Appendix U

Detailed greenhouse gas calculations

WestConnex

Appendix U Detailed greenhouse gas calculations

U.1 Greenhouse gas calculation methodology

The following steps have been taken in estimating the greenhouse gas emissions associated with the project's construction and operation (as per the TAGG Workbook 2013):

1. The greenhouse gas emissions relevant to the stages of project construction and operation have been identified
2. The greenhouse gas inventory boundary has been determined, which defined the emissions sources to be considered in the assessment (**Chapter 21**, **Table 21.1**) and those to be excluded
3. The emissions sources have been quantified (refer to **Table U-4** to **U-6**)
4. For the different emissions sources, emissions factors have been established and the emissions calculated. This Appendix provides the methodology used for calculating greenhouse gas emissions from fuel use, electricity consumption, vegetation removal, the embodied energy of materials used and the decomposition of waste generated during the project.

Guiding principles

The assessment has been conducted according to the following greenhouse gas accounting and reporting principles:

- Relevance – select and use greenhouse gas sources, sinks, data and methodologies appropriate for the project/organisation and intended use of greenhouse gas inventory results
- Completeness – include all relevant greenhouse gas emissions and information which support methodology and criteria used
- Consistency – use consistent data, calculation/modelling methods, criteria and assumptions to enable valid comparisons
- Transparency – include clear, sufficient and appropriate information to enable others to understand the basis for results and make decisions regarding use of greenhouse gas inventory results with reasonable confidence
- Accuracy – reduce bias and uncertainties, as much as practical.

In addition to the accounting and reporting principles presented above, the issue of materiality has also been assessed in the greenhouse gas assessment. This is a core accounting and auditing principle which ensures that sources, assumptions, values and procedures included in the greenhouse gas assessment are material to the project. As materiality is valued within the context of the project being assessed, this can vary significantly between projects.

The Materiality checklist provided in the TAGG Workbook (2013) has been used to identify potential sources of emissions to be included or excluded in the assessment. Based on this guidance the use of inert materials such as imported fill, sand and fly ash are considered to be insignificant to the assessment (represent less than five per cent of total emissions) and are excluded from the assessment boundary.

Vegetation clearance has been included in the greenhouse gas assessment boundary in line with the materiality checklist, as more than 0.5 hectares of vegetation would be required to be removed as part of the project.

The project does not include ongoing motorway maintenance activities during operation or work required for reconfiguring Parramatta Road as part of urban revitalisation. These would be subject to separate assessment and approval as appropriate.

In addition, a benchmarking exercise was undertaken to estimate the proportion of emissions associated with the maintenance of project infrastructure, compared with a project of a similar scale. The greenhouse gas assessment undertaken for the NorthConnex environmental impact statement estimates that maintenance emissions would account for 1.3 per cent of that project's total construction emissions, and hence are below the materiality threshold of five per cent of that project's total emissions. It is assumed that ongoing motorway maintenance activities during operation of the project would similarly fall below the materiality threshold and were therefore excluded from the assessment.

Specific methodologies for the calculation of emissions from each emissions source (eg fuel use, electricity consumption, vegetation clearance, material use and waste) are provided in the following sections.

Fuel

The method used to calculate the Scope 1 greenhouse gas emissions from the combustion of liquid fuels, for transport energy purposes is given by the formula below, sourced from the National Greenhouse Accounts (NGA) Factors 2014:

Greenhouse gas emissions (t CO_2-e) = ((Q x ECF)/1000) x (EF_{CO2} + EF_{CH4} + EF_{N2O})

Where: Q is the quantity of fuel (in kL).

ECF is the relevant energy content factor (in GJ/kL).

EF_{CO2} is the relevant Carbon dioxide (CO_2) emission factor (in kg CO_2-e/GJ).

EF_{CH4} is the relevant Methane (CH_4) emission factor (in kg CO_2-e/GJ).

EF_{N2O} is the relevant Nitrous oxide (N_2O) emission factor (in kg CO_2-e/GJ).

The method used for calculating the Scope 3 greenhouse gas emissions from the combustion of liquid fuels, for transport energy purposes is given by the formula below, as given by the NGA Factors 2014:

Greenhouse gas emissions (t CO_2-e) = (Q x ECF x $EF_{Scope\ 3}$)/1000

Where: Q is the quantity of fuel (in kL).

ECF is the relevant energy content factor (in GJ/kL).

$EF_{Scope\ 3}$ is the relevant emission factor (in kg CO_2-e/GJ).

The Scope 1 and Scope 3 emission factors for diesel and petrol (post 2004 vehicles) are given in **Table U-1**.

Table U-1 Scope 1 and Scope 3 emission factors for the use of fuels (post 2004 vehicles) (NGA Factors 2014 Tables 4 and 40)

Fuel	Energy content factor (GJ per kL)	Scope 1 emission factor (kg CO_2-e/GJ)			Scope 3 emission factor (kg CO_2-e/GJ)	Emissions per unit quantity (t CO2-e per kL)		
		CO_2	CH_4	N_2O		Scope 1	Scope 2	Scope 3
Diesel	38.6	69.2	0.01	0.6	5.3	2.6947	0	0.2046
Petrol	34.2	66.7	0.02	0.2	5.3	2.2887	0	0.1813

Electricity

The method used to calculate the Scope 2 and Scope 3 greenhouse gas emissions from the consumption of purchased electricity is given by the formula below, as given by the NGA Factors 2014:

Greenhouse gas emissions (t CO_2-e) = Q x ($EF_{for\ scope}$ /1000)

Where: Q is the quantity of purchased electricity (in kWh).

$EF_{for\ Scope}$ is the Scope 2 or Scope 3 emissions factor for NSW (in kg CO_2-e/kWh).

The emission factors for the consumption of purchased electricity are given in **Table U-2**.

Table U-2 Scope 2 and Scope 3 emission factors for the use of purchased electricity 1 (NGA Factors 2014 Table 41)

Fuel	Emissions per unit quantity		Units
	Scope 2	Scope 3	
Electricity	0.00086	0.00013	t CO_2-e per kWh

Vegetation removal

The TAGG Workbook (2013) provides a methodology for estimating the loss of carbon sequestration potential associated with the removal of vegetation that would be required as part of land clearing activities during the project. The methodology provided in Appendix E of the TAGG Workbook was developed by GHD (2012) and is in line with the methodology used by the Department of the Environment to estimate Australia's national greenhouse gas emissions for reporting under the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol.

The methodology is based on a conservative approach, in line with relevant greenhouse gas guiding and reporting principles, and the following assumptions:

- All carbon pools are removed as part of the clearance of vegetation (eg debris and soil)
- All carbon removed is converted to CO_2 and released to the atmosphere
- Sequestration as a result of revegetation works carried out as part of the project has not been included in the assessment.

The methodology estimates the greenhouse gas emissions associated with the loss of carbon sequestration that exists in vegetation at the time of clearing and the potential carbon that could have been sequestered in the future if the vegetation was not cleared. The greenhouse gas emissions associated with the loss of CO_2 sequestration potential through the removal of vegetation have been calculated using the following steps:

1. The potential maximum biomass class ('Maxbio' class) has been determined for the project location using vegetation maps provided in Appendix E of the TAGG Workbook
2. The class of vegetation (Table 1 of the TAGG Workbook Appendix E) and the area in hectares for each vegetation type to be cleared as part of the project has been identified
3. The vegetation clearance emissions factors have been identified for each vegetation class for the selected 'Maxbio' class from Table 2 of the TAGG Workbook Appendix E
4. The greenhouse gas emissions associated with the loss of CO_2 sequestration potential have been estimated by multiplying the area of vegetation to be cleared (in hectares) by the corresponding emissions factor (t CO_2-e per hectare) for each vegetation type
5. The total estimate of greenhouse gas emissions associated with the loss of CO_2 sequestration potential for the project has been obtained by adding the results for each vegetation type.

Vegetation clearance emissions factors for the project are identified in **Table U-3**.

Table U-3 Vegetation clearance emissions factors (TAGG Workbook Appendix E, 2013)

Maxbio class	Vegetation type	Vegetation class	Emissions factor (t CO_2-e per hectare)
Class 3 (100 – 150 tonnes of dry matter per hectare)	Planted trees and screening vegetation	Open Forest / Open Woodland (C/D)	307
	Parklands and open space	Grassland (I)	110

Note: the 'Maxbio' class is derived from the Australian Greenhouse Office and estimates the maximum tonnes of dry vegetation matter per hectare for a specific location. Conservative assumptions were used to classify non-native vegetation types.

Construction materials and waste

Indirect Scope 3 GHG emissions from the embodied energy of materials used in the project and the decomposition of waste generated by the project have been calculated according to the formula below:

Greenhouse gas emissions (t CO_2-e) = Q (t) x EF (tCO_2-e/t)

Where: Q is the quantity of material or waste (in tonnes).

EF is the relevant Emission Factor (in t CO_2-e per tonne of material/waste).

Emission factors have been sourced from the TAGG Workbook (2013) and the NGA Factors 2014, as given in **Table U-4**.

Table U-4 Material Emission Factors (TAGG Workbook, 2013; NGA Factors 2014)

Material	Emission factor (t CO_2-e/t)	Assumptions
Construction materials		
Concrete (40MPa)	0.155	TAGG Workbook 2013, Appendix D; Concrete 40MPa (1:1.5:3) applied as a conservative assumption as a breakdown of concrete by MPa was not available at the time of the assessment
Cement (Portland cement)	0.82	TAGG Workbook 2013, Appendix D
Steel reinforcement/structural steel	1.05	TAGG Workbook 2013, Appendix D; Structural steel
Aggregate	0.007	TAGG Workbook 2013, Appendix D
Asphalt	0.058	TAGG Workbook 2013, Appendix D; Hot Mix Asphalt (400MJ/t) used as a conservative assumption
Copper	5.15	TAGG Workbook 2013, Appendix D
Plastic (PVC)	2.41	TAGG Workbook 2013, Appendix D
Mains water	0.001	SimaPro: Water, drinking, Sydney/AU U
Waste		
Construction and demolition waste	0.2	NGA Factors 2014, Table 44

U.2 Construction greenhouse gas emissions activity data

This section details the quantification of the GHG emission source data used to estimate emissions associated with construction of the project, including the sources of information used and assumptions made.

Table U-5 details the GHG emission source data used in the GHG assessment.

Table U-5 Construction stage GHG emission source data and emissions factors

Emission source category	Emission source	Assumptions	Quantity	Units	Emissions factors			
					Scope 1	Scope 2	Scope 3	Units
Fuel − diesel combustion	Mobile construction plant and equipment (diesel)	Assumed to include fuel consumption for mobile plant and equipment for all construction works undertaken as part of the project	11,616	kilolitres (kL)	2.695		0.205	t CO_2-e per kL
	Transport of materials, spoil and waste to/from site	Materials and items transported by heavy vehicles including concrete, steel products, pre-cast concrete elements, excavation consumables, various items of plant and waste. Transport to and from Australian suppliers only.	20,000	kilolitres (kL)	2.695		0.205	t CO_2-e per kL
Fuel use − petrol (gasoline) combustion	Mobile construction plant and equipment (petrol)	Assumed to include fuel consumption for mobile plant and equipment for all construction works undertaken as part of the project	27	kilolitres (kL)	2.289		0.181	t CO_2-e per kL
	Transport of project vehicles − light vehicles (petrol)	Light vehicle movements associated with the use of project vehicles and construction employee movements to and from site	1,200	kilolitres (kL)	2.289		0.181	t CO_2-e per kL
Vegetation clearance	Removal of planted trees and screening vegetation	Emissions calculated using the TAGG Workbook 2013, Appendix E	12.9	hectares (ha)	307			tCO_2-e per ha
	Removal of parklands and open space	Emissions calculated using the TAGG Workbook 2013, Appendix E	2.8	hectares (ha)	110			tCO_2-e per ha

Emission source category	Emission source	Assumptions	Quantity	Units	Emissions factors			
					Scope 1	Scope 2	Scope 3	Units
Electricity purchased from the grid	Electricity consumption during construction	Assumed to include electricity consumption of road headers, and lighting and ventilation during construction, site offices and other onsite electrical equipment	76,338,420	kilowatt hours (kWh)		0.00086	0.00013	tCO_2-e per kWh
Construction materials	Concrete	2.3t/m^3 (TAGG Appendix C), 40MPa. Australian suppliers assumed	974,050	tonnes (t)			0.155	tCO_2-e per t
	Cement	Assume Portland cement, Australian suppliers assumed	365	tonnes (t)			0.82	tCO_2-e per t
	Steel – structural steel	Assume structural steel, Australian suppliers assumed	920	tonnes (t)			1.05	tCO_2-e per t
	Steel – steel reinforcement	Assume structural steel, Australian suppliers assumed	29,000	tonnes (t)			1.05	tCO_2-e per t
	Steel - rock bolts	Assume structural steel, Australian suppliers assumed	1,850	tonnes (t)			1.05	tCO_2-e per t
	Aggregate	Road base, Australian suppliers assumed	350,000	tonnes (t)			0.007	tCO_2-e per t
	Asphalt	Hot mix asphalt, Australian suppliers assumed	40,000	tonnes (t)			0.058	tCO_2-e per t
	Copper	Australian suppliers assumed	1,400	tonnes (t)			5.15	tCO_2-e per t
	Plastic	Assume 0.0016 tonnes per metre length (as advised by the contractor), Australian suppliers assumed	675	tonnes (t)			2.41	tCO_2-e per t
	Mains water	1 kilolitre per tonne (kL/t)	1,300,000	tonnes (t)			0.001	tCO_2-e per t
Waste	Construction and demolition waste	Quantity of waste provided by the contractor (not including spoil, contaminated soils or other inert waste). Disposal at landfills within NSW assumed	40,000	tonnes (t)			0.2	tCO_2-e per t

Note: Estimated quantities have been rounded to the nearest whole number.

U.3 Detailed construction greenhouse gas assessment results

Table U-6 gives the GHG assessment results for the emissions estimated to occur during construction of the project, reported according to Scope 1, Scope 2, Scope 3 and total emissions. GHG emissions are reported in this assessment as tonnes of carbon dioxide equivalent (tCO_2-e).

Table U-6: Detailed construction GHG emissions results

Emission source category	Emission source	Quantity	Unit	GHG emissions (t CO_2-e)				
				Scope 1	Scope 2	Scope 3	Total	% Total
Fuel use − diesel combustion	Mobile construction plant and equipment	11,616	kilolitres (kL)	31,301		2,376	**33,677**	8.81%
	Transport of materials and spoil to/from site	20,000	kilolitres (kL)	53,893		4,092	**57,985**	15.17%
Fuel use − petrol (gasoline) combustion	Mobile construction plant and equipment	27	kilolitres (kL)	62		5	**67**	0.02%
	Transport of project vehicles − light vehicles	1,200	kilolitres (kL)	2,747		217	**2,964**	0.78%
Vegetation clearance	Removal of vegetation	15.7	hectares (ha)	4,268			**4,268**	1.12%
Electricity purchased from the grid	Electricity consumption during construction	76,338,420	kilowatt hours (kWh)		65,651	9,924	**75,575**	19.78%
Construction materials	Concrete	974,050	tonnes (t)			150,978	**150,978**	39.51%
	Cement	365	tonnes (t)			299	**299**	0.08%
	Steel	31,770	tonnes (t)			33,359	**33,359**	8.73%
	Aggregate	350,000	tonnes (t)			2,450	**2,450**	0.64%
	Asphalt	40,000	tonnes (t)			2,320	**2,320**	0.61%
	Copper	1,400	tonnes (t)			7,210	**7,210**	1.89%

Emission source category	Emission source	Quantity	Unit	GHG emissions (t CO_2-e)				
				Scope 1	Scope 2	Scope 3	Total	% Total
	Plastic	675	tonnes (t)			1,627	**1,627**	0.43%
	Mains water	1,300,000	tonnes (t)			1,300	**1,300**	0.34%
Waste	Construction and demolition waste	40,000	tonnes (t)			8,000	**8,000**	2.09%
Total				**92,271**	**65,651**	**224,157**	**382,079**	100.0%
Total %				**24%**	**17%**	**59%**	**100%**	

U.4 Greenhouse gas emissions from road infrastructure operation

Methodology

This section estimates the GHG emissions that would be generated from the operation of the project.

Emissions associated with the operation of road infrastructure have been estimated based on the annual consumption of electricity, purchased from the grid. Annual use of electricity for powering tunnel lighting and ventilation, communications systems, control systems, computer and safety systems, electronic signage and other associated electrical systems is based on annual electricity consumption estimates provided in the contractor's design.

Specific methodologies for the calculation of emissions from electricity consumption are provided in **section U.1** of this Appendix.

GHG emissions activity data

Table U-7: GHG emission source data

Emissions source category	Emissions source	Quantity	Units	Source
Electricity consumption	Western ventilation facility – power for ventilation	10,694,000	kWh per year	Contractor's design
	Eastern ventilation facility – power for ventilation	4,327,000	kWh per year	Contractor's design
	Tunnel – power for tunnel lighting, pumps and ventilation	5,601,000	kWh per year	Contractor's design
	Street lighting, intelligent transport systems (ITS) and operations management control system	840,000	kWh per year	Contractor's design
	Water treatment plant and drainage pumps	1,026,000	kWh per year	Contractor's design
	Substation cooling	2,993,000	kWh per year	Contractor's design
	Motorway control centre and maintenance facility at Homebush Bay Drive	2,645,000	kWh per year	Contractor's design
Total annual electricity consumption		**28,126,000**	**kWh per year**	

Table U-8: GHG emissions factors

Emissions source	Emissions per unit quantity			
	Scope 1	Scope 2	Scope 3	Units
Electricity consumption		0.00086	0.00013	tCO_2-e per kWh

Detailed operation results

Table U-9: Detailed annual operational GHG emissions results

Emission source category	Emission source	Quantity	Unit	GHG emissions (t CO_2-e per year)				
				Scope 1	Scope 2	Scope 3	Total	
Electricity consumption	Western ventilation facility – power for ventilation	10,694,000	kWh per year		9,197	1,390	**10,587**	38.0%
	Eastern ventilation facility – power for ventilation	4,327,000	kWh per year		3,721	563	**4,284**	15.4%
	Tunnel – power for tunnel lighting, pumps and ventilation	5,601,000	kWh per year		4,817	728	**5,545**	19.9%
	Street lighting, ITS and operations management control system	840,000	kWh per year		722	109	**832**	3.0%
	Water treatment plant and drainage pumps	1,026,000	kWh per year		882	133	**1,016**	3.6%
	Substation cooling	2,993,000	kWh per year		2,574	389	**2,963**	10.6%
	Motorway control centre and maintenance facility at Homebush Bay Drive	2,645,000	kWh per year		2,275	344	**2,619**	9.4%
Total per year		**28,126,000**	kWh per year		**24,188**	**3,656**	**27,845**	100.0%
Total %					86.9%	13.1%	100.0%	

U.5 Greenhouse gas emissions from operational road use

As improvements to traffic flow and congestion are achieved through increased speeds, reduced travel distances and reduced frequency of stopping, fuel efficiency is improved and subsequently GHG emissions associated with road use are reduced. As such, it is anticipated that the project would result in GHG emissions savings when compared to the base case scenario ('without project').

Methodology

To assess the Scope 3 (indirect downstream) emissions associated with the fuel consumed by vehicles using the project, and to evaluate any potential GHG emissions savings as a result of the project, four road use scenarios were considered:

- Operation 'do minimum' (2021):
  - The primary 'do minimum' case assumes that the King Georges Road Interchange Upgrade and the M4 Widening are complete, but the remainder of the WestConnex projects are not built. It is called 'do minimum' rather than 'do nothing' as it assumes that infrastructure schemes currently incomplete but scheduled for opening prior to the assessment year are operational, thus the network conditions are different to the 'existing case (2012)'
- Operation 'do something' (2021):
  - As per the primary 'do minimum' with the project complete and open to traffic, but without any other subsequent WestConnex projects (note: the NSW Government has committed to achieving completion of the project by 2019)
- Operation 'do minimum' (2031):
  - A future network including the WestConnex King Georges Road Interchange Upgrade and the M4 Widening and some upgrades to the broader transport network over time to improve capacity and cater for traffic growth but does not include the other subsequent WestConnex projects
- Operation 'do something' (2031):
  - All WestConnex projects complete and also includes the Sydney Gateway and the Southern Extension (note: the NSW Government has committed to achieving completion of the New M5 and M4–M5 Link projects by 2023).

Traffic volumes were modelled in line with the traffic and transport assessment provided in Chapter 8 (Traffic and transport).

The analysis is based on the Vehicle Kilometres Travelled (VKT) and the average speed of vehicles for 2021 and 2031, for the operational traffic impact footprint (Traffic and Transport Assessment (Appendix G)). The GHG assessment for operational road use involved calculation of the following inputs:

- Length and average speed by road type
- Vehicle kilometres travelled
- Rate of fuel consumption
- Total fuel quantity
- Fuel quantity by fuel type
- Calculation of GHG emissions.

Calculation of operational vehicle road use emissions

Average speed by road type

For each scenario, for the years 2021 and 2031, the average week day AM and PM speeds, for eastbound and westbound traffic, were sourced from the WestConnex Road Traffic Model (WRTM) and the Traffic and Transport Assessment (Appendix G), for the operational traffic impact footprint. Table U-10 gives the projected average speeds for the different road sections within the traffic impact footprint, including respective road section lengths.

Table U-10 Average speeds and section length estimates

Route	Section start	Section end	Length (km)	Average daily AM/PM speed (km/h) (eastbound/westbound)			
				Without project		With project	
				2021	2031	2021	2031
M4 Motorway	Homebush Bay Drive	Concord Road/ Leicester Avenue	2.5	66	62	69	66
Parramatta Road	Marlborough Road/ Centenary Drive/ Homebush Bay Drive	Underwood Road	1.5	23	22	22	21
	Underwood Road	Concord Road/ Leicester Avenue	1.0	35	35	35	34
	Concord Road/ Leicester Avenue	Burwood Road	1.0	23	26	23	20
	Burwood Road	Harris Road	1.6	27	21	32	29
	Harris Road	Arlington Street/ Croydon Road	0.4	32	31	37	35
	Arlington Street/ Croydon Road	Great Northern Road	0.1	12	8	15	13
	Great Northern Road	Frederick Street/ Wattle Street	0.4	18	13	32	23
	Frederick Street/ Wattle Street	Dalhousie Street	1.0	31	31	36	38
	Dalhousie Street	Liverpool Road/ Hume Hwy	0.3	24	23	22	23
	Liverpool Road/ Hume Hwy	Sloane Street	0.3	25	24	24	15
	Sloane Street	Tebbutt Street	0.6	19	10	16	12
	Tebbutt Street	Flood Street/ West Street	0.2	13	9	12	8
	Frederick Street/ Wattle Street	Ramsay Road/ Ramsay Street	0.5	29	29	36	35
	Ramsay Road/ Ramsay Street	Timbrell Drive/ Mortley Avenue	0.8	28	27	30	32
M4 East tunnel	Homebush Bay Drive Interchange	Wattle Street/ Parramatta Road Interchange	5.5	NA	NA	73	67

Vehicle kilometres travelled

For each scenario, for the years 2021 and 2031, VKT were sourced from the WRTM and the Traffic and Transport Assessment (Appendix G). VKT for light and heavy vehicles are presented in **Table U-11**, and give the average volume of traffic for each section of the road over 365 days per year. The VKT assessed is based on model outputs of average weekday traffic projections. This provides a conservative assessment for annual VKT based on higher weekday traffic volumes, rather than average daily traffic which accounts for reduced traffic flows on weekends.

Table U-11 VKT Estimates (LV: light vehicles, HV: heavy vehicles)

Route	Section start	Section end	Without project				With project			
			2021 - VKT		2031 - VKT		2021 - VKT		2031 - VKT	
			LV (two-way)	HV (two-way)	LV (two-way)	HV (two-way)	LV (two-way)	HV (two-way)	LV (two-way)	HV (two-way)
M4 Motorway	Homebush Bay Drive	Concord Road/ Leicester Avenue	61,371,100	7,040,850	66,179,975	8,758,175	17,426,925	923,450	21,140,800	1,038,425
Parramatta Road	Marlborough Road/ Centenary Drive/ Homebush Bay Drive	Underwood Road	14,032,425	832,200	17,591,175	1,036,600	17,231,650	1,162,525	21,151,750	1,224,575
	Underwood Road	Concord Road/ Leicester Avenue	8,725,325	416,100	10,188,975	552,975	12,778,650	651,525	15,193,125	815,775
	Concord Road/ Leicester Avenue	Burwood Road	29,619,750	2,642,600	30,995,800	3,157,250	14,523,350	640,575	17,510,875	748,250
	Burwood Road	Harris Road	41,139,150	3,971,200	42,872,900	4,752,300	20,412,625	989,150	25,351,075	1,186,250
	Harris Road	Arlington Street/ Croydon Road	9,468,100	1,062,150	9,683,450	1,282,975	3,947,475	231,775	5,164,750	295,650
	Arlington Street/ Croydon Road	Great Northern Road	3,361,650	323,025	3,542,325	392,375	1,624,250	73,000	2,158,975	98,550
	Great Northern Road	Frederick Street/ Wattle Street	11,882,575	978,200	12,298,675	1,173,475	6,610,150	257,325	8,278,200	266,450
	Frederick Street/ Wattle Street	Dalhousie Street	16,025,325	1,264,725	17,401,375	1,543,950	12,070,550	693,500	11,939,150	445,300
	Dalhousie Street	Liverpool Road/ Hume Hwy	5,241,400	390,550	5,586,325	469,025	6,170,325	456,250	5,297,975	233,600
	Liverpool Road/ Hume Hwy	Sloane Street	6,254,275	425,225	7,057,275	532,900	6,759,800	459,900	5,883,800	264,625
	Sloane Street	Tebbutt Street	11,791,325	766,500	13,057,875	952,650	12,619,875	821,250	11,205,500	479,975
	Tebbutt Street	Flood Street/ West Street	5,336,300	321,200	5,803,500	379,600	5,571,725	330,325	4,920,200	217,175
	Frederick Street/ Wattle Street	Ramsay Road/ Ramsay Street	7,935,100	720,875	7,708,800	843,150	4,891,000	268,275	5,394,700	372,300
	Ramsay Road/ Ramsay Street	Timbrell Drive/ Mortley Avenue	16,083,725	1,314,000	16,123,875	1,556,725	15,850,125	1,261,075	14,893,825	1,122,375

Route	Section start	Section end	Without project				With project			
			2021 - VKT		2031 - VKT		2021 - VKT		2031 - VKT	
			LV (two-way)	HV (two-way)	LV (two-way)	HV (two-way)	LV (two-way)	HV (two-way)	LV (two-way)	HV (two-way)
M4 East tunnel	Homebush Bay Drive Interchange	Wattle Street/ Parramatta Road Interchange	NA	NA	NA	NA	103,915,500	13,809,775	199,370,300	47,716,450

Rate of fuel consumption

The rate of fuel consumption was calculated for each vehicle type within the traffic impact footprint, using the basic fuel-speed formula given below (Equation 1 in Austroads Guide to Project Evaluation Part 4: Project Evaluation Data, Part 6):

Fuel Consumption (L/100km) = A+ (B/V) + (CxV) + (DxV^2)

Where: A, B, C and D are the Fuel consumption parameter values given in Table U-12.
V is the all day average link speed in km/h

Table U-12 Fuel consumption parameter values on freeways − litres/100 km (Austroads Guide to Project Evaluation Part 4: Project Evaluation Data Table 6.3)

Vehicle type	A	B	C	D
Cars	-18.433	1306.02	0.15477	0.0003203
Light commercial vehicle (LCV)	-27.456	2060.5	0.1911	0.000851
Rigid trucks	-65.056	4156.75	0.49681	0.0006798
Articulated vehicles	-80	6342.8	0.48496	0.0020895
Buses	-80	5131.63	0.60539	0.0015775

As the GHG emissions from road use were assessed for two vehicle categories (light vehicles and heavy vehicles), weighted average fuel consumption parameters were applied according to the likely proportional makeup of vehicle types within each category, based on the most recent Australian Bureau of Statistics NSW Registration vehicle type data for the Census date 31 January 2014 (given in **Table U-13**). **Table U-14** details the likely proportional makeup of cars and light commercial vehicles (LCVs) within the category of 'light vehicles' and of rigid trucks, articulated vehicles and buses within the category 'heavy vehicles'. The weighted average fuel consumption parameters applied are given in **Table U-15**.

Table U-13 Australian Bureau of Statistics NSW Registration vehicle type data for calculating weighted average fuel consumption parameters for light and heavy vehicles (ABS 9309.0 Motor Vehicle Census at the Census date 31 January 2014)

Category	2014 NSW registrations	Proportion of total vehicles	Heavy/ light	Sub-classification according to fuel consumption parameters	Proportion heavy/light
Articulated trucks	19,906	0.39%	H	Articulated vehicles	0.11
Buses	24,617	0.48%	H	Buses	0.14
Heavy rigid trucks	86,973	1.70%	H	Rigid trucks	0.49
Non-freight carrying trucks	2,931	0.06%	H	Rigid trucks	0.02
Light rigid trucks	43,412	0.85%	H	Rigid trucks	0.24
Total	**177,839**	**3.49%**	**-**	**-**	1.00
Light commercial vehicles	747,280	14.65%	L	LCV	0.15
Motor cycles	211,040	4.14%	L	Cars	0.04
Passenger vehicles	3,953,655	77.49%	L	Cars	0.81

Category	2014 NSW registrations	Proportion of total vehicles	Heavy/ light	Sub-classification according to fuel consumption parameters	Proportion heavy/light
Campervans	12,538	0.25%	L	Cars	0.00
Total	**4,924,513**	**96.51%**	**-**	**-**	1.00

Table U-14 Estimated proportional makeup of light and heavy vehicles according to vehicle type

Category	Cars	LCV	Rigid Trucks	Articulated vehicles	Buses
Light vehicles	0.85	0.15	0	0	0
Heavy vehicles	0	0	0.75	0.11	0.14

Table U-15 Fuel consumption parameter values on freeways for light and heavy vehicles − litres/100 km (adapted from Austroads Guide to Project Evaluation Part 4: Project Evaluation Data Table 6.3)

Vehicle category	A	B	C	D
Light	-19.78645000	1419.19200000	0.16021950	0.00039991
Heavy	-68.79200000	4533.69870000	0.51070770	0.00096055

Rates of fuel consumption calculated according to the parameters in Table U-12 are applicable for the year 2008 (year of publication of Austroads Guide to Project Evaluation). Annual rates of fuel efficiency improvement were applied to calculate rates of fuel consumption, for light and heavy vehicles, in the years 2021 and 2031, according to road transport fuel intensity projections by vehicle type, given by SKM (2011) in Australian Transport Emissions Projections to 2050 (**Table U-16**), as follows:

- Rates of fuel consumption for the year 2021 were calculated by applying the annual percentage change in fuel intensity from 2020 to 2030, given in **Table U-16**.
- Rates of fuel consumption in the year 2031 were calculated by applying the annual percentage change in fuel intensity from 2030 to 2050, given in **Table U-16**.

Table U-16 Estimated fuel intensity projections by Road Type (SKM (2011) Australian Transport Emissions Projections to 2050)

Vehicle Type	Annual % fuel intensity change (2020-2030)	Annual % fuel intensity change (2030-2050)	Heavy/Light vehicle classification	Annual % fuel intensity change (2020-2030) (based on vehicle proportions)	Annual % fuel intensity change (2030-2050) (based on vehicle proportions)
Passenger	-1.4	-1.8	Light	-1.37	-1.80
Motorcycles	-0.8	-0.8			
LCV	-1.2	-1.8			
Buses	0.3	1.1	Heavy	-0.53	-0.64
Rigid	-0.6	-0.9			
Articulated	-1.1	-1.1			

Total fuel quantity combusted

For each scenario, for 2021 and 2031, VKT was factored by the rate of fuel consumption for each road type to determine the total quantity of fuel consumed in each scenario.

Fuel quantity combusted by fuel type

The analysis considered three fuel types: petrol, diesel and LPG. The total quantity of fuel combusted in each scenario, for 2021 and 2031, was apportioned according to fuel type, based on Australian Bureau of Statistics Survey of Motor Vehicle Census at the Census date 31 January 2014. Estimates of the proportional makeup of light and heavy vehicles by fuel type are given in **Table U-17** below.

Table U-17 Fuel type proportions for light and heavy vehicles (calculated from data in ABS 9309.0 Motor Vehicle Census for the Census date 31 January 2014)

Vehicle Category	Fuel Type	Estimated Proportion
Light vehicles	Petrol	0.816
	Diesel	0.156
	LPG/CNG/dual fuel/hybrid (assume LPG)	0.028
Heavy vehicles	Petrol	0.068
	Diesel	0.920
	LPG/CNG/dual fuel/hybrid (assume LPG)	0.012

The estimated total quantities of each fuel type used in each scenario for 2021 and 2031 are given in **Table U-18** below.

Table U-18 Fuel quantity estimates by fuel type

Route	Section start	Section end	Fuel consumption without project (kL)						Fuel consumption with project (kL)					
			2021			2031			2021			2031		
			Petrol	Diesel	LPG	Petrol	Diesel	LPG	Petrol	Diesel	LPG	Petrol	Diesel	LPG
M4 Motorway	Homebush Bay Drive	Concord Road/ Leicester Avenue	7,047	3,738	267	7,786	4,592	300	1,933	674	70	2,350	800	84
Parramatta Road	Marlborough Road/ Centenary Drive/ Homebush Bay Drive	Underwood Road	5,206	2,046	190	6,777	2,674	247	6,773	2,851	249	8,633	3,381	315
	Underwood Road	Concord Road/ Leicester Avenue	1,891	660	68	2,173	809	79	2,772	997	100	3,361	1,247	122
	Concord Road/ Leicester Avenue	Burwood Road	11,072	5,455	416	9,776	5,238	371	5,367	1,835	193	7,563	2,572	272
	Burwood Road	Harris Road	12,572	6,458	475	17,739	10,106	680	4,960	1,750	179	6,859	2,404	247
	Harris Road	Arlington Street/ Croydon Road	2,337	1,308	89	2,458	1,549	96	800	307	29	1,102	421	40
	Arlington Street/ Croydon Road	Great Northern Road	2,762	1,443	105	4,541	2,627	175	1,013	352	36	1,567	552	56
	Great Northern Road	Frederick Street/ Wattle Street	6,009	2,842	224	9,041	4,733	342	1,602	515	57	2,995	907	106
	Frederick Street/ Wattle Street	Dalhousie Street	4,086	1,852	152	4,369	2,134	164	2,531	962	92	2,286	721	81
	Dalhousie Street	Liverpool Road/ Hume Hwy	1,850	820	68	2,048	980	77	2,429	1,075	90	1,923	661	69
	Liverpool Road/ Hume Hwy	Sloane Street	2,093	881	77	2,447	1,100	91	2,382	1,005	88	3,606	1,259	130
	Sloane Street	Tebbutt Street	5,556	2,301	204	12,906	5,783	478	7,327	3,046	269	8,917	3,056	320
	Tebbutt Street	Flood Street/ West Street	3,957	1,584	145	6,446	2,722	237	4,534	1,803	166	6,197	2,158	223
	Frederick Street/ Wattle Street	Ramsay Road/ Ramsay Street	2,210	1,091	83	2,119	1,182	81	1,025	381	37	1,155	486	42
	Ramsay Road/ Ramsay Street	Timbrell Drive/ Mortley Avenue	4,675	2,171	174	4,840	2,504	183	4,215	1,922	157	3,579	1,588	132

Route	Section start	Section end	Fuel consumption without project (kL)						Fuel consumption with project (kL)					
			2021			2031			2021			2031		
			Petrol	Diesel	LPG	Petrol	Diesel	LPG	Petrol	Diesel	LPG	Petrol	Diesel	LPG
M4 East tunnel	Homebush Bay Drive Interchange	Wattle Street/ Parramatta Road Interchange	NA	NA	NA	NA	NA	NA	11,505	6,631	442	22,937	20,320	957

Results

The GHG emissions calculation

The Scope 3 GHG emissions associated with the use of petrol, diesel and LPG in each scenario for 2021 and 2031 were calculated according to the formula below, as given by the NGA Factors 2014:

Greenhouse gas emissions (t CO_2-e) = (Q x $EF_{full\ fuel\ cycle}$)/1000

Where: Q is the quantity of fuel (in kL).
$EF_{full\ fuel\ cycle}$ is the relevant emission factor (in kg CO_2-e/kL).

The emission factor applied represents the full fuel cycle, which is the sum of Scope 1 and Scope 3 emissions. The emission factors for petrol, diesel and LPG, for general transport as a conservative assumption, are given in **Table U-19**.

Table U-19: Scope 1, Scope 3 and full fuel cycle emission factors for general transport (Source: NGA Factors 2014 Tables 4 and 40)

Fuel	Energy content factor (GJ per kL)	Scope 1 emission factor (kg CO_2-e/GJ)			Scope 3 emission factor (kg CO_2-e/GJ)	Emissions per unit quantity (t CO_2-e per kL)			Full fuel cycle (t CO_2-e per kL)
		CO_2	CH_4	N_2O		Scope 1	Scope 2	Scope 3	
Petrol (gasoline)	34.2	66.7	0.6	2.3	5.3	2.38032	0	0.18126	2.56158
Diesel oil	38.6	69.2	0.2	0.5	5.3	2.69814	0	0.20458	2.90272
Liquid petroleum gas (LPG)	26.2	59.6	0.6	0.6	5	1.59296	0	0.131	1.72396

The estimated GHG emissions from the use of fuel in each scenario for 2021 and 2031 are given in **Table U-20** below.

Table U-20: GHG emissions results for operational road use

Route	Section start	Section end	Without project – GHG emissions		With project – GHG emissions		*Difference between scenarios (With Project - Without Project)*	
			2021	2031	2021	2031	2021	2031
M4 Motorway	Homebush Bay Drive	Concord Road/ Leicester Avenue	29,365	33,793	7,027	8,485	-22,337	-25,308
Parramatta Road	Marlborough Road/ Centenary Drive/ Homebush Bay Drive	Underwood Road	19,603	25,549	26,057	32,470	6,454	6,922
	Underwood Road	Concord Road/ Leicester Avenue	6,878	8,051	10,168	12,439	3,291	4,388
	Concord Road/ Leicester Avenue	Burwood Road	44,913	40,887	19,408	27,307	-25,506	-13,580
	Burwood Road	Harris Road	51,768	75,948	18,094	24,972	-33,674	-50,976
	Harris Road	Arlington Street/ Croydon Road	9,938	10,958	2,990	4,115	-6,947	-6,843
	Arlington Street/ Croydon Road	Great Northern Road	11,444	19,557	3,681	5,712	-7,763	-13,845
	Great Northern Road	Frederick Street/ Wattle Street	24,027	37,488	5,698	10,489	-18,329	-27,000
	Frederick Street/ Wattle Street	Dalhousie Street	16,104	17,668	9,436	8,089	-6,668	-9,579
	Dalhousie Street	Liverpool Road/ Hume Hwy	7,238	8,225	9,499	6,963	2,262	-1,262
	Liverpool Road/ Hume Hwy	Sloane Street	8,052	9,619	9,169	13,115	1,117	3,496
	Sloane Street	Tebbutt Street	21,263	50,669	28,076	32,265	6,813	-18,405
	Tebbutt Street	Flood Street/ West Street	14,985	24,824	17,132	22,522	2,147	-2,302
	Frederick Street/ Wattle Street	Ramsay Road/ Ramsay Street	8,971	8,997	3,796	4,442	-5,175	-4,556
	Ramsay Road/ Ramsay Street	Timbrell Drive/ Mortley Avenue	18,577	19,984	16,648	14,005	-1,929	-5,978
M4 East tunnel	Homebush Bay Drive Interchange	Wattle Street/ Parramatta Road Interchange	NA	NA	49,481	119,389	49,481	119,389
		Totals	**293,124**	**392,216**	**236,359**	**346,780**	**-56,764**	**-45,437**

Note: negative values indicate a savings in GHG emissions for the project compared to the 'without project' scenario.