out:

- Material quantity estimates were determined by cost estimators, in the form of Bills of Quantity for major construction materials
- The Bills of Quantity were refined to provide greater detail as required. This included tasks such as differentiating between different concrete strength grades, and translating data where quantities were provided as a number, which could not be directly applied to a relevant emissions factor (such as volume or weight)
- A gap analysis was carried out to determine those areas not addressed in the Bills of Quantity, which would need to be addressed separately. Separate calculations were made as needed to fill the gaps.

The quantities of construction materials determined for each project is presented in Table 3-6.

The quantities presented in Table 3-6 were multiplied against corresponding emission factors as provided in the ISMC for individual materials to determine the resulting Scope 3 greenhouse gas emissions.

Table 3-6 Construction materials input volumes

Material	Units	Total
Asphalt	t	371,400
Sprayed bitumen	t	1000
Ready mixed concrete		
25 MPa	m^3	13,600
32 MPa	m^3	30,200
40 MPa	m^3	329,600
50 MPa	m^3	5200
Precast concrete*		
40 MPa	m^3	33,600
Aggregates		
Gravel	m^3	51,200
Sand	m^3	3600

Material	Units	Total
General fill	m^3	162,900
Other		
Steel	t	80,600
Aluminium	t	80
Glass	m^3	<1
Piping – PVC	t	2200
Piping – concrete	t	4700
Plastic sheet/film	m^3	520
Composites – cement fibreboard	t	800
Coatings	t	1
Water treatment chemicals	t	50

*Precast concrete with a strength of 32 MPa has been modelled as 40 MPa, as 32 MPa is not an optional input in the ISMC.

Fuel combustion from the transport of materials

To determine the greenhouse gas emissions resulting from the transport of materials to the construction support sites, the quantity and type of material, the distance for individual materials to be transported and the modes of transport were determined.

The following formula was used, using the emission factors in the ISCA calculator for the transport of materials by specific modes of transport:

Greenhouse Gas Emissions (t CO_2e) = M x EF x D

Where:

- M is the material quantity to be transported in (either tonnes or cubic metres) (see Table 3-6)
- EF is the relevant emission factor (tonnes CO_2e/unit) (refer to Table 3-7)
- D is the distance the material is required to be transported (kilometres).

The above equation was applied to road and ship transport that would be used to import material to the project sites. It was assumed that any imported overseas material would be transported from Shanghai, China by ship, to Botany Bay, and then by rigid truck to the construction support sites. As the source of imported overseas material would be confirmed during detailed construction planning, Shanghai, China was selected as a conservative assumption as the furthest possible location within the Asia-Pacific region.

Table 3-7 presents the emission factors used to determine the greenhouse gas emissions resulting from different modes of transport. The table presents the emission factors based on the quantity of materials in tonnes and cubic metres. Table 3-8 presents the inputs for calculating the greenhouse gas emissions resulting from the transport of materials to construction support sites.

Table 3-7 Emission factors for modes of transport (ISCA)

Mode of transport	Emission factor (t CO_2e-/ tonne of material/km)	Emission factor (t CO_2e-/ m3 of material/km)
Rigid truck	0.000216	0.00034
Concrete agitator	0.000128	0.00031
Shipping domestic (including barge)	0.000035	0.00006
Shipping international freight	0.000009	0.00001

Table 3-8 Material transport inputs

Material	Total	Anticipated sources	Assumed distance (km)	Assumed mode of transport
Asphalt (t)	371,400	Sydney suppliers	30	Rigid truck
Sprayed bitumen (t)	1000	Sydney suppliers	30	Rigid truck
Ready mixed concrete (m^3)	378,600	Sydney suppliers close to project	30	Concrete agitator truck
Precast concrete (m^3)	16,800	Sydney	50	Rigid truck
	16,800	Northern NSW	300	Rigid truck
	33,600 (total)			
Aggregates – gravel (m^3)	51,200	NSW South Coast and Central Coast	120	Rigid truck
Aggregates – sand (m^3)	3600	NSW South Coast and Central Coast	120	Rigid truck
Aggregates – general fill (m^3)	162,900	Project tunnel spoil or sourced from within the Sydney	20	Rigid truck
Steel (t)	40,300	Sydney	50	Rigid truck
	40,300	Overseas	8500	Ship (assumed from Shanghai, China)
			40	Rigid truck (Botany Bay to project)
	80,600 (total)			
Aluminium(t)	80	Overseas (assumed Shanghai, China)	8500	Ship (assumed from Shanghai, China)
Glass (m^3)	<1	Australia or overseas	50	Rigid truck (assumed from Sydney – small quantities)
Piping – PVC (t)	2200	Australia or overseas	50	Rigid truck (assumed from Sydney – small quantities)
Piping – concrete (t)	4700	Australia	50	Rigid truck

Material	Total	Anticipated sources	Assumed distance (km)	Assumed mode of transport
Plastic sheet/Film (m^2)	520	Australia or overseas	50	Rigid truck (assumed from Sydney – small quantities)
Composites – cement fibreboard (t)	800	Australia	50	Rigid truck
Coatings and finishes (t)	1	Australia or overseas	50	Rigid truck (assumed from Sydney – small quantities)
Water treatment chemicals (t)	50	Australia or overseas	50	Rigid truck (assumed from Sydney – small quantities)

Fuel combustion from the transport of waste and spoil

The fuel consumption associated with the transport of construction waste, dredged material and spoil was calculated using the following steps:

- Identify or obtain data on the quantities of excavated spoil generated by tunnelling and surface works
- The distances between each of the proposed disposal facilities and the construction support sites were estimated using Google Earth
- The quantity of all imported spoil was determined, including the transport of spoil from one part of the project to another. The distances of transport for imports were estimated using Google Earth
- Dredged material unsuitable for offshore disposal has been assumed to be transported to a licensed facility in Kemps Creek, NSW
- Dredged material quantities and disposal locations were determined, assuming the majority is disposed offshore with appropriate approvals.

The following formula was used to determine the greenhouse gas emissions generated from the transport of waste, dredged materials and spoil:

Greenhouse Gas Emissions (t CO_2e) = M x EF x D

Where:

- M is the material quantity to be transported (in tonnes)
- EF is the relevant emission factor, depending on the mode of transport (tonnes CO_2e/unit) (see Table 3-7)
- D is the distance the material is required to be transported (kilometres).

The waste material, dredged material and spoil quantities used to determine emissions from transport are presented in Table 3-9.

Table 3-9 Indicative waste and spoil material quantities

Type	Disposal or import location	Distance (kilometres)	Total (tonnes)
Terrestrial activities			
Disposal – spoil excavation and crushed rock removal/top soil removal	Penrith Lakes, NSW	66	5,031,000
Disposal – aggregates/ crushed rock and concrete	Camelia, NSW	30	3,941,173
Disposal – construction waste (from building and other demolition)	Camelia, NSW	30	100,200
Import of spoil	Western Sydney, NSW	50	8850
Import of aggregates	Bombo, NSW	123	18,400
Dredged material spoil			
Dredged material unsuitable for offshore disposal	Kemps Creek	52	228,000
Dredged material suitable for offshore disposal	Offshore	10	1,219,200

Electricity consumption

The method used to calculate the Scope 2 and Scope 3 greenhouse gas emissions resulting from the consumption of purchased electricity is given by the formula below, as given by the NGA Factors 2017:

Greenhouse gas emissions (t CO_2e) = Q x EFScope x /1000

Where:

- Q is the quantity of purchased electricity (kWh)
- EFScope x is the Scope 2 or Scope 3 emissions factor for NSW (kg CO_2e/kWh).

Scope 2 factors relate to the emissions resulting from the generation of the electricity itself, while the Scope 3 emissions relate to the extraction and production of fuels, as well as distribution losses.

Multiple roadheaders would be used concurrently for the project with tunnelling occurring 24 hours a day, seven days a week until completion. Power for roadheaders would be sourced from the electricity grid, with power delivered to roadheaders via the relevant construction support site. No other site grid power consumption has been assessed as part of this assessment as roadheaders would be the primary demand for power.

The inputs for calculating the total power to be consumed by roadheaders and by each of the construction support sites, including site offices and other plant and equipment, is presented in Table 3-10. The Scope 2 and Scope 3 greenhouse gas emission factors for electricity consumption are presented in Table 3-11.

Table 3-10 Roadheaders and construction support sites indicative power consumption

Construction support site (Site ID)	Total indicative power requirements (megavolt ampere (MVA)	No. of roadheaders	Duration of tunnelling (months)	Assumed load (%)
Victoria Road (WHT2)	8.5	6	24	80
Yurulbin Point (WHT4)	4	3	24	80
Berrys Bay (WHT7)	5	3	24	80
Cammeray Golf Course (WFU8/WHT10)	5	3	24	80

Table 3-11 Emission factors for electricity consumption (NGA 2017)

Source	Scope 2 Emission Factor	Scope 3 Emission Factor
Electricity	0.83kgCO_2e / kWh	0.12 kgCO_2e / kWh

Vegetation removal

The Transport Authorities Greenhouse Gas (TAGG) Supporting Document for Greenhouse Gas Assessment Workbook (2013) outlines the method for estimating greenhouse gas emissions as a result of carbon loss associated with the removal of vegetation. This assessment employs vegetation data used by the Department of Climate Change and Energy Efficiency (DCCEE) to estimate greenhouse gas emissions for Australia's international reporting requirements under the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol.

This methodology can be considered conservative, in that there is an assumption that all carbon pools are removed, and all carbon that is removed is converted to CO_2 and released to the atmosphere. It is also assumed that sequestration from the revegetation of project sites is not included.

The methodology for estimating the loss of CO_2 equivalent sequestration potential from vegetation during road construction involves the following steps:

1) Determine the 'Maxbio' class, by determining the location of the project area on a colour coded map presenting the maximum potential biomass class for all areas of Australia (provided in the TAGG 2013 workbook)
2) Identify the vegetation classes within the project area, and the area of each class to be cleared (from ecological surveys carried out as part of this approval)
3) Using default emission factors provided for Maxbio values against vegetation classes, determine the potential greenhouse gas emissions by multiplying the area to be cleared by the relevant emissions factor.

To determine the emissions from the vegetation clearance associated with the project, vegetation species were identified by qualified ecology personnel. The identified species were categorised into the required vegetation classes for this assessment. This data and the area to be cleared per class are presented in Table 3-12. The Maxbio class for the project areas were determined to be Class 3, which represents areas which have around 100 to 150 tonnes of dry matter per hectare, as per the TAGG Workbook.

Vegetation classified as 'miscellaneous ecosystems' or 'exotic plants' consists of landscaped and maintained areas. These areas are more urban in classification and have been classified as 'grassland (classification I), as per guidance in the TAGG Workbook.

Table 3-12 Vegetation input data

Identified plant community type	Vegetation class (VIS database)	Description	Area to be cleared (ha)
Exotic plants	I*	Grassland	0.35
Miscellaneous ecosystems – highly disturbed with no or limited native vegetation (Native Plantings)	I*	Grassland	5.83
Miscellaneous ecosystems – highly disturbed with no or limited native vegetation (Urban Exotic/Native)	I*	Grassland	1.11
Total			**7.29**

*Assumed 'grassland' vegetation class, as per the TAGG Workbook. Areas to be cleared consist of highly landscaped areas, with very few trees.

3.1.5 Greenhouse gas emissions estimation – operation

This section presents the methodology used to estimate greenhouse gas emissions associated with operation of the project.

Operational electricity consumption

Annual electricity consumption of road infrastructure and associated management systems are presented below in Table 3-13. The emission factors used to calculate the greenhouse gas emissions from this electricity consumption is presented in Table 3-11.

The assessment has (conservatively) assumed there would not be any use of 'green power', nor that the NSW grid would become less emissions intensive over time.

Table 3-13 Annual operational electricity consumption

Source	Quantity (kWh/y)
Lighting	3,644,160
Hydraulics	147,749
Wastewater treatment plant	87,600
Substation ventilation and air conditioning	2,190,000
Motorway control centre	1,314,000
Tunnel ventilation system (2027)	31,488,000
Tunnel ventilation system (2037)	34,135,000

Maintenance activities

The assessment has considered greenhouse gas emissions generated by ongoing maintenance activities in accordance with ISCA guidance, noting that the project does not seek approval for this particular activity. Fuel consumption and materials associated with ongoing maintenance activities were assessed using Carbon Gauge. The maintenance works assessed apply to the road pavement only (for which values were available) and are input to Carbon Gauge in terms of the area of proposed paving type. Carbon Gauge then provides an assessment of the emissions for a 50-year period.

For this assessment, pavement areas were summed and allocated as either ‘full depth asphalt’ or ‘plain concrete’ according to Bill of Quantity data. These values were then added to Carbon Gauge, which in turn provided an assessment of the fuel consumption and materials required for expected maintenance activities over the life of the project. The values were divided by 50 to provide an annualised figure.

Fuel consumption by vehicles using the road network

The operational assessment was designed to determine the net greenhouse gas effect of the project from road traffic, given that its introduction would contribute to changes to traffic over a wide area. The project would facilitate an increase in road traffic but the traffic should be able to travel at a greater level of efficiency (ie experience fewer delays and stop/starts).

To assess this effect, a wide network model was required, including modelling of selected roads which would not be upgraded as part of the project. The model would establish a baseline against which a project scenario could be compared to display the impact of the project.

Traffic emissions were modelled using TRAQ, which takes outputs from the Sydney Motorway Project Model (SMPM) – provided by Roads and Maritime. SMPM provides estimates of the traffic volumes on around 6000 road links, for each assessment scenario, across a domain that covers an area in the order of 20 kilometres by 20 kilometres.

The environmental impact statement assesses the scenarios provided in Table 3-14 for the year of opening (taken to be 2027) and 10 years after opening (2037). The ‘Do minimum’ scenario reflects the business as usual road network conditions that would occur if the project was not built. The two ‘Do something’ scenarios reflect the road network conditions once the project is built, both on its own and in conjunction with other projects that connect to it.

To determine how greenhouse gas emissions from vehicles using the road network changes as a consequence of the project, the ‘Do minimum’ has been considered against the ‘Do something’ and ‘Do something cumulative’.

Table 3-14 Summary of modelled scenarios

Scenario	Description
Do minimum	The existing road network (including the full M4-M5 Link). This represents the road network without project.
Do something	Traffic model scenario with Western Harbour Tunnel and Warringah Freeway Upgrade project but without Beaches Link and Gore Hill Freeway Connection, Sydney Gateway and F6 Extension (Stage 1) projects.
Do something cumulative	Traffic model scenario with Western Harbour Tunnel and Warringah Freeway Upgrade, Beaches Link and Gore Hill Freeway Connection, Sydney Gateway and F6 Extension (Stage 1) projects.

The SMPM outputs provides information on the length and type of each road, as well as the traffic volumes, speeds and vehicles composition (heavy, light commercial and passenger vehicles) for each road link.

Greenhouse gas emissions have been calculated within TRAQ for every road link in the strategic model, then summed to obtain the estimates for each scenario. Emissions for each link have been calculated using traffic data supplied by Roads and Maritime (for every hour of the day, using hourly traffic mix, and hourly speed data) in combination with emission factors from the EPA Motor Vehicle Emissions Inventory (MVEI).

The calculation for each link involved:

- Distributing the traffic volumes, heavy vehicle percentages and traffic speed for the four time of day periods (7.00am–9.00am, 9.00am–3.00pm, 3.00pm–6.00pm and 6.00pm–7.00am) from the SMPM into volumes for each hour of the day
- Matching the SMPM road types to the EPA road types
- Categorising the traffic into nine vehicle types for each hour of the day. The traffic mix data by road type and year were derived from data used in the Technical working paper: Air quality (ERM, 2018)
- Calculating emissions of CO, HC and CO_2 (primary) in kilograms per hour (kg/h) for each hour of the day, for each vehicle type, by multiplying the vehicle numbers for each vehicle type by the respective EPA emission factors. Emissions of NOx, PM10 were also calculated but not used further for the CO_2e calculation. The maximum of the summer, winter and spring/autumn emission factors were used
- Applying EPA speed correction factors for each vehicle type, based on the road type
- Calculating fuel consumption for petrol and diesel vehicle types by carbon balance where:

- Fuel consumption (litres per kilometre) = (CO x 0.429 +CO_2 x 0.273 + HC x 0.866)/ (0.866 x fuel density x 10)
- 0.429, 0.273 and 0.866 are the carbon mass fractions of the exhaust gases
- Petrol density = 0.74 kilograms per litre
- Diesel density 0.84 kilograms per litre
- CO, CO_2 and hydrocarbons are in grams per kilometre

- Estimating CO_2e emissions using fuel consumption and Department of Environment and Energy emission factors
- Collating total CO_2e emissions for each assessment scenario.

Traffic data is presented in terms of vehicle kilometres travelled (VKT). This is simply a measure of one vehicle travelling one kilometre – and is used in traffic studies to report and present on traffic volumes. Table 3-15 presents the total VKTs modelled for 2027 and 2037 scenarios.

Table 3-15 Traffic (VKT) for base case/'Do minimum' case – year of opening (2027) and future year (2037)

Year	Scenario	VKT/day
2027	Do minimum 2027	12,637,193
	Do something 2027	12,863,883
	Do something cumulative 2027	13,261,788

Year	Scenario	VKT/day
2037	Do minimum 2037	13,633,873
	Do something 2037	14,004,279
	Do something cumulative 2037	14,584,266

3.2 Assessment

3.2.1 Construction

Fuel combustion from construction plant and equipment

The projected greenhouse gas emissions from fuel consumption during the construction of the project is presented in Table 3-16 with surface works predicted to be the largest contributor of greenhouse gases.

Table 3-16 Greenhouse gas emissions from diesel fuel consumption during construction

Construction support site/component (site ID)	Total fuel consumption (kL)	Greenhouse gas emissions (t CO_2e)		
		Scope 1	Scope 3	Total
Rozelle Rail Yards (WHT1)	1000	2708	139	2847
White Bay (WHT3)	2527	6847	351	7198
Victoria Road (WHT2)	778	2108	108	2216
Yurulbin Park (WHT4)	1479	4009	206	4215
The crossing of Sydney Harbour	178	482	25	507
Berrys Bay (WHT7)	821	2224	114	2338
Cammeray Golf Course (WFU8/WHT10)	1341	3634	186	3820
Surface works	5328	14,437	740	15,177
Barge movements (materials and personnel)	1321	3581	184	3765
Total	**14,773**	**40,030**	**2053**	**42,083**

Fuel combustion from generators during harbour construction activities

Projected greenhouse gas emissions resulting from the consumption of fuel by generators during harbour construction activities is presented in Table 3-17.

Table 3-17 Greenhouse gas emissions from fuel consumption by generators for harbour construction activities

Total fuel consumption (kL)	Greenhouse gas emissions (t CO_2e)		
	Scope 1 emissions	Scope 3 emissions	Total
10,254	27,784	1425	29,209

Construction materials

The projected greenhouse gas emissions resulting from individual construction materials for specific construction stages are presented in Table 3-18. Due to the large quantity required for the project, steel is projected to have the highest contribution to the total emissions from materials, followed by 40 MPa strength ready mixed concrete. These high contributions can be directly attributed to the quantity required, as well as the higher energy required to produce concrete.

Table 3-18 Projected greenhouse gas emissions from material production

Material*	Scope 3 greenhouse gas emissions (t CO_2e)
Asphalt	24,065
Sprayed bitumen	387
Ready mixed concrete	
25 MPa	4082
32 MPa	12,055
40 MPa	164,765
50 MPa	3146
Precast concrete	
40 MPa	16,782
Aggregates	
Gravel	406
Sand	25
Other	
Steel	172,109
Aluminium	1576
Glass	4
Piping – PVC	5353
Piping – concrete	1434
Composites – cement fibreboard	865
Coatings and finishes	<1
Water treatment chemicals	40
Total	**407,055**

*The production of general fill has no greenhouse gas emission impacts as this material is sourced elsewhere in the project (and transport impacts are already included elsewhere)

Fuel combustion from the transport of materials

Table 3-19 presents projected greenhouse gas emissions from the transport of materials to the project, based on volumes of materials, assumed travel distances and modes of transport. It is projected that the transport of ready mix concrete, precast concrete and steel would generate the most greenhouse gas emissions, due to the volume of material required to be transported and the distance of transporting these materials. This is especially the case for the transport of steel, due to the assumption that the material could be sourced from Shanghai.

Table 3-19 Greenhouse gas emissions from the transport of materials to project construction support sites

Material	Assumed mode of transport	Scope 3 greenhouse gas emissions (t CO_2e)
Asphalt (t)	Rigid truck	2412
Sprayed bitumen (t)	Rigid truck	6
Ready mixed concrete (m^3)	Concrete agitator truck	3494
	Rigid truck	440
Precast concrete (total) (m^3)	Rigid truck	2642
Aggregates – gravel (m^3)	Rigid truck	1862
Aggregates – general fill (m^3)	Rigid truck	1128
Steel (t)	Rigid truck (domestic sources)	435
	Ship (assumed from Shanghai, China)	3046
	Rigid truck (overseas sources) (Botany Bay to project)	348
Aluminium (t)	Ship (assumed from Shanghai, China)	6
Glass (m^3)	Rigid truck (assumed from Sydney – small quantities)	<1
Piping – PVC (t)	Rigid truck (assumed from Sydney – small quantities)	24
Piping – concrete (t)	Rigid truck	50
Plastic sheet/film (m^2)	Rigid truck (assumed from Sydney – small quantities)	6
Composites – cement fibreboard (t)	Rigid truck	8
Coatings and finishes (t)	Rigid truck (assumed from Sydney – small quantities)	<1
Water treatment chemicals (t)	Rigid truck (assumed from Sydney – small quantities)	1
Total		**15,907**

Fuel combustion from the transport of spoil and waste

The projected greenhouse gas emissions resulting from the transport of construction waste, construction associated spoil and imported spoil is presented in Table 3-20. The majority of waste spoil is expected to be transported to Penrith Lakes waste facility, and so the highest emissions would result from transporting spoil to this location.

Table 3-20 Greenhouse gas emissions from the transport of construction waste and spoil

Activity	Sub activity	Location	Scope 3 emissions (t CO_2e)
Disposal of land waste	Spoil excavation/crushed rock removal/ top soil removal	Disposal to Penrith Lakes waste facility	71,878
	Disposal – aggregates/crushed rock and concrete	Disposal to Camelia waste facility	25,595
	Construction waste (from building demolition)	Disposal to Camelia waste facility	651
Land based import of spoil	Import of spoil	Import from Western Sydney	96
	Import of aggregates	Import from Bombo	489
Dredging	Unsuitable for offshore disposal	Disposal to Kemps Creek	2567
	Suitable for offshore disposal	Offshore disposal	854
Total			**102,130**

Electricity consumption

The projected greenhouse gas emissions relating to electricity consumption, purchased for the proposed use by road headers, land based ancillary sites, plant and equipment is presented in Table 3-21.

Table 3-21 Greenhouse gas emissions from electricity consumption – construction support sites and associated equipment

Construction support sites (site ID)	Emissions (t CO2e)		
	Scope 2	Scope 3	Total
Victoria Road (WHT2)	52,421	7579	60,000
Yurulbin Point (WHT4)	31,453	4547	36,000
Berrys Bay (WHT7)	31,453	4547	36,000
Cammeray Golf Course (WFU8/WHT10)	31,453	4547	36,000
Total	**154,611**	**22,353**	**176,964**

Vegetation removal

The projected greenhouse gas emissions from the removal of vegetation as a loss of a carbon sink is presented in Table 3-22.

Areas of vegetation proposed to be removed which consist of non-native, landscaped areas, have been classified as grassland for the purpose of this assessment as per guidance in the TAGG Workbook.

Table 3-22 Greenhouse gas emissions during resulting from vegetation removal during construction

Identified plant community type	Description	Area to be cleared (hectares)	Scope 1 Greenhouse gas emissions (t CO_2e)
Exotic plants	Grassland	0.35	36
Miscellaneous ecosystems – highly disturbed with no or limited native vegetation (Native Plantings)	Grassland	5.83	419
Miscellaneous ecosystems – highly disturbed with no or limited native vegetation (Urban Exotic/Native)	Grassland	1.11	151
Total		**7.29**	**606**

Summary of greenhouse gas emission from construction

Table 3-23 and Figure 3-1 presents the summary of emissions estimated to result from the construction of the project, reported for Scope 1, Scope 2 and Scope 3 and total emissions. Table 3-23 shows that the construction of the project is expected to generate around 784 ktCO_2e. Of this, the greatest proportion of emissions is related to construction materials at 407 ktCO_2e and electricity consumption at 213 ktCO_2e.

Table 3-23 Summary of construction greenhouse gas emission results

Construction - sources of greenhouse gas emissions	Emission (tCO_2e)			
	Scope 1	Scope 2	Scope 3	Total
Diesel combustion – plant and equipment	40,030	-	2053	42,083
Diesel combustion – generators for harbour activities construction	27,784	-	1425	29,209
Diesel combustion – transport of materials to site (terrestrial only)	-	-	16,038	16,038
Diesel combustion – transport of waste, dredged material and spoil	-	-	76,535	76,535
Vegetation removal	606	-	-	606
Electricity consumption	-	186,064	26,901	212,965
Construction materials	-		407,055	407,055
Total	**68,420**	**186,064**	**530,007**	**784,491**

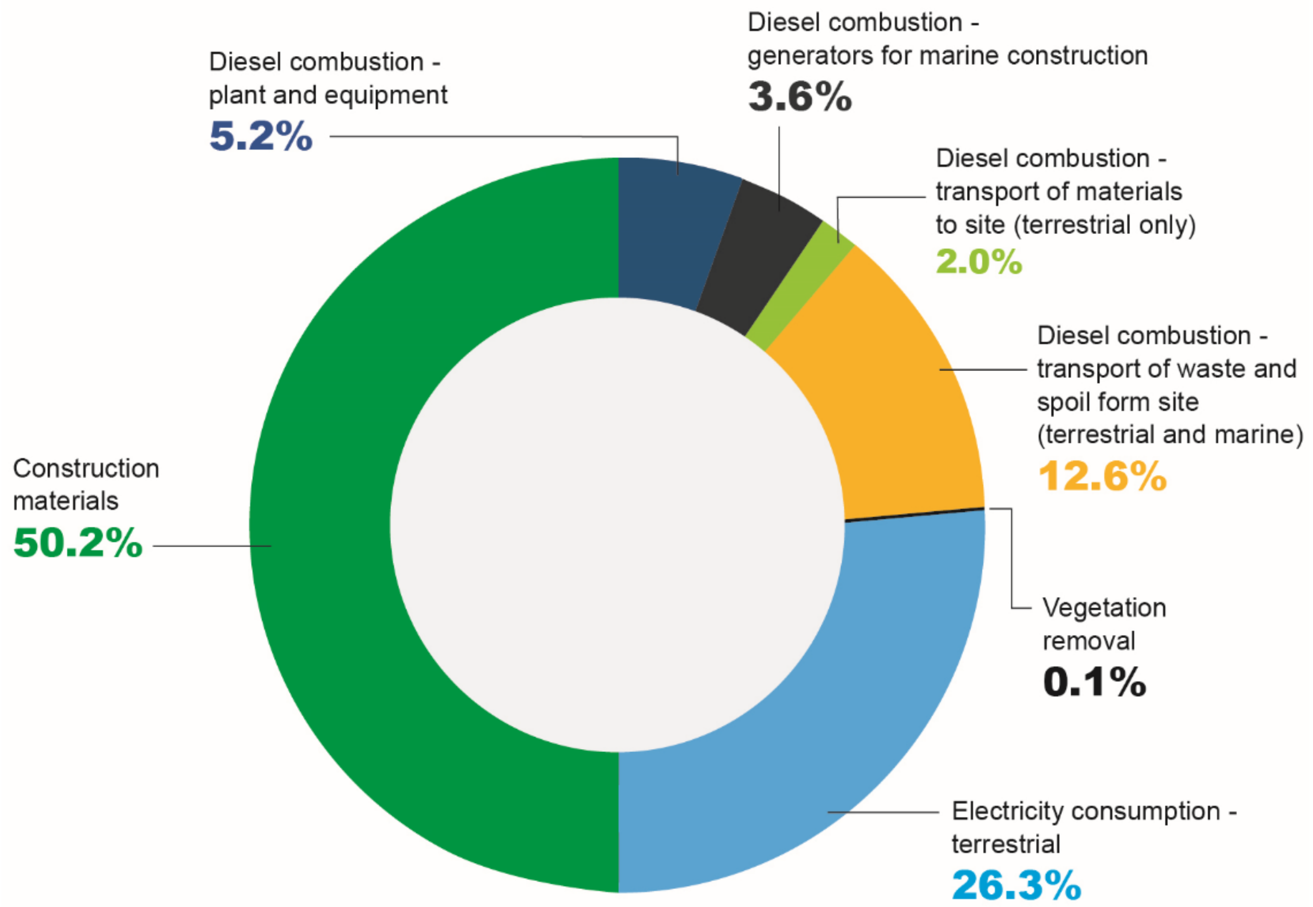

Figure 3-1 Projected contribution of greenhouse gas emissions (construction)

3.2.2 Operation

Operational electricity consumption

The projected greenhouse gas emissions resulting from the operational consumption of electricity is presented in Table 3-24. The results show that the electricity demand for tunnel ventilation would increase in 2037 in comparison with 2027, due to the projected increase in traffic volume.

Table 3-24 Projected greenhouse gas emissions from operational electricity consumption

Source	Quantity (kWh/y)	Greenhouse gas emissions (t CO_2e/year)		
		Scope 2	Scope 3	Total
Lighting	3,644,160	3025	437	3462
Hydraulics	147,749	123	18	140
Wastewater treatment plant	87,600	73	11	83
Substation MVAC	2,190,000	1818	263	2081
Motorway control centre	1,314,000	1091	158	1248
Tunnel ventilation system (2027)	31,488,000	26,135	3779	29,914

Source	Quantity (kWh/y)	Greenhouse gas emissions (t CO_2e/year)		
		Scope 2	Scope 3	Total
Tunnel ventilation system (2037)	34,135,000	28,332	4096	32,428
Total (2027)	**38,871,509**	**32,263**	**4665**	**36,928**
Total (2037)	**41,518,509**	**34,460**	**4982**	**39,443**

Maintenance activities

Greenhouse gas emissions associated with maintenance activities (projected annual average) is presented in Table 3-25. These emissions are a result of the combustion of diesel fuel in maintenance vehicles and equipment (Scope 1) as well as embedded emissions in construction materials used for the maintenance activity (Scope 3).

Table 3-25 Projected greenhouse gas emissions from maintenance activities

Source	Greenhouse gas emissions (t CO_2e/year)			
	Scope 1	Scope 2	Scope 3	Total
Maintenance (annual)	535	0	468	1003

Fuel consumption by vehicles on the road network

The projected greenhouse gas emissions generated by vehicles within the assessed model domain is provided in Table 3-26.

The 'Do minimum' scenario represents the baseline for the road network (including all stages of WestConnex M4-M5 Link) in the absence of the Western Harbour Tunnel and Beaches Link program of works, as well as other planned motorway projects (Sydney Gateway and F6 Extension). The 'Do something' scenario represents the addition of the project to the baseline road network, with the 'Do something cumulative' representing the full Western Harbour Tunnel and Beaches Link program of works alongside other planned motorway projects.

The greenhouse gas emissions associated with the traffic numbers were calculated using traffic speeds, gradients and traffic mix types, number of road links as well as the numbers of vehicles.

As can be seen in Table 3-26, under a 'Do minimum' scenario, the VKTs are projected to increase from year of opening to 10 years' post opening by around eight per cent. This projected change in VKTs would be due to a number of factors, including (but not limited to) population growth, travel mode shifts and constraints of the road network. This would result in an increase in greenhouse gas emissions for the 'Do minimum' scenario between 2027 and 2037.

Under the 'Do something' scenario, greenhouse gas efficiency is projected to only slightly increase from the 'Do minimum' scenario, both in 2027 and 2037. This represents a greater volume of traffic which is able to flow more freely, but at an improved fuel efficiency.

As traffic numbers across the network are projected to grow, greenhouse gas emissions are also projected to increase; however, over time, fuel efficiency is expected to improve (0.211 tCO_2e/VKT on average for 2027 versus 0.206 tCO_2e/VKT for 2037).

Factors applied to 2037 forecasts are (in the majority) slightly better than that for the earlier projection (2027), but this improvement is also a function of expected reduction in congestion – the project would allow for a greater number of vehicles to bypass existing roads and use the project – resulting in fewer stop/starts, less congestion and a greater average speed.

Table 3-26 Greenhouse gas emissions (both directions) for Do minimum and Do something (with project and cumulative) cases – year of opening (2027) and future year (2037)

Greenhouse gas emissions – estimated CO_2e emission (t/year)						Difference estimated CO_2e emission (t/year)			
Do minimum		Do something (with project)		Do something cumulative		Do something minus Do minimum		Do something cumulative minus Do minimum	
2027	2037	2027	2037	2027	2037	2027	2037	2027	2037
968,703	1,022,317	989,358	1,053,968	1,013,739	1,090,267	20,655	31,651	45,036	67,950

Operational summary

Table 3-27 provides a summary of the operational emissions associated with the project. For this summary, only the difference between the 'Do minimum' and 'Do something' traffic emissions are presented and for year of opening (2027) and 10 years post opening (2037).

Table 3-27 shows that the emissions associated with operational electricity consumption are comparable (same order of magnitude) as the difference in traffic emissions between the 'Do minimum' scenario and the 'Do something' scenario. It should be noted that the full operational emissions (for the extent of the modelled area) dwarf the operational electricity emissions.

Road traffic emissions are forecast to grow slightly from the current level due to an increase in road links associated with the project. However, due to improvements in road layout and widening, the efficiency of vehicles using the road network in the study area is forecast to improve. This, as well as analysis of the benefits of future fuel efficiency, suggests that efforts to support the free flow of traffic along the project would likely have lifecycle benefits.

Table 3-27 Operational emission summary

Source	Greenhouse gas emissions ($ktCO_2e$)	
	Project only	Cumulative
2027		
Operational electricity	36.9	69.7
Maintenance	1.0	1.6
Vehicle emissions – traffic (difference between the Do minimum and Do something)	20.6	45.0
Total	58.5	116.3
2037		
Operational electricity	39.4	73.7
Maintenance	1.0	1.6
Vehicle emissions – traffic (difference between the Do minimum and Do something)	31.7	68.0
Total	**72.1**	**143.3**

3.2.3 Greenhouse gas emissions summary

Table 3-28 provides a summary of the emissions associated with construction and operation of the project. Emissions associated with operation have been annualised, and as no traffic projections beyond 2037 are available, no data past this point is presented. The project would have an expected lifespan of 100 years, although during this time, it is likely that traffic volumes and composition would change significantly, as would technology used in cars affecting fuel types and therefore emissions rates.

Table 3-28 Construction and operation greenhouse gas summary

Source	Greenhouse gas emissions ($ktCO_2e$)	
	Project only	Cumulative
Construction	809	1477
Operation 2027	59	116
Operation 2037	72	143

Construction emissions are expected to be much higher than the increase in operational emissions over the network as a result of the project, facilitating additional transport across Sydney. The efficiency of this transport is expected to improve for the project through the removal of congestion and the creation of freer-flowing routes.

The construction and operational emissions are set in the context of state and national greenhouse gas inventories to determine their potential contribution. Based on the latest dataset available (2016 (from the Australian Greenhouse Emissions Information System (AEGIS)) the NSW state and national emissions inventories were:

- 532,971 $ktCO_2e$ (Australian emissions)
- 131,600 $ktCO_2e$ (NSW state emissions).

Table 3-29 displays the percentage that the construction and operation emissions would contribute to these targets.

Table 3-29 Contribution to State and National inventories

Source	Project only	Cumulative
NSW State Emissions		
Construction	0.61%	1.12%
Operation – 2027	0.04%	0.09%
Operation – 2037	0.05%	0.11%
Australian National Emissions		
Construction	0.15%	0.28%
Operation – 2027	0.01%	0.02%
Operation – 2037	0.01%	0.03%

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