Australian Government | Infrastructure Australia

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Infrastructure Market Capacity

Supporting Appendices

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APPENDIX A – ASSUMPTIONS AND METHODOLOGY

1. Major Public Infrastructure Pipeline Demand Side Analysis

General Cost Assumptions

- Project costs have been assumed to be exclusive of non-capital works costs, such as land acquisition costs.
    - Where land acquisition costs have been removed from total project budgets where explicitly available.
- Project typecast cost breakdown based on '*Royal Institution of Chartered Surveyors International Construction Measurement Standards (ICMS) Appendix B – Construction/building*'.[1]
- Where there is not an applicable cost category in the *ICMS Appendix B*, the costs have been allocated to the closest match and noted in the specific assumptions section for that project typecast.
- Multiple projects have been assessed to create an average percentage cost split for each relevant project typecast.
- A percentage split range has been produced with a low and high percentage split based on typical percentage range from the median based on industry experience. This high and low range provides a 95% probability interval.
- Initial Labour/Plant/Material/Equipment percentage cost splits are based upon Rawlinsons Australian Construction Handbook 2021 - Edition 39.[2]
- Further Labour percentage split into subcategories for each project typecast is based on Turner & Townsend industry experience, highly dependent on individual project demands.
- Further Plant percentage split into subcategories for each project typecast is based on Turner & Townsend industry experience, highly dependent on individual project demands.
- Further Material percentage split into subcategories for each project typecast is based on Turner & Townsend industry experience, highly dependent on individual project demands.
- Further Equipment percentage split into subcategories for each project typecast is based on Turner & Townsend industry experience, highly dependent on individual project demands.
- To convert the resource costs to units (for example tonnes, litres, and cubic metres) an average unit rate for each element was provided and the cost per resource element per month was divided by the rate for all the timeline data.
- The average rates for each resource element were converted to month rates (if the rates were hourly, a 168 hour working month was assumed).
- The unit conversion to obtain the ranges has been applied using the median price but the lower unit percentage to generate a fair high, mid, and low comparison in unit measure.
- Unit rates for plant are based on:
    - Site Offices and Lunchroom based on dimensions (on-plan) of 12x3m.

    - Excavators based on average 15t – 22t.
    - Graders based on average 18t.
    - Bulldozers are assumed to be Cat D6.
    - Compactor type is assumed to be smooth drum roller with 8t to 12.5 tonne capacity.
- Unit rates for labour are based on:
    - All professionals (white-collar) are mid to senior level (5-10 years) working experience.
    - Rates for general labour and plant operators (blue-collar) is based on 'base' hourly rate and on a 36 hour week and exclude contractor's overheads and profit and any special allowances like structural or height allowances.
- Unit rates for material are based on:
    - Aggregate (in concrete) assumed to be Class 2 FCR type
    - Concrete (composite) strength is assumed to be 25 Mpa
    - Grade of bitumen binders is assumed to be 170 emulsion
- Equipment units (count) are not provided due to the highly variable nature in unit cost – equipment are reported in cost only.
- Future cost escalation and/or inflation have not been explicitly accounted for.

Project Schedule Assumptions

- Three schedule phases have been used to allocate cost and resources: Planning, Implementation and Commissioning.
- The phase time split (as a percentage of total project time) is assumed as 21% Planning, 59% Implementation and 10% Commissioning.
- The phase cost split (as a percentage of total project cost) is assumed as 15% Planning, 80% construction and 5% Commissioning.
- It is assumed that the project costs within the source data are for the full project cost and therefore needs to be allocated into the splits listed above.
- For the planning and commissioning phases the typecast breakdown has been calculated based upon an average of all project types. From this average all non-applicable resources have been removed and the remaining resources have been rebalanced to 100%. The breakdown of these resources has been consistently applied to the commissioning and planning phases across all project types.
- The cost profile of the typecasts for the planning and commissioning phases have been applied in linear fashion based upon the monthly spend for those phased durations.
- For the construction period a logistic equation (representing a classic S shaped project spend curve when considering cumulative spend) was applied to the identified construction costs.

- This logistic equation describing monthly project spend was assumed to be:

$$Spend_{monthly}(month) = Spend_{total} \times \frac{\propto^2 \; e^{(\propto t - t_0)}}{(1+\propto \; e^{(\propto t - t_0)})^2}$$

- Where t is the time in months, and the constants $\propto$ and t_0 are assumed to be

$$\propto = \frac{14.4}{Duration\ in\ Months}$$

  and

$$t_0 = 5.76$$

  which were derived based on the generalised assumption that half of construction costs are cumulatively spent mid-way through the construction period.

- If the monthly spend values modelled by the logistic equation at the start of the construction phase was lower than the previous monthly planning value then the planning cost was assumed until the logistic spend profile overtook that value.

Assumptions relevant to specific project types

Airport

- Assessment based on brownfield works.
- Assumed 40mpa concrete.
- Assessment based on a typical airport project with new terminal works to existing airport, with some apron repair works.
- New runway works are not considered.

Civil Only

- Percentage split breakdown based on average of all other project typecast percentage cost split.
- Assumed civils job that does not fit into any of the other categories.

Correctional Facility

- Structure based on steel framed building with in-situ concrete walls, timber joists and metal roof sheets.
- Upper floors consist of grated steel walkway.
- Includes for exercise yard with mesh screen.
- Includes for security fence to perimeter.
- Excludes any costs for hazardous or contaminated materials.

Dams

- Assumed average depth of 6m for 'grout curtain'.
- Assumed respread of existing topsoil for landscaping works.
- Land acquisition is excluded.
- Excludes any associated works required downstream.

- No data was available for dredging/ harbours – Dams typecast breakdown has been applied for these.

Heavy Rail (Greenfield)

- Based on 60kg rails.
- Based on ballasted track.
- Escalation costs placed under risk category.
- Assumed Electric rather than Diesel Rolling Stock.
- Design costs placed under preliminaries/overheads category.
- Occupations, Driver Training, Safe Working and Traffic Management placed under consultant category.
- Signalling cost placed under services category.
- Traction Power cost placed under services category.
- Fencing works cost placed under non-structural works category.
- Mobilisation and Demobilisation under cost item 8.04.
- Drilling and boring under cost item 2.02.
- Road/track base (i.e. rail sub-base and base) cost item under 3.05.
- Control systems and instrumentation under cost item 5.25.
- "Paid by the Client in relation to the construction contract payments (i.e. Agency's cost, etc) under 10".

Hospital (Brownfield)

- Structure based on steel framed building with in-situ concrete walls, timber joists and metal roof sheets.
- Allows for all necessary demolition.
- Allows for all necessary utility protection/alterations.
- Car Park - Special Equipment under cost item 5.25.
- Margin under cost item 9.03.

Hospital (Greenfield)

- Structure based on steel framed building with in-situ concrete walls, timber joists and metal roof sheets.
- Concrete works under cost item 2.02.
- Structural Steel under cost item 3.03.
- Masonry under cost item 4.02.

Level Crossings

- Assumed 60kg rail in 27.5m lengths.
- Assumed ballasted track.
- Assumed concrete sleepers.
- Includes for elevated stations.

- Traction power works dependant on project demands and existing power supplies in area.
- Assumed elevated viaduct structure on in-situ concrete piers utilised for grade separation.
- Track installation categorised under 3.05.
- Removal of signals under cat 5.25 as specialist works.

Light Rail (Brownfield)

- Includes for reconfiguration of road intersections.
- Includes for Light Rail Station construction.
- Based on cast in-situ concrete with rails imbedded.
- Excavation, disposal, and lateral supports (specifically to receive any substructure construction but excluding general site formation and slope treatment) under cost item 2.02".
- Sub-base to pavements and rail track structures (i.e. rail sub-base) under cost item 2.02.
- Deck (i.e. Bridge deck) under cost item 3.03.
- Road/track base (i.e. rail base, steel rail, fixings, etc) under cost item 3.05.
- Civil pipework under cost item 6.02.
- Non-structural construction (i.e. canopy) under cost item 4.03.
- T-Lok 600 High Barrier, battered concrete median under 7.06.
- High-voltage power supply under 5.02.
- Other electrical services (i.e. u/ground power) under cost item 5.02.
- Control systems and instrumentation (i.e. signalling system, etc) under cost item 5.25.

Light Rail (Greenfield)

- Includes for reconfiguration of road intersections.
- Includes for Light Rail Station construction.
- Based on cast in-situ concrete with rails imbedded.
- Excavation, disposal, and lateral supports (specifically to receive any substructure construction but excluding general site formation and slope treatment) under cost item 2.02".
- Sub-base to pavements and rail track structures (i.e. Rail sub-base) under cost item 2.02.
- Deck (i.e. Bridge deck) under cost item 3.03.
- Road/track base (i.e. rail base, steel rail, fixings, etc) under cost item 3.05.
- Civil pipework under cost item 6.02.
- Non-structural construction (i.e. canopy) under cost item 4.03.
- T-Lok 600 High Barrier, battered concrete median under cost item 7.06.
- High-voltage power supply under cost item 5.02.

- Other electrical services (i.e. u/ground power) under cost item 5.02.
- Control systems and instrumentation (i.e. signalling system, etc) under cost item 5.25.

Low Complexity Building

- All low complexity buildings have been assumed to have the same typecast breakdown profile – Airport buildings has been assumed to be a Low complexity building.
- Structure based on steel framed building with in-situ concrete walls, timber joists and metal roof sheets.
- Includes for services i.e. water/electric/air con/fire safety etc.
- Assumed brownfield construction.

Rail Station

- Assumed at grade station.
- Assumed standard station finish (not a final destination station).
- Passengers' lifts not priced / captured.
- Ramps slab not priced.
- Assumed greenfield construction.

Rail Tunnel

- Assumed tunnel boring machine utilised for construction of tunnels.
- Assumed precast segmental walls to tunnel.
- Includes for underground stations.
- Includes for all relevant surface works.
- Excludes procurement of rolling stock.
- Excludes land acquisition.
- Shaft Excavation under cost item 1.08.
- Shaft internal structure under cost item 2.03.
- Procurement of precast segments under cost item 3.05.
- Rail Track under cost item 4.08.
- Tunnelling works under cost item 5.25.
- Signalling works under cost item 5.25.
- Simulation facility under cost item 8.07.
- Contractors margin % under cost item 8.12.
- Occupations under cost item 13.02.

Road Highway

- Includes for new bridge over freeway.
- Where projects are bridge works only road tunnel typecast content has been applied.

- Includes for new footbridges.
- Includes for pump station.
- Roadworks at grade.

Low Use Road

- Assumed standard 4 lane road, parking on outer lanes, clearway during the busy periods.
- Inclusive of pedestrian walkways.

Road Tunnel

- Assumed tunnel boring machine utilised for construction of tunnels.
- Assumed precast segmental walls to tunnel.

School (Brownfield)

- Structure based on steel framed building with in-situ concrete walls, timber joists and metal roof sheets.
- Major Public Infrastructure Pipeline Management Fees and Other Project Cost under cost item 13.01.
- Outdoor learning area under cost item 4.08.

School (Greenfield)

- Structure based on steel framed building with in-situ concrete walls, timber joists and metal roof sheets.
- Major Public Infrastructure Pipeline Management Fees and Other Project Cost under cost item 13.01.
- Outdoor learning area under cost item 4.08.

Stadium

- Includes for demolition of existing structures.
- Structure based on steel framed building with pre-cast concrete walls, floors, and stairs.
- Structural steel frame and roof cladding system.
- Includes wall cladding system.

Water Treatment Plant

- Assessment based on sewage treatment plant.
- Includes for primary treatment consisting of equalization tank and flash mixer.
- Includes for secondary treatment and biological treatment consisting of clari-flocculator, rapid gravity filter and sludge drying bed.
- Includes for disinfection tank.

Data classification

The project database classifies publicly funded infrastructure projects at varying resolutions for a range of different purposes. – each project is assigned a Typecast of which there are 31 distinct areas of activity. Each typecast lies within a corresponding Master Type of which there are 13 different subsectors.

Finally, the master types can be aggregated into the following three infrastructure sectors:

- Transport, which includes roads, railways, level crossings and other transport projects such as ports and airport runways (noting that airport buildings are separated into the building sector)
- Utilities, which includes water and sewerage, energy and fuels, gas and water pipelines and telecommunications, and
- Building, which includes buildings across education, health, justice and sport, as well as low complexity buildings (offices, arts facilities and airport buildings) and other buildings (mainly civic buildings and convention centres).

Projects are also classified according to project stage and funding status. The following project stage classifications have been used for this initial study:

- Planning
- Procurement
- Implementation
- Completed (in operations and maintenance).

The funding status classifications used in this initial report are as follows:

- Budgeted and announced
- Unbudgeted and announced
- Unbudgeted and unannounced.

Creating a portfolio of major project activity

Generating a portfolio (monthly timeline) of major project activity from aggregations of project-level data was undertaken by engineering consultants Turner and Townsend. For each individual project, the total investment cost was split across time using the (estimated) start and finish dates (for projects not yet commenced or finalised). This distribution of costs assumed that each project undergoes three distinct phases of investment, in order of size: the construction phase (80%), planning phase (15%) and the commissioning stage (5%).

Investment costs per project are allocated to the planning and commissioning phases in a linear fashion, whereas a sigmoidal function[3] (or ‘S-curve’) has been applied to the proportion of investment within the construction phase. This method of cost distribution best captures the pattern of project expenditure over the course of the construction phase as activity progresses from small beginnings that accelerates and approaches a climax over time before slowing to project completion.

Project Classifications

Master Type	Project Type	Super Sector
Education	School (Greenfield)	Buildings
	School (Brownfield)	
Energy and Fuels	Pumped Hydro (Greenfield)	Utilities
	Pumped Hydro (Brownfield)	
	Transmission/Distribution/Battery Storage	
	Photovoltaic	
	Wind Turbines	
Health	Hospital (Greenfield)	Buildings
	Hospital (Addon/Brownfield)	
Justice	Correctional Centre	
	Courthouses	
Low Complexity Buildings	Office	
	Arts Facility	
	Airport Buildings	
Other	Telecommunications	Utilities
Other Building	Civic/Convention Centres	Buildings
Other Transport	Airport Runways	Transport
	Dredging/Harbours	
Pipelines	Gas and Water Pipelines	Utilities
Rail	Station	Transport
	Main Line Works (Greenfield)	
	Tunnel (Rail)	
	Light Rail (Greenfield)	
	Light Rail, Stabling, and Signalling Works (Brownfield)	
Road	State Road (Highway/Freeway)	

	Bridge	
	Low Use Road	
	Tunnel (Road)	
Road/Rail	Level Crossing	
Sports Facilities	Arena/Sporting Facility	Buildings
Water and Sewerage	Dams	Utilities
	Water Treatment Plant	

Resource Classifications

Plant

Construction Plant
Mobile Cranes
Tower Cranes
Scaffold (Tubular)
Scissor Lifts
Site Offices, Lunchrooms
Water Closet
Excavators
Graders
Bulldozers
Compactor
Speciality Plant

Labour

Occupational Group	Occupational Resource	Roles Included	ANZSCO Occupational Code	ANZSCO role title
Project Management Professionals	Risk Management	Risk Manager Risk Lead Risk Engineer	*unknown*	*unknown*
	Project Management	Project Manager Project Lead Project Director Project Sponsor Package Lead Project Engineer Project Controls (Estimators/ Schedulers/ Controllers)	*unknown*	*unknown*
	Commercial Management	Commercial Director Commercial Manager	*unknown*	*unknown*

	Procurement	Strategic Sourcing Purchasing Leads Procurement Manager	133612	Procurement Manager
	Environmental and Occupational Health Professionals	HSE Managers HSE Directors Safety Manager Quality Managers	2513	Occupational and Environmental Health Professionals
	Construction Management	Construction Manager Construction Director Construction Foreman	133111	Construction Project Manager
Engineering , Scientists, and Architects	Engineering Manager	Engineering Manager Head of Engineering	133211	Engineering Manager
	Materials Engineer	Materials Engineer Materials Lead	233112	Materials Engineer
	Electronic Engineer	Electronic Engineer Electronic Lead	233411	Electronics Engineer
	Electrical Engineer	Electrical Engineer Electrical Lead	233311	Electrical Engineer
	Mechanical Engineer	Mechanical Engineer Mechanical Lead	233512	Mechanical Engineer
	Production engineer	Production engineer Production Lead Systems Engineer	233513	Production or Plant Engineer
	Civil Engineer	Civil Engineer	233211	Civil Engineer
	Geotech Engineer	Geotech Engineer	233212	Geotechnical Engineer
	Quantity Surveyor	Quantity Surveyor Construction Estimator Cost Estimator Project Controller	233213	Quantity Surveyor
	Structural Engineer	Structrual Engineer Structural Lead	233214	Structural Engineer
	Telecommunications Engineers	Telecommunications Engineer Telecommunications Designer Network Engineer	2633	Telecommunications Engineering Professionals
	Draftsperson	Architectural Draftsperson	3121	Architectural Engineering Draftspersons And Technicians
		Mechanical Draftsperson	3125	Mechanical Engineering Draftspersons And Technicians
		Civil Draftsperson	3122	Civil Engineering Draftspersons And Technicians
		Electrical and Electronic Draftspersons	3123	Electrical Engineering Draftspersons And Technicians

			3124	Electrical Engineering Draftspersons And Technicians
	Architect	Architect Designer	232111	Architect
	Landscape Architect	Landscape Architect Landscape Designer	232112	Landscape Architect
	Environmental Professionals	Environmental Engineer Environmental Scientist Environmental Consultant Conservation Officer Heritage Consultant	2343	Environmental Scientists
	Geologists, Geophysicists and Hydrogeologists	Geologist Geophysicist Hydrogeologist	2344	Geologists, Geophysicists and Hydrogeologists
	Land Surveyor	Land Surveyor	232212	Surveyor
	Building Surveyor	Site Inspector Building Survey	312113	Building Inspector
	IT professionals/Engineers	ICT Support Engineer ICT Systems Test Engineer ICT Support and Test Engineers	2632	ICT Support and Test Engineers
	Maintenance Planner		312911	Maintenance Planner
	Other professional engineers, scientists, etc.		233999	Engineering Professionals nec
Structures and Civil Trades and Labour	Rigger and Dogman	Rigger Dogman	821711	Construction Rigger
	Structural Steel Erector		821714	Structural Steel Erector
	Plant Operator	Earthmoving Plant Operator Backhoe Operator Bulldozer Operator Excavator Operator Grader Operator Loader Operator Forklift Driver	7212	Earthmoving Plant Operators
	Road based civil plant operator	Linemarker; Paving Plant Operator Road Roller Operator	7219	Other Mobile Plant Operators
	Bricklayer		331111	Bricklayer
	Carpenters and Joiners		3312	Carpenters and Joiners
	Concreter	Concreter Formworker Steel Fixer	821211	Concreter
	Rail Track Worker	Railway Track Worker	821611	Railway Track Worker

		Railway Track Plant Operator		
	Crane Op		712111	Crane, Hoist or Lift Operator
		Truck Drivers	7331	Truck Drivers
	Driller (Piling/ Foundations)	Pilings and foundations driller Drilling Plant Operator Driller	712211	Driller
Finishing Trades and Labour	Telecoms Field Staff	Telecommunications Field Engineer Telecommunications Network Planner Telecommunications Technical Officer/Technologist	3132	Telecommunications Technical Specialists
	Plumbers	Airconditioning and Mechanical Services Plumber Drainer Plumber (General) Gasfitter Roof Plumber Airconditioning and Refrigeration Mechanic	3341	Plumbers
		Metal Fitters and Machinists Precision Metal Trades Workers	323	Mechanical Engineering Trades Workers
	Painting Trades	Painter	332211	Painting Trades Worker
	Plasterers	Fibrous Plasterer Solid Plasterer	3332	Plasterers
	Tiler	Wall Tiler Floor Tiler Floor Finisher	3334	Wall and floor tiler
	Glazier		333111	Glazier
	Electricians	Electrician Lift Mechanic	3411	Electricians
	Electrical Line Workers		3422	Electrical Distribution Trades Workers
			899914	Electrical or Telecommunications Trades Assistant
	Telecoms Cabler	Data and Telco Cabler Telecommunications Cable Jointer Telecommunications Linesworker Telecommunications Line Mechanic Telecommunications Technician	3424	Telecommunications Trades Workers
			899914	Electrical or Telecommunications Trades Assistant

	General Construction Labourer	Builder's Labourer Earthmoving Labourer Plumbers Assistant	8211	Building and Plumbing Labourers
	Safety Officer		312611	Safety Inspector
Other	Other			

Equipment

Equipment
Electrical Equipment
Control Equipment
Mechanical

Materials

Bulk Materials
Concrete
Aggregate
Sand
Cement
Steel Reinforcement
Steel - Structural Elements
Rail Track
Rock/Bluestone
Bitumen Binders
Asphalt
Electrical Bulk

2. Major Public Infrastructure Pipeline Supply Side Analysis

Modelling methodology

Introduction

The fundamental question addressed by this report is to what extent the current and projected supply of labour can support Australia's proposed investment in public infrastructure. To understand this, it was necessary to clearly define the occupations and skills that underpin this workforce and estimate the numbers of people available at different points in time, including projections for the future. The broad approach was to estimate numbers of people in or near the workforce as determined by official statistics and our own forecasts or modelling based on those statistics; and confront these estimates with additional data (such as job advertisements) that provides extra information on variables (such as skills) not covered by the official statistics; and extra granularity on variables which required further detail than official statistics provided.

The analytical work can be understood as two distinct types: development of classifications, and development of estimates. The two types overlap – we used data-based estimates to define our classifications – but it is useful to understand the steps separately.

There were two key classifications developed for this work and are used through the report. These classifications build on the Australian and ANZSCO and the ANZSIC by using data to categorise, combine and (in some cases) add occupational classifications to give additional granularity to the standard measures. The two key classifications are:

- Occupations and roles that are relevant to public infrastructure.
- The workforce in relevant occupations that are engaged, adjacent trainable or distant from public infrastructure.

These classifications were developed to capture the full range of occupations that contribute to public infrastructure in single streamlined taxonomy. They also support a more nuanced view of the labour force recognising the portability of skills across and between sectors. Finally, the addition of roles provides a level of granularity not present in ANZSCO, yet critical to understand skill needs.

There were six key pieces of data analysis that built on those classifications, seeking to estimate:

- historical and current labour supply
- anticipated workforce attrition
- future labour supply
- workforce shortages
- skill profiles
- demographics.

The methods used for these two classifications and six pieces of analysis are outlined in more detail below.

The most important data sources across the project were the 2016 Census and the ongoing Labour Force Survey to quantify where supply matched demand until 2036; and job advertisement data from Burning Glass Technologies as an indicator of demand.

Each of these data sources has its own strengths and weaknesses leading to limitations in the conclusions that can be drawn.

The Census is comprehensive but infrequent; it is self-completed and depends on respondents identifying their own occupation and industry. The Labour Force Survey is carefully calibrated to definitive population totals, has higher quality consistent use of classifications but is based on a sample. The job advertisements are also a sample but of a varying and unknown proportion of the full quantum of demand – varying not just over time but also by occupation and industry. The classification of job advertisements to industry and occupation is done by a statistical/machine learning algorithm based on analysis of the original text, introducing its own statistical noise.

Key limitations of the analysis can be understood in several categories:

- Measurement noise – such as Census respondents misclassifying their industry or occupation, in a way different to any misclassification that takes place in the Labour Force survey.
- Processing noise – such as the Burning Glass Technologies machine learning algorithm misclassifying the occupation of a job advert.
- Analytical assumptions – such as assuming that the proportions of detailed job titles within an ANZSCO unit Group in the workforce reflect the proportion of those titles appearing in job adverts for that ANZSCO unit group; or that the proportion of people in each industry working in each occupation at the time of the Census (the best source at that level of granularity) has not changed materially since.

Every effort has been made to control for these problems, as outlined in the detail below, but significant uncertainty and limitations are inevitable.

Defining public infrastructure relevant occupations and roles

Methodology

An occupational and role taxonomy including occupation group, classification and sub classifications was developed and mapped to ANZSCO classifications. The full mapping is available in the Occupation and role mapping to ANZSCO section.

With classifications defined, job advertisement data provided by Burning Glass Technologies Ltd was used to identify key roles by occupational classification. Roles are a level below ANZSCO unit group.

Many project management roles on public infrastructure projects were undertaken by individuals captured under other occupations. Nous analysed job advertisements data to identify roles that required a similar skill set using cosine similarity. A weighting was then developed to apportion a share of sub classifications to the project manager sub classification. Any ANZSCOs that contained less than 1% of project management professional roles in its job advertisements, were excluded from further analysis.

Assumptions

The following assumptions were adopted in defining infrastructure relevant occupations:

- Job advertisements are matched appropriately to ANZSCO unit groups in Burning Glass data set.
- All individuals covered by a mapped ANZCO unit group have skills relevant to public infrastructure.

Limitations of analysis

Potential limitations identified in completing our analysis include:

- The workforce engaged in public infrastructure is diverse. Several occupations involved in pre-planning stages have been omitted from the analysis such as construction lawyers, transport economists and policy analysts.
- Infrastructure relevant occupations are limited to those identified as working in the sector. Individuals outside of defined occupations may share a sufficient base of skills to be relevant for public infrastructure. This is most likely true for labouring occupations such as general construction labour, riggers or operators of basic plant.

Defining engaged, adjacent, trainable and distance share of workforce

Methodology

Individuals were allocated to ANZSIC Group segments by ANZSCO based on census data. ANZSIC groups were then classified based on those directly linked to the construction of public infrastructure and those that were not. ANZSIC groups identified as directly linked included ANZSIC E, 692, 942 and 529. These formed the basis of estimates for the engaged and adjacent workforces, while estimates of the trainable and distant workforces are drawn from the remaining ANZSICs.

Weightings were developed to apportion workers in the selected ANZSICs between the engaged and adjacent categories. Workforce-to-spend ratios were developed and used to calculate public-private split estimates based on labour, rather than for the total value of projects by state and type of project. Occupational profiles by ANZSIC Groups, were then used to estimate which occupations were most likely to be working on public and private projects, allowing us to map the monetary public-private split data to the actual supply of labour for engaged and adjacent individuals.

Skills profiles were developed for each ANZSIC group that was not directly linked to construction of public infrastructure, using Burning Glass job advertisement data. This was compared to the profile for the same occupation in directly linked ANZSICs using cosine similarity analysis. Based on similarity score, the ANZSCO-ANZSIC segment was allocated to either trainable (higher similarity) or distant (lower similarity) categories.

Assumptions

The following assumptions were adopted in defining the engaged, adjacent, trainable and distant share of workforce:

- ABS data collections capture the full extent of government investment in public infrastructure.
- ANZSIC E, 692, 94 and 529 account for most of the building and engineering construction activity.
- Ratios used to translate value to employment are consistent with industry practice.

Limitations of analysis

Potential limitations identified in completing our analysis include:

- Our definition includes work funded by all tiers of government (federal, state and territory and local councils). We are unable to differentiate based on funder.

Estimating historical and current labour supply for public infrastructure

Methodology

Bespoke estimates of workforce supply by ANZSCO unit and ANZSIC group for relevant occupations were developed by Nous. Estimates were developed for 2016 based on census data at ANZSCO 4 and Burning Glass job advertisement data. This approach was used due to ABS perturbation of data where there is a risk of identifying individuals due to small numbers. Iterative proportional fitting was used to ensure that figures at the ANZSCO 6-digit level were consistent with higher level census results. A tailored ABS request was used to validate estimates based on the ANZSCO unit by ANZSCO group level data provided.

Supply estimates were projected forward to 2021 based on results of ABS labour force survey using iterative proportional fitting. The result was estimates for total workforce in infrastructure relevant roles. This workforce was than apportioned based on weightings developed in previous step to determine the number of engaged, adjacent, trainable or distant individuals from 2016 to 2021.

Assumptions

The following assumptions were adopted to estimate the historical and current labour supply for public infrastructure:

- The distribution of job advertisements by ANZSCO unit group is a reasonable approximation of the workforce under each ANZSCO minor group.
- Individuals are classified in the same way under census, labour force survey and Burning Glass data.

Limitations of analysis

Potential limitations identified in completing our analysis include:

- Small variations in estimates may occur at sub-jurisdictional level from official statistics due to the approach adopted to overcome limitations in census microdata.

Estimating anticipated future workforce attrition

Methodology

Estimates of workforce attrition are based on changes to the age profile of the current infrastructure workforce between two consecutive Census surveys.

Age profiles of individuals in the current workforce were approximated using 2016 ABS Census demographic data of individuals working in construction related industries, split by five-year age groups. Attrition rate was calculated based on movement between the 2011 Census and 2016 Census of consecutive five-year age groups for individuals older than 45 years old under the construction ANZSIC. The change between the two Census surveys and consecutive age groups captures mortality, retirement, and career changes.

Nous then iteratively shifted the age distribution of the current workforce every five years, and applied attrition estimates to the respective five-year age groups. This produced attrition estimates by occupation and age to 2036.

Assumptions

The following assumptions were adopted in projecting workforce attrition:

- The age distribution of the current infrastructure workforce is well-approximated by the age profile of individuals working in construction related industries.
- The change in workforce between the two Census surveys mostly captures mortality and retirement.
- The change in workforce at an ANZSCO 6-digit level is well-approximate by changes at the ANZSCO 4-digit level.

Limitations of analysis

Potential limitations identified in completing our analysis include:

- Estimated attrition ranges may vary within the ANZSCO 6-digit level compared to the ANZSCO 4-digit level.
- We are unable to differentiate attrition by mortality, retirement, or career changes.

Estimating future labour supply for public infrastructure.

Workforce supply forecasts from 2021 to 2036 were developed by integrating current supply with education and migration inflows starting from 2022 and 2023 respectively. Once the two components were integrated, Nous overlayed attrition projections, prorated relevant ANZSCO groups, and applied an engaged ratio developed in calculated in determining the share of engaged, adjacent, trainable and distant workforce to determine the overall engaged workforce supply.

Education inflow

New entrants via education were estimated based on the number of workforce ready graduates across higher education and VET (including apprenticeships and traineeships, qualifications and individual units of competency) in each year and mapped to infrastructure related ANZSCOs.

Forecast population to 2036 by five-year age groups

Population projections derived by the Australian Institute of Health and Welfare (AIHW) were used to model population in five-year age groups at the Statistical Area Level 2 granularity up until 2032. Population projections between 2032 to 2036 were interpolated using the compound annual growth rate (CAGR) from 2027 to 2032.

Projecting the number of workforce ready graduates (all pathways)

Domestic undergraduate (higher education) commencements were calculated each year, by age group and translated to a ratio of commencements in each region, per age group, by its population. The commencement ratio was then combined with population forecasts to 2036 to obtain commencements into 2036. Commencements were then overlayed with estimated completion rates from the Department of Education, Skills and Employment to project graduations. Estimates were then adjusted to account for students who may delay workforce entry to pursue further study.

VET graduates were calculated in three parts – Apprenticeships and traineeships, Qualification completer and part completers (people that may only undertake a few units of competency for occupational or high-risk licencing purposes). Apprentice and trainee completions were calculated with a similar approach used for domestic bachelor graduates, with completion rates based on prior Nous work. Our approach for non-apprenticeships or traineeship was adjusted to accommodate individuals who did not complete their full training but had completed all intended training to obtain the job they needed. The completion rates for non-apprenticeships and non-completers who had completed all intended training draw on NCVER data. Both apprenticeships and non-apprenticeship graduates were filtered to only include individuals studying to get a job or transition careers to avoid double counting of individuals already in the labour market.

The workforce ready graduates were mapped to groups and subclasses using Nous' proprietary concordance that link education to occupation.

Migration inflow

Estimates of supply are based on census data that is inclusive of individuals on temporary and permanent visas. AIHW population projections including a combination of assumptions on future levels of fertility, mortality and migration are used to drive forecasts of future potential education and training activity and subsequently workforce. Overall figures are then adjusted for the likely number of permanent migrants that will be added to the labour force over this period. Data was broken down by visa subclass at an ANZSCO group level. Estimates are based on data supplied by the Department of Home Affairs on four visas that relate to permanent labour increases: 186 Employer Nomination Scheme; 187 Regional Sponsored Migration Scheme; 189 Skilled – Independent; and 190 Skilled – Nominated. Temporary visas were excluded from analysis to avoid double counting of the workforce due to their time bound nature. Migration figures were apportioned to regions based on existing distributions.

Assumptions

The following assumptions were adopted to estimate future labour supply for public infrastructure:

- New supply is estimated on an annual basis and distributed evenly across the calendar year.
- Population forecasts from 2032 to 2036 follow the compound annual growth rate of the AIHW's 2027-2032 population forecast.
- The current rates of people commencing study is maintained to 2036.
- The relationship between field of education and ANZSCO career outcomes are maintained.
- 40% of commencing higher education students join the workforce after 4 years of commencing study. An additional 40% join the workforce over the next 4 years (years 5-8).
- 0.2% of bachelor completions move to postgraduate study each year and enter the workforce two years later.
- 57% of apprentices and civil trainees join the workforce after 4 years of commencing study. An additional 8% join the workforce over the next 4 years (years 5-8).
- 20% of non-apprenticeship students join the workforce after one year of commencing study. An additional 20% join the workforce in the following year.

- 15% of all non-apprenticeship commencements are non-completers who have acquired the skills required to transition to the workforce. They join the workforce the following year.
- VET students have been segmented into different categories based on reason of study. “Skillers” and “starters” (as identified through the student outcomes survey) are students who represent a net addition to the workforce. The ongoing proportion of “skillers” and “starters” maintain the same ratio as per student survey outcomes.
- The visa classes of interest are: 186 employer nomination scheme; 187 regional sponsored migration scheme; 189 skilled independent; and 190 skilled nominated. These permanent visa classes represent a net workforce migration to Australia.
- The 2018-2019 migration value for the above subclasses is assumed to be maintained from 2023-2036.
- Perturbed data instances in the migration data which have a value of “<5” has been assumed to take on a value of three.
- The distribution of migration to different states is assumed to follow the current distribution of infrastructure workers.

Limitations of analysis

Potential limitations identified in completing our analysis include:

- Education completion rates could vary due to factors including age, region and field of study. This has not been individually estimated in this study,
- Distribution of migrants to states could vary depending on external market factors. This has not been individually estimated in this study.

Identifying shortages based on modelled supply and demand

Methodology

Demand estimates were matched to Nous supply forecasts by sub classification to estimate potential shortage or surplus at group, classification and sub classification.

Assumptions

The following assumptions were adopted to estimate future labour supply for public infrastructure:

- Occupational definitions are consistent for demand and supply side estimates.

Limitations of analysis

Potential limitations identified in completing our analysis include:

- Demand estimates are based on known infrastructure investment as of 30 April 2021.
- Demand estimates do not incorporate demand from individual councils for public infrastructure.

Identifying shortages based on labour market indicators

Methodology

Burning Glass job advertisements were used to calculate three indictors of potential shortage; change in advertised salary, change in share of job advertisements and share of advertisements posted for greater than 30 days. Values were calculated for all ANZSCO unit groups and compared with sub classifications and roles. Occupation and roles were ranked on relative performance to identify those that were more likely to be experiencing shortages. Results were tested with industry associations.

Assumptions

The following assumptions were adopted to identify shortages based on labour market indicators:

- Movement in indicators is reflective of difficulties by employers in sourcing labour.

Limitations of analysis

Potential limitations identified in completing our analysis include:

- A range of factors may contribute to movement in identified indicators. Consequently, indicators should be viewed in conjunction with other assessments of shortage to provide a fuller picture.

Developing skills profiles for identified occupations

Methodology

Burning Glass job advertisements were used to develop skills profiles by occupation and roles based on the Burning Glass skills taxonomy and text analytics algorithm.

Nous assessed each skill identified by whether they were general or specialist as defined by Burning Glass and the distinctiveness of the skill – how likely a skill is requested in a job advertisement from a particular industry, compared to the entire labour market. These combined to create the three categories general, technical and specialist outlined in section one of the report.

Nous also assessed the degree of change in mentions of a particular skill. Two periods 2015-2017 and 2018-2020 were compared to identify skills with increasing, declining or stable demand.

Assumptions

The following assumptions were adopted to develop skills profiles for relevant occupations:

- Mentions of skills in job advertisements are representative of an employer’s skills needs for a given occupation.

Limitations of analysis

Potential limitations identified in completing our analysis include:

- Sample sizes can be small for some occupations. To ensure sufficient samples all job advertisements were used for a given occupation, rather than restricting to those industries directly linked to public infrastructure.

Demographic analysis

Methodology

Detailed data tables were provided by the ABS on Census 2016 employment figures. The tables provided employment data by gender, age, SA3 of residence, and ANZSCO 6-digit level occupation.

The figures were used to summarise age and gender distribution across occupations in scope for this report. The geographic indicators were used to explore concentrations of the infrastructure labour force across Australia.

The data used for these analyses required no modeling or estimation, just summary of custom tables, not publicly available.

Assumptions

- Gender, age and geographic distributions within infrastructure-specific occupations are consistent with broader industry trends and population estimates from 2016 to 2021.
- Gender and age distributions for common job titles within the infrastructure industry do not differ significantly from distributions in other industries.

Limitations of analysis

Potential limitations identified in completing our analysis include:

- Demographic information could not be explored by ANZSIC industry classifications because of (1) table size restrictions imposed by the ABS data warehouse and (2) individual categories with small numbers, which the ABS is unable to provide to protect individual privacy.
- A key implication for analysis was the inability to accurately explore different segments of the infrastructure workforce (such as Engaged, Adjacent, Trainable and Distant) by demographic breakdown. Only broader aggregations were possible.
- Gender and age distributions could not be explored per geographic unit because the ABS had to send the information in separate tables.

Data sources and usage

A range of data sources have been used to support analysis for this report. These are outlined in Table 1.

Table 1: Data sources used and purpose

Data source	Definition of occupations	Definition of public infrastructure	Estimation of current and historical supply	Estimation of future workforce attrition	Estimation of future workforce supply	Modelled supply and demand shortages	Labour market indicators of shortage	Development of skills profiles	Demographic analysis
Burning Glass labour market data	x	X	x		x	x	x	x	
ABS Census 2011-2016[4]		X	x	x	x	x			x
ABS Engineering Construction Activity[5]			x		x				
ABS Building Construction Activity[6]			x		x				
ABS Detailed Employment[7]			X						
ABS Payroll Jobs and Wages[8]			X						
Australian Institute of Health and Welfare[9]					x	x			
Department of Home Affairs migration data[10]					x	x			
Higher education completion rates[11]					x	x			
Higher education graduates[12]					x	x			
VET completion rates[13]					x	x			
VET student outcomes survey data [14]					x	x			
HEIMS enrolment data[15]					x	x			
NCVER Total VET Activity data[16]					x	x			
Infrastructure demand data[17]						x			

Current occupational shortages detail

The visuals below provide an assessment of the likely existing occupational shortages as determined by an analysis of the following criteria:

- Migration shortage list – where an occupation was included on an existing migration priority list. This included the Medium and Long-term Strategic Skills List (MLTSSL), the Short-term Skilled Occupation List (STSOL), the Regional Occupation List (ROL) and the Regional Sponsored Migration Scheme (RSMS) ROL List.
- Recognised by industry – where an occupation was suggested to be in shortage in relevant literature or by industry stakeholders in consultation.
- Existing worker shortage in public infrastructure – when historical and forecast supply was combined with public infrastructure demand and the occupations current supply was assessed as not meeting current demand (as at May 2021).
- Labour Market Indicators – where an occupation was assessed as being in shortage against the following criteria: change in advertised salary, change in share of job advertisements and share of advertisements posted for greater than 30 days.

Occupations were assessed as likely in shortage (fulfilled three or more criteria), potentially in shortage (two criteria) or unlikely in shortage (under two criteria). Occupations were categorised as unlikely to be shortage where they met two criteria and the second was indicated as 'varying views in literature and consultation as to whether shortage exists.

Table 2 to Table 6 illustrate the existence of shortages against the criteria:

⊗ Considered a shortage against the specific indicator.

⊖ Varying views in literature and consultation as to whether shortages exist.

Table 2: Project management professionals – indicators of shortage

OCCUPATIONS	IA indicators	INDICATORS OF SHORTAGE			
		Migration shortage list	Recognised by industry	Existing worker shortage	Labour Market Indicators
Construction management	Potential	⊗	⊗		
Project management	Unlikely		⊖	⊗	
Commercial management	Unlikely			⊗	
Procurement managers	Likely	⊗		⊗	⊗
Environmental and occupational health professionals	Unlikely			⊗	
Risk management	Potential		⊗	⊗	

Table 3: Engineers, scientists and architects (1/2) – indicators of shortage

OCCUPATIONS	IA indicators	INDICATORS OF SHORTAGE			
		Migration shortage list	Recognised by industry	Existing worker shortage	Labour Market Indicators
Production engineer	Potential		⊗		
Draftsperson	Unlikely	⊖	⊖		
Architect	Unlikely		⊖		
Civil engineer	Likely	⊗	⊗	⊗	
Quantity surveyor	Likely	⊗	⊗	⊗	
Landscape architect	Unlikely				
Environmental professionals	Likely	⊗	⊗		⊗
Land surveyor	Likely	⊗	⊗	⊗	
Maintenance planner	Potential	⊗		⊗	
Structural engineer	Likely	⊗	⊖	⊗	

Table 4: Engineers, scientists and architects (2/2) – indicators of shortage

OCCUPATIONS	IA indicators	INDICATORS OF SHORTAGE			
		Migration shortage list	Recognised by industry	Existing worker shortage	Labour Market Indicators
IT Professionals / engineers	Potential		⊗	⊗	
Mechanical engineer	Potential	⊗	⊗		
Electrical engineer	Likely	⊗	⊗	⊗	
Engineering manager	Likely	⊗	⊗		⊗
Geologists, geophysicists and hydrogeologists	Likely	⊗	⊗	⊗	⊗
Geotechnical engineer	Likely	⊗		⊗	⊗
Electronic engineer	Potential	⊗			⊗
Materials engineer	Likely	⊗	⊗	⊗	
Telecommunications engineers	Potential	⊗		⊗	
Building surveyor	Likely	⊗	⊗	⊗	⊗
Other professional engineers, scientists, etc.	Likely	⊗	⊗	⊗	

Table 5: Structures and civil trades and labour – indicators of shortage

OCCUPATIONS	INDICATORS OF SHORTAGE				
	IA indicators	Migration shortage list	Recognised by industry	Existing worker shortage	Labour Market Indicators
Carpenters and joiners	Potential	⊗	⊗		
Truck drivers	Unlikely		⊖		
Plant operator	Unlikely				
Concreter	Potential		⊗		⊗
Bricklayer	Potential	⊗	⊗		
Rigger and dogman	Unlikely				
Crane operator	Potential		⊗	⊗	
Driller (piling / foundations)	Likely		⊗	⊗	⊗
Structural steel erector	Unlikely			⊗	
Rail track worker	Potential		⊖	⊗	
Road based civil plant operator	Potential			⊗	⊗

Table 6: Finishing trades and labourers – indicators of shortage

OCCUPATIONS	INDICATORS OF SHORTAGE				
	IA indicators	Migration shortage list	Recognised by industry	Existing worker shortage	Labour Market Indicators
Electricians	Potential	⊗	⊗		
Plumbers	Unlikely	⊗	⊖		
General Construction Labourer	Potential		⊗	⊗	
Mechanical Engineering Trades Workers	Unlikely	⊗			
Painting Trades	Potential	⊗	⊗		
Tiler	Likely	⊗	⊗		⊗
Plasterers	Unlikely	⊗			
Glazier	Potential	⊗	⊗		
Telecommunications Cabler	Likely	⊗	⊗		⊗
Electrical Line Workers	Likely	⊗	⊗	⊗	
Safety Officers	Unlikely			⊗	
Telecommunications Field Staff	Likely		⊗	⊗	⊗
Electrical or Telecommunications Trades Assistant	Unlikely		⊗		

Role shortages detail

Table 7 to Table 11 set out the potential shortages at the role level as determined by Labour Market Indicator Analysis. The figures used below to indicate where a shortage *likely to exist* or *potentially exists* only reflects an assessment against the Labour Market Indicator analysis.

Table 7: Project management professionals – potential role shortages

OCCUPATIONS		INDIVIDUAL ROLES		
		Likely shortages	Potential shortages	Shortages unlikely
Construction management	✓		• Construction supervisor	• Construction manager • Foreman • Site manager / Supervisor • Site administrator
Project management	✓		• Project administrator • Project officer	• Project manager • Senior project manager • Senior project officer • Project coordinator
Commercial management	✓		• Chief operating officer • Senior strategic planner	• Commercial manager • Business manager • General manager • Operations manager
Procurement managers	⊖	• Purchasing officer	• Procurement officer • Senior procurement officer • Procurement specialist	• Buyer • Procurement analyst
Environmental and occupational health professionals	✓	• HSE advisor • Safety advisor		• HSE manager • Safety manager • Environmental health and safety officer
Risk management	✓	• Risk and compliance manager		• Quality assurance manager • Quality assurance coordinator

Table 8: Engineers, scientists and architects (1) – potential role shortages

OCCUPATIONS		INDIVIDUAL ROLES		
		Likely shortages	Potential shortages	Shortages unlikely
Production engineer		• Senior software engineer	• Systems Engineer • Operations Engineer • Production Engineer • Software Engineer	• Senior Systems Engineer • Solutions Architect
Draftsperson		• Mechanical Engineering Technician • Automation Tester	• Civil Designer • Senior Civil Designer • Mechanical Designer	• Draftsperson • Revit Drafter • Electrical Technician
Architect				• Architect • Senior Architect • Interior Designer • Design Manager
Civil engineer			• Site Engineer • Civil Supervisor	• Civil Engineer • Hydraulic Engineer • Senior Civil Engineer
Quantity surveyor		• Senior Estimator		• Quantity Surveyor • Senior Quantity Surveyor • Estimator
Landscape architect			• Senior Landscape Architect	• Landscape Architect
Environmental professionals		• Environmental Advisor • Sr Environmental Advisor • Ecologist	• Stormwater Engineer • Environmental Engineer • Sr Environmental Officer	• Environmental Officer • Senior Ecologist
Land surveyor		• Mine Surveyor	• Engineering Surveyor	• Surveyor • Senior Surveyor
Maintenance planner			• Maintenance Manager • Maintenance Officer	• Maintenance Technician • Maintenance Planner
Structural engineer				• Sr Structural Engineer • Structural Engineer

Table 9: Engineers, scientists and architects (2) – potential role shortages

OCCUPATIONS		INDIVIDUAL ROLES		
		Likely shortages	Potential shortages	Shortages unlikely
IT professionals / engineers	✓	• Application Support Analyst	• IT Support • Test Manager	• Automation Test Analyst • Senior Test Analyst
Mechanical engineer	✓		• Mechanical Design Engineer	• Senior Mechanical Engineer • Mechanical Engineer
Electrical engineer	✓			• Electrical Engineer • Sr Electrical Engineer
Engineering manager	–	• Head of Engineering	• Engineering Manager	
Geologists, geophysicists and hydrogeologists	✗	• Geologist • Mine Geologist • Hydrogeologist		
Geotechnical engineer	–	• Principal Geotechnical Engineer	• Geotechnical Engineer • Senior Geotechnical Engineer	
Electronic engineer	–	• Electronic Engineer • Sr Signalling Engineer		
Materials engineer	✓			• Materials Engineer
Telecommunications engineers	✓	• Telecommunications Engineer		• Communications Engineer* • Wideband Designer*
Building surveyor	–	• Building Inspector • Building Certifier	• Building Surveyor	• Senior Building Surveyor
Other professional engineers, scientists, etc.	✓		• Engineer • Senior Engineer	• Design Engineer • Maintenance Engineer

Table 10: Structures and civil trades and labour – potential role shortages

OCCUPATIONS		INDIVIDUAL ROLES		
		Likely shortages	Potential shortages	Shortages unlikely
Carpenters and joiners	✓		• Joiner • Apprentice Carpenter	• Carpenter • Shopfitter • Leading Hand
Truck drivers	✓	• Multi Combination Driver		• Truck Driver • Heavy Combination Driver
Plant operator	✓	• Grader Operator • Dozer Operator	• Reach Forklift Driver • Excavator Operator • Backhoe Operator • Final Trim Grader Operator	• Forklift Driver • Loader Operator • Scraper Operator
Concreter	–	• Concreter		• Concrete Finisher
Bricklayer	✓			• Bricklayer • Apprentice Bricklayer
Rigger and dogman	✓			• Rigger • Dogman
Crane operator	✓		• Crane Operator	
Driller (Piling / Foundations)	✗	• Driller • Blast Hole Driller		
Structural steel erector	✓			• Structural Steel Erector
Rail track worker	✓			• Rail Track Worker
Road based civil plant operator	–			• Roller Operator

Table 11: Finishing trades and labourers – potential role shortages

OCCUPATIONS	INDIVIDUAL ROLES		
	Likely shortages	Potential shortages	Shortages unlikely
Electricians		• Electrician • Industrial Electrician • Electrical Supervisor	• Maintenance Electrician
Plumbers		• Drainer • Maintenance Plumber • Pipefitter	• Plumber • Roof Plumber • Apprentice Plumber
General construction labourer			• Construction Labourer
Mechanical engineering trades workers		• Diesel Fitter • Fitter • Mechanical Fitter	• Field Service Technician • Electrical Fitter • Maintenance Fitter
Painting trades		• Industrial Painter • Apprentice Painter • Powder Coater	• Painter
Tiler		• Tiler • Wall and Floor Tiler	
Plasterers		• Solid Plasterer	• Plasterer
Glazier			• Glazier
Telecommunications cabler			• Telecommunications Technician
Electrical line workers	• Linesperson		
Safety officers			• Safety Inspector*
Telecommunications field staff			• Radio Communications Technician*
Electrical or telecommunications trades assistant		• Electrical Trade Assistant	

Occupation and role mapping to ANZSCO

Table 12 details the ANZSCO mapping to the four key infrastructure categories.

Table 12: Occupation and role taxonomy mapping

	IA sub-classification	Roles	ANZSCO
Project management professionals	Risk Management	Risk manager	139914
	Project Management	Project Manager Project Director Project Sponsor Project Controls Project Officer Project Administrator/Coordinator Project Engineer	511112
	Commercial Management	Commercial Director	111211
	Procurement	Purchasing Leads Procurement Manager Purchasing Officer Procurement Officer	591113
	Environmental and Occupational Health Professionals	HSE Managers Safety Manager Quality Managers HSE Advisors	2513
	Construction Management	Construction Manager Construction Director Construction Foreman Superintendents	133111 312112

Engineers, scientists and architects	Engineering Manager	Engineering Manager Head of Engineering Coordinators	133211
	Materials Engineer	Materials Engineer Materials Lead Welding Engineer Materials Scientist	233112
	Electronic Engineer	Electronic Engineer Electronic Lead Signalling Engineer	233411
	Electrical Engineer	Electrical Engineer Electrical Lead Control Engineer Engineering and design managers	233311
	Mechanical Engineer	Mechanical Engineer Mechanical Lead	233512
	Production Engineer	Production engineer Production Lead Operations Engineer Flow Assurance Engineer Production Engineering Managers	233513
	Civil Engineer	Civil Engineer Site Engineer Civil Managers and Supervisors Civil Lead and Principal Engineer Hydraulic Engineers	233211 233215
	Geotech Engineer	Geotech Engineer Geotechnical lead or principal engineer	233212

	Quantity Surveyor	Quantity Surveyor Construction Estimator Lead or quantity survey manager	233213 312114
	Structural Engineer	Structural Engineer Structural Lead Building or façade engineers Fire engineers Structural designers	233214
	Telecommunications Engineers	Telecommunications Engineer Wideband designer	2633
	Draftsperson	Architectural Draftsperson Revit documenter/technician Mechanical Draftsperson Mechanical engineering technician Civil Draftsperson CAD related occupations Civil engineering technician Electrical Engineering Draftsperson Electrical and Electronic Draftspersons Electrical engineering technician Electronic technician Civil Designer	312111 3125 3122 3123 3124
	Architect	Architect Designer Design Manager Managing or Lead Architect	232111 232511
	Landscape Architect	Landscape Architect Landscape Designer Principal Landscape Architect	232112

	Environmental Professionals	Environmental Engineer Environmental Scientist Environmental Consultant Conservation Officer	2343 233915
	Geologists, Geophysicists and Hydrogeologists	Geologist Geophysicist Hydrogeologist	2344
	Land Surveyor	Land Surveyor Building Surveyor Lead or Surveyor Manager	232212
	Building Surveyor	Building Survey Building Inspector Building Certifier Planning Enforcement Officer Civil Inspector	312113
	IT professionals/Engineers	ICT Support Engineer ICT Systems Test Engineer ICT Support and Test Engineers ICT Quality assurance engineer	2632
	Maintenance Planner	Maintenance Manager, supervisor, superintendent Maintenance Officer Maintenance Planner Maintenance Technician Maintenance coordinator	312911
	Other professional engineers, scientists, etc	Various specialist engineers Project engineer Lead or managing engineers and professionals Engineer	233999

Structures and Civil Trades and Labour	Rigger and Dogman	Rigger Dogman Rigging supervisor	821711 821911
	Structural Steel Erector	Steel erectors and structural steel erectors	821714
	Plant Operator	Earthmoving Plant Operator Backhoe Operator Bulldozer Operator Excavator Operator Grader Operator Loader Operator Forklift Driver Linemarker Paving Plant Operator Road Roller Operator	7212 721311 721912 721913 721915
	Road based civil plant operator	Road based civil plant operator	721999
	Bricklayer	Brick or Block Layer/Labourer	331111
	Carpenters and Joiners	Carpenter Carpenter and Joiner Joiner	3312
	Concreter	Concrete or cement worker/labourer Pre-cast worker/labourer Concrete/cementing supervisor	821211 712914 821713

	Rail Track Worker	Railway Track Worker	821611
	Crane Op	Crane or lift operator/Driver Hoist or Piling Rig Operator Crane or Piling Rig Supervisor	712111
	Truck Drivers	Truck Drivers	733111
	Driller (Piling/Foundations)	Pilings and foundations driller Drilling Plant Operator Driller	712211
Finishing trades and labourers	Telecoms Field Staff	Telecommunications Field Engineer Telecommunications Technical Officer/Technologist Radiocommunications technician	3132
	Plumbers	Airconditioning and Mechanical Services Plumber Drainer Plumber (General) Gasfitter Roof Plumber	3341
	Mechanical Trades Workers	Metal Fitters and Machinists Precision Metal Trades Workers	3232 323314
	Painting Trades	Painter Power Coater Painting Contractor or Supervisor	332211

	Walls and Floors Worker	Fibrous Plasterer Solid Plasterer Floor Finisher Wall and floor tiler	3332 3334 332111
	Glazing	Glazier Window or glass installer/worker	333111
	Electricians	Electrician Lift Mechanic	3411
	Electrical Line Workers	Electrical Linesworker Field Service Engineer Surveyor	3422
	Telecommunications Trade Assistant	Telecommunications Trainee	899914
	Telecoms Cabler	Data and Telco Cabler Telecommunications Cable Jointer Telecommunications Technician Telecommunications Linesworker/mechanic	3424
	General Construction Labourer	Builder's Labourer Earthmoving Labourer Plumbers Assistant Construction Labourer	8211 821511 821712 821913 821915
	Safety Worker	Safety Inspector Safety Officer	312611 899923

Gender diversity by occupation

Figure 1 to Figure 4 includes information, for each occupation, on the male/female figures of the current workforce.

Figure 1: Project management professional gender breakdown by occupation

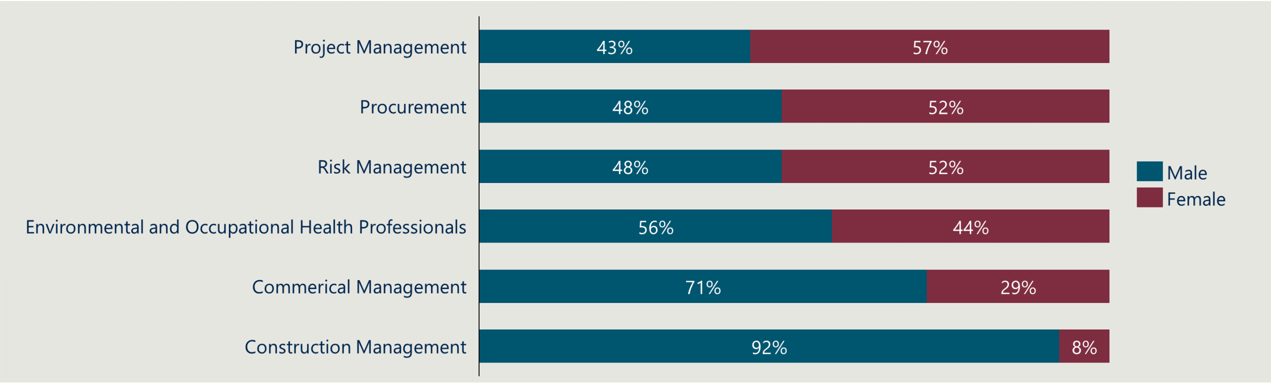


Figure 2: Engineers, scientists and architects gender breakdown by occupation

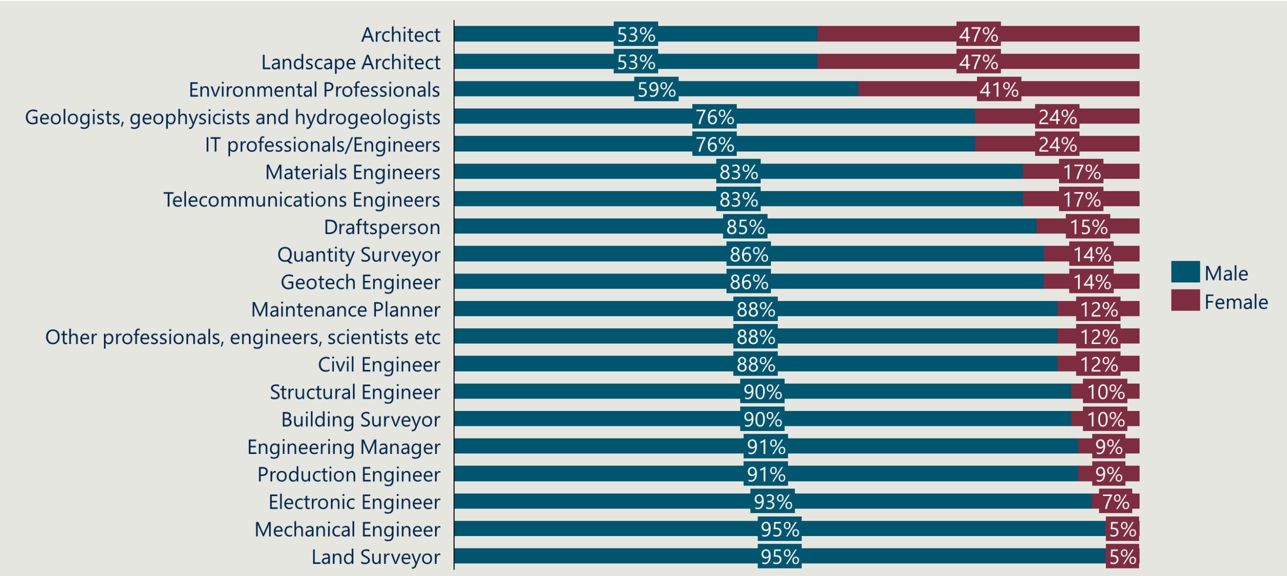


Figure 3: Structural and civil trades and labour gender breakdown by occupation

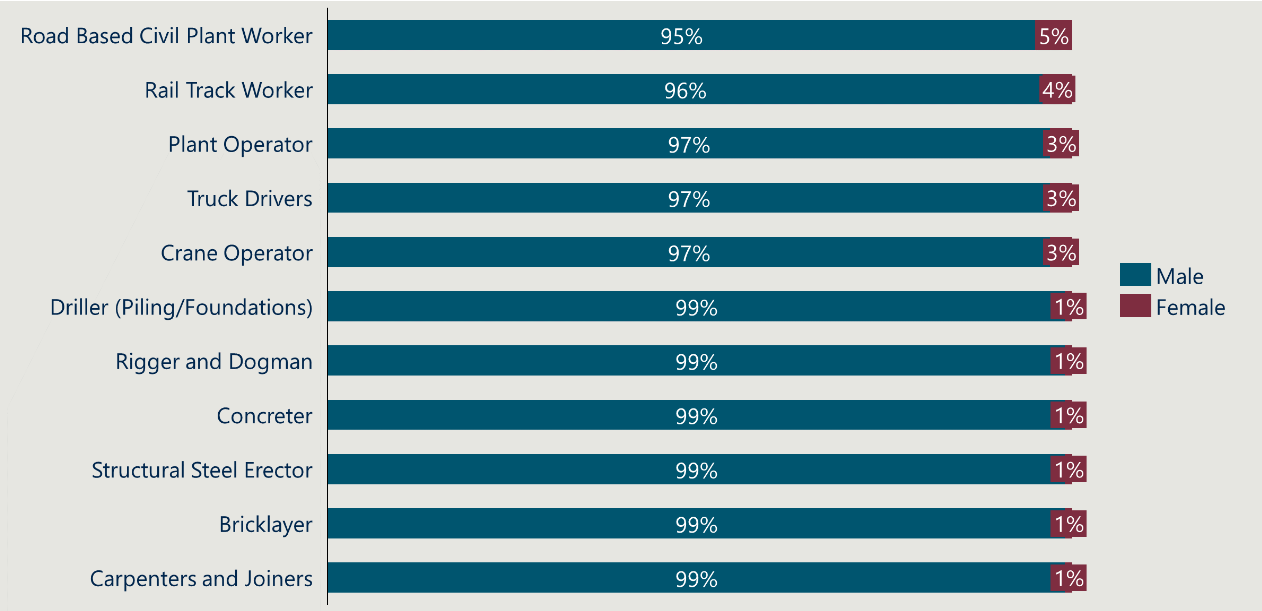
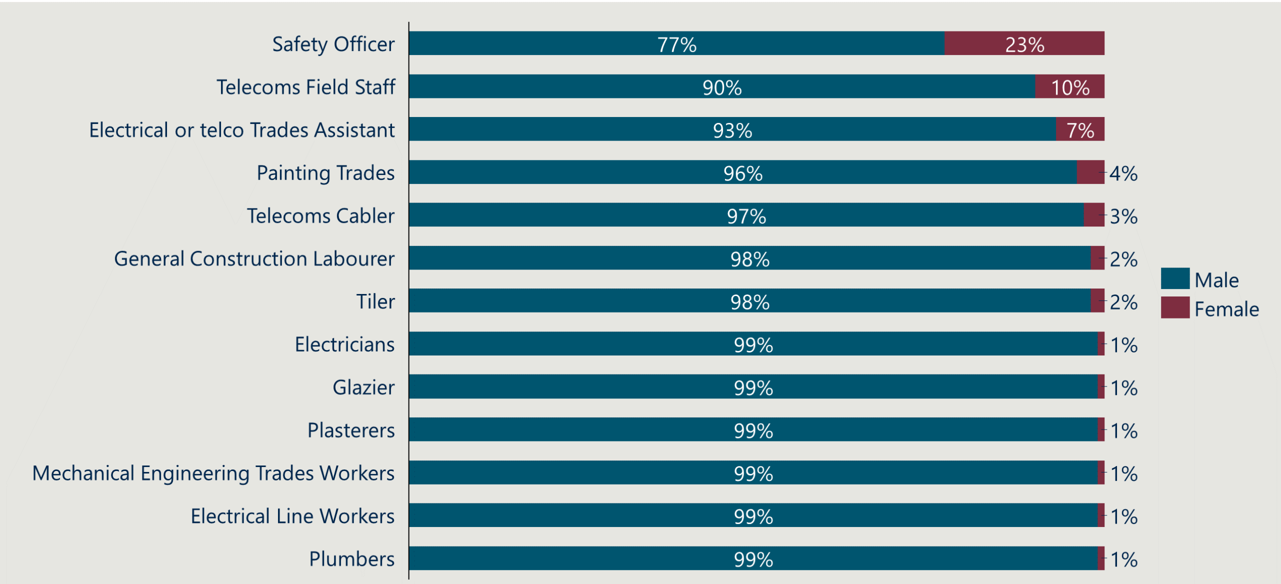


Figure 4: Finishing trades and labourers gender breakdown by occupation



3. Integrated System Plan-based demand side analysis of the energy sector

REZ Programs and targets

State	RE Target	Renewable Energy Zones	Other key programs
NSW	n/a	The *Electricity Infrastructure Investment Act 2020* has declared five REZs with a target of 12 GW (generation) and 2 GW (storage).[18] - Hunter Valley-Central Coast - Illawarra - Central-West Orana - New England - South West NSW	Under the Act, the NSW Government has established a Consumer Trustee, Electricity Infrastructure Jobs Advocate and NSW Renewable Energy Sector Board to maximise local supply chain and employment.[19]
Victoria	40% by 2025 50% by 2030	Six REZs to facilitate 10 GW (generation) - Central North - Gippsland - Murray River - Ovens Murray - South Victoria - Western Victoria	A $540 million program to support the development of the six REZs.[20] An auction for 600MW of renewable energy for Government consumption.
Queensland	50% by 2030	Three Renewable Energy Corridors that include eight REZs nominated by the ISP: - Southern Queensland (Darling Downs) - Central Queensland (Fitzroy, Wide Bay) - Northern Queensland (Isaac, Barcaldine, North Queensland, North Queensland Clean Energy Hub, Far North Queensland)	$145 million program to support the development of the Renewable Energy Corridors.

Transmission Employment – Methodology

Overview

There is a significant gap in available data on the workforce requirements for transmission line construction in Australia. While the ABS publishes occupational data every five years, classified under the 'Electricity Transmission' sector, this is unlikely to include the construction workforce, as most, if not all of these workers will be classified under construction. A detailed breakdown of both the occupational volume and composition in transmission construction is needed to understand the workforce requirements associated with new transmission construction under the AEMO Integrated System Plan (ISP) for the NEM.

Consequently, Infrastructure Australia commissioned the Institute for Sustainable Futures, University of Technology Sydney to undertake a survey of employment in transmission infrastructure in Australia. This follows on from a survey on renewable energy infrastructure undertaken for the Clean Energy Council in 2020.[21]

Employment in transmission infrastructure is calculated using employment factors, with the employment factors derived for this project. Industry surveys were used to develop the employment factors for line projects (in FTE jobs/km) and non-line projects (in FTE jobs/$ million) to cover transmission construction projects in Australia, which are then compared with data from literature.

Three steps were used to estimate the employment volume and occupational composition for the construction of new transmission infrastructure assets:

1. Literature review: we undertook research to gain background information on employment in transmission construction from international studies and projects, gather any available data, and identify whether there were employment factors for the development and construction phases of line and non-line transmission projects. A combination of academic literature, industry reports, environmental reports and project specific fact sheets were used to gather project specific information and derive employment indicators where possible. However, data is scarce, results are highly variable, there are considerable data gaps, calculation methods use industry averages, and generally combine a number of different asset classes and project phases into the project employment total.
2. Derivation of employment factors using industry surveys:
    a. Develop a classification index for line and non-line assets and an occupational concordance for new construction projects in the electricity transmission sector, to inform the design of an industry stakeholder survey.
    b. An industry survey was undertaken with Transmission Network Service Providers (TNSPs) and EPCs in Australia to derive employment volumes and composition according to the asset classification index and occupational breakdown.
    c. Analysis of survey data and calculation of employment factors, verified with international literature.
3. Collate scenarios for the transmission infrastructure pipeline from the AEMO ISP for the NEM, supplemented by publicly available information on project timing.
4. Calculate employment projections and occupational composition using an excel model built during previous projects.

Calculating the employment

As shown in Figure 5, the calculation is simple. However, the accuracy of the final employment calculations are dependant on the accuracy of the data used to derive the employment factor.

Figure 5: Total employment calculation: methodological overview

Transmission construction employment for year	=	KM installed per year (line projects) $m value per year (non-line projects)	x	Construction employment factor	/	Project construction time
Generation construction employment for year	=	MW installed per year (generation)	x	Construction employment factor for that year	/	Average construction time
Operation and Maintenance jobs	=	Cumulative capacity	x	Operation and maintenance employment factor for that year		
Fuel supply jobs	=	GWh generated per year	x	Fuel employment factor for that year		
Employment factor for year	=	Base year employment factor	x	$(1 - \text{average technology decline factor})^{\text{years after base year}}$		

Previous research

Institute for Sustainable Futures collaborated with the Clean Energy Council on stage one of the first major national survey of renewable energy employment in Australia.[22] Stage one focused on employment in the construction and operation of new renewable energy generation and storage technologies such as onshore wind power, solar, hydro and batteries. This project extends this research to employment in transmission connection assets required to integrate new renewable energy generators into the NEM grid.

Transmission industry survey

An industry survey was used to collect data for the electricity transmission sector to derive employment factors, occupational composition and key skills shortages that might be experienced with the roll out of transmission infrastructure projects outlined in the ISP.

A total of nine surveys were conducted with TNSPs and their EPCs across the NEM member states. Respondents contributed data for line and non-line transmission projects at various stages of completion. The survey collected data on:

- **Transmission infrastructure characteristics**: line, non-line, voltage, line length, non-line cost, terrain, new or uprate (upgrading the capacity of an existing asset);

- **Project data**: project timeline, workforce numbers for each project stage (development, civil construction and electrical construction/commissioning) and occupational breakdown;
- **Skills shortages and recruitment risks**: level of difficulty recruiting for job types and the causes for recruitment issues;
- **Other skill information**: skills shortages, training issues, opportunities and perceived risks associated with skills shortages.

We were able to collect detailed employment data on 23 transmission projects across a range of line and non-line categories. Survey coverage is outlined in Table 13.

Table 13: Transmission survey coverage

Project type	No. of respondents	No. projects	Length (km)	Total value ($m)
Line projects (all)	6	9.8	2454	-
Line projects (double circuit)	2	4.8	1907	-
Line projects (single circuit)	4	5.0	547	-
Non-line projects (all)	7	6.1	-	$697m
Non-line projects (high voltage)	5	4.6	-	$635m
Non-line projects (medium voltage)	1	1.0	-	$61m

The survey collected data on the attributes of transmission projects, total employment volumes in FTE per construction phase, and employment numbers at a more detailed level according to the ANZSCO. Employment data was then grouped based on common transmission characteristics to derive employment factors in FTE per km for line assets and FTE per million $ for non-line assets. These characteristics are shown in Table 14.

Table 14: Transmission asset types

Transmission asset type	Definition and notes
Line	Includes transmission lines, towers and associated civil and electrical works
Non-line	Includes substations and other non-line transmission projects and associated civil and electrical works
Line project attributes	New / uprate, single / double circuit, new / existing transmission corridor, transmission tower height, tower type, number of towers, total line length in km
Non-line	Capital cost in million $
Voltage	High (500 kV / 330 kV / 275 kV), medium (220 kV / 132 kV) or low (under 220 kV /132 kV)
Terrain type	Forested, mountainous, flat, and/or wetland

Employment and occupational composition data was collected based on FTE jobs per project and combined with data on project years per phase to derive FTE employment indicators in job-years. These project phases are defined in Table 15.

Table 15: Project phases

Phase	Definition and notes
Development	Development of projects up until financial close
Construction (civil works)	Civil construction includes works required to establish the site and build transmission infrastructure. This includes: Site clearing, Constructing access roads and tracks, Constructing foundations, Installation of transmission towers and substation structures, Site cleanup.
Construction (electrical installation and commissioning)	This phase includes line stringing, electricial installation and final electrical commissioning of transmission assets.

Further information was gathered through the survey covering skills shortages, recruitment risks and training requirements.

Transmission employment indicators derived from survey data

We produced weighted data for the gross employment indicators for the lines/ non-line project by averaging the total employment years (FTE) per project and divided this by the average length of kilometres for line assets and $ million for non-line assets:

$$\text{Employment factor} = \frac{\text{average total employment for asset classification}}{\text{average length of line OR average \$ million}}$$

A summary of the employment factors derived from the survey data are given in Table 16. The number of circuits for lines appeared to give a genuine variation for employment per km, so this distinction was retained in the later calculations. No consistent variations in employment levels occurred as a result of voltage, new or uprated lines or terrain type. Non-line assets were extremely variable, and a consistent relationship was not found between different characteristics; this may be because there were insufficient numbers of projects in each category, and the projects themselves are extremely variable.

A number of assets were excluded from employment factor calculations due to a lack of data. Accordingly, employment indicators were derived for three classifications of transmission assets:

- double circuit lines (with length as indicator)
- single circuit lines (with length as indicator)
- all non-line projects grouped together (with value as indicator)

Table 16: Employment indicators derived from survey data

	Average line (all)	Average line (double circuit)	Average line (single circuit)	Average non-line (all)	Average non-line, High voltage	Average non-line, Medium voltage
Type	Line	Line	Line	Non-line	Non-line	Non-line
Line length (km)	227	330	110			
Non-line value $ million				M$ 96.4	M$ 109.4	M$ 60.5
Circuits	Any	Double	Single	-	-	-
Voltage	Any	Any	Any	Any	High	Medium
Average project years	2.9	4.4	1.4	2.7	2.8	2.5
Number in category	10.8	5.8	5.0	6.1	4.6	1.0
Average FTE	376	646	46	67	74	21
Job years/km	3.0	3.7	0.7	n/a	n/a	0.0
job years/m$				1.9	1.9	0.9
	0.3 – 13.7	0.4 – 13.7	0.3 – 2.5			
Range Job years/km				0.9 - 41	0.9 - 41	n/a

Transmission employment indicators from literature

Of the literature available, very few studies are published in recent years and most studies use Input Output (IO) analysis over survey methods to estimate employment volumes. The IO method calculates employment volumes based on dollars spent in a certain sector and uses industry averages to estimate employment – in contrast, survey methods gather data directly from industry participants or workers, and can be more representative of workforce numbers if data quality is high. The majority of literature sources identified in the review are focused on the US transmission sector. This is primarily due to the rapid energy transition, age of transmission infrastructure, scale of transmission projects in the pipeline, and concerns over grid reliability in the US – prompting increased research interest in recent years.

Two literature sources focus on other regions. One source focuses on 'Project Energy Connect' in Australia.[23] Another focused on 'Powerlinks Transmission Limited' in India.[24] Both of these sources use the IO method, combining multiple transmission asset types to derive employment estimates. The employment factor used for India is also significantly higher than other regions due to the higher number of workers used for construction projects in the region. For example, the 'Powerlinks Transmission Project' - a combination of 400 kV (high voltage) and 220 kV (medium voltage) double circuit transmission lines from Siliguri to Mandaula in India - combines multiple transmission line asset types to calculate total employment volume and the resulting employment factor is significantly higher than other studies due to the higher employment intensity in the region. Given the high level, aggregated nature of the IO method and the regional variations impacting the employment factors found in the literature, the employment factors from these studies are indicative only and best used as a sense check for the employment factors derived through our survey method.

A few industry reports provide better representations of employment requirements for transmission asset construction.[25] [26] [27] The method used breaks down construction projects into tasks and provide estimates of crew numbers for each task, the reports also provide a total timeline for the project. This method is a slightly more accurate measure of the workforce structure and volume required for these projects. However, line and non-line asset types are still combined into one category in these studies and detailed occupational information is not provided. These studies are therefore best used as test cases against which a more detailed Australian survey can be compared.

Additional studies from the EU and US have provided job numbers at a national/regional scale for transmission line construction and Operation and Maintenance (O&M).[28] [29] However, for the EU study, industries are not sufficiently disaggregated, and for both studies, there is a lack of detailed information on the length or size of transmission infrastructure under construction during the study period.

The employment factors derived from survey data for transmission projects were compared with international literature and found to be within the same range. As shown in Table 17, factors from international studies fell between 0.8 job-years/km and 14.6 job-years/km with an outlier study reporting 36.7 job-years/km, possibly because the project was in India which may have generally higher employment intensity for construction. Job-years/$m were available for a few studies, these fell between 0.8 job-years/$m and 20.2 job-years/$m, showing the high variability of an employment in these assets.

Table 17: Transmission employment indicators

Project name	Study date	Region	Voltage	Line/non-line	Single or double circuit	Job-years/$m	Total Job-years/km	Method	Reference
Energy Gateway South	2016	US	High	Line	Single	n/a	0.8	Industry Estimate	(PacifiCorp, 2016)
Southline	2010	US	High	Mix	Double	n/a	0.9	Industry Estimate	(Southline Transmission LLC, 2010b, 2010a)
Southline	2010	US	Medium	Mix	Double	n/a	1.4	Industry Estimate	Southline Transmission LLC, 2010b, 2010a)
Project Energy Connect	2019	Aus	High	Mix	Mix	n/a	2.3	Hybrid Input/Output (Tasman Global Model)	(ACIL Allen Consulting, 2019)
Grain Belt Express Clean Line	2013	US	High	Mix	-	n/a	10.6	Input/Output (IMPLAN Model)	(Loomis et al., 2013)[30]
Wyoming Study	2011	US	High	Line	Mix	n/a	14.6	Input/Output (JEDI Model)	(Lantz and Tegen, 2011)[31]
Powerlinks Transmission Limited Project	2012	India	Mix	Mix	-	n/a	36.7	Input/Output	(IFC, 2012)
MISO	2015	US	High	Line	Mix	0.8	-	Input/Output	(MISO, 2015)[32]
Transmission in the SPP region	2010	US	High	Line	-	20.2	-	Input/Output (IMPLAN Model)	(Pfeifenberger et al., 2010)[33]

Deriving occupational breakdowns

Survey data was used to estimate the percentage of total employment attributed to different occupations. Occupational employment was estimated at two levels:

- ANZSCO, 1-digit: employment was calculated for six occupational categories – managers, professionals, trades and technicians, clerical and administrative staff, machine operators and drivers, and labourers[34]
- Composite profile: occupations at the 6 digit level according to the ANZSCO classification, based on the concentrations of employment.

The occupational composition for each phase of employment (development, civil works, and electrical works) was calculated from the average for the projects in that category, that is, for each double circuit line project, for each single circuit line project, and for all the non-line projects. Weighting by km or value was not applied.

The overall occupational breakdown for that category of transmission was then calculated using the weighted split of job-years between development, civil works, and electrical works.

The resultant percentages are applied to the gross number for the relevant type of project, for any given year to produce time series, averages, and snapshots of the occupational mix overall and per technology.

Integrating the ISP transmission projects into the employment model

Splitting projects into individual elements

Project descriptions were extracted from the ISP and separated into line and non-line elements. Each project element retained its project title identifier and was then coded according to the asset type.

Projects were coded as double circuit lines, single circuit lines, or non-line projects further classified into "substation" or "other". Some project elements were excluded due to a lack of available data.

Table 18 summarises the types of transmission projects included or excluded.

Table 18: Transmission asset types included/ excluded from the modelling

Asset classification	Further classification	Description
INCLUDED		
Line	Single circuit	New or uprate single circuit, all terrain types, all voltages – included
Line	Double circuit	New double circuit, all terrain types, all voltages – included
Transmission (other, non-line)	Substation	New substations and substation augmentation works – included
Transmission (other, non-line)	-	Transformers, reactors and capacitors - included where we could assign a value
EXCLUDED		
Transmission (other, non-line)	-	Tapping, cutting-in, turning-in lines – excluded
Transmission (other, non-line)	-	Ambivalent descriptors for project elements (e.g. 'special protection scheme') – excluded
Transmission (other, non-line)	-	Power flow controllers – excluded

Project elements describing 'tapping, cutting-in, and/or turning-in' lines were excluded in the model due a lack of data at this granularity. We also assumed that these elements could be accounted for under employment data for new transmission lines.

We were unable to obtain financial data for power flow controllers, although efforts were made through stakeholder engagement without result, so these were excluded from the final modelling. Additionally, some project parts with ambivalent descriptors were also excluded.

Allocating to state

ISP projects were allocated to states based on their geographical location. Where a project crossed state boarders, the project elements were assigned according to how much lies in each state. For example, for Project EnergyConnect, the respective portions of the 'new Bundey–Buronga–Dinawan–Wagga Wagga 330 kV double circuit' transmission line were assigned to NSW and SA using the kms of line located in each state. Likewise, non-line project elements were assigned to each state based on their geographical location. For example, the non-line project element 'augmentation of the existing substation in Wagga Wagga' was assigned to NSW, whereas transformers at Bundey were assigned to SA.

Identifying length and costs

To estimate line length and attribute km line portions to different states, a combination of the AEMO transmission map and the google maps distance measurement feature was used.

For example, as part of the QNI Minor project, the following project elements were described:

- Uprate Liddell-Tamworth 330 kV line
- Uprate Liddell-Muswellbrook-Tamworth 330 kV

The AEMO transmission map was used to locate these lines and the associated transmission corridor. [35] The next step was to roughly follow the prescribed transmission corridor, according to the AEMO map, and measure the distance of the proposed transmission line infrastructure corridor. The total distance was rounded to the nearest 5 km, in this case 290km. Where a transmission corridor crossed state borders, the length of line was split between states.

Allocating start time and duration

The impact of construction on labour demand is of course highly influenced by timing.

The ISP gives a 5 or 10 year window for most transmission projects, and although some project specific information is available in public documents, there is very little information on exact project start dates and project timelines beyond the indicative dates represented in the ISP.

The start dates used for modelling employment for each major project identified in the ISP are listed in Table 19. Where information is publicly available or the project is already under construction, the project timeline and start date was set firmly in the model. Where project durations were unavailable, default values of 2 years for non-line projects and 3 years for line projects were set. Those projects that fall outside the 2021-2035 window were excluded from the modelling results.

Table 19: Project start dates and timelines used to model transmission employment

Project name	Modelled start date	Project duration (years)	Timing notes
Central VIC	2020/ 2022	2	Timing confirmed (2020-2023)
QNI Minor	2020	2	Project commenced (due to be commissioned Dec 2021)
Eyre Peninsula	2021	2	Timing confirmed
VNI minor upgrade	2021	2	Timing confirmed (commissioning expected 2022-2023)
Central NSW	2022 - 2031	2 years non-lin 3 years line	Project partly commenced (next element at 2026, remainder commence 2031)
Project EnergyConnect	2022	4	Timing confirmed (commencement set 2022, completion expected during 2025)
Humelink	2024	3	Timing confirmed (2024-2026)
Far North Queensland	2026	3	One line elements set at 2026 for Step Change, post 2035 for other scenarios. Some elements excluded from model as thought too late.
Gladstone Grid section	2026	2 years non-line 3 years line	Timing confirmed (2026 for earlier elements, 2031 for others)
Northern West NSW	2026	4	Timing confirmed (brought forward to 2026)
Central to Southern Queensland	2027	3	Timing adjusted through stakeholder engagement
QNI Medium	2031	2 years non-line 3 years line	Commence at 2031, complete 2035
South East SA	2031	3	Step change scenario only, commence 2031
Marinus Link	2026	5	Timing advised by AEMO
Mid North SA	2035	3	Only included in Step Change
QNI Large	n/a	-	Post 2035, not included in model
South West Victoria	n/a	-	Post 2035, not included in model
North Queensland	n/a	-	Post 2035, not included in model
VNI West Option 6	n/a	-	Post 2035, not included in model
VNI Option 7	n/a	-	Post 2035, not included in model

Data on non-line assets

In order to calculate employment or materials for non-line transmission assets we needed to assign a cost. We were able to obtain some financial data for specific substations identified in the ISP, but by no means all. Where data was unavailable, average figures were used based on the data from other projects in the survey and publicly costed ISP projects. However, the cost of substations is extremely variable, so these costs are indicative at best.

We used the cost guide provided in the ISP inputs and assumptions workbook for transformers, reactors and capacitors wherever possible as no project specific data was available for these asset types.

Given the highly variable nature of non-line transmission asset works and the average data used to estimate both employment for non-line assets, and costs of the infrastructure, total employment figures produced in the model should be taken as indicative only.

Table 20: Occupational classifications and corresponding ANZSCO code

ANZSCO 1 digit classification	ANZSCO 6 digit code	Employment Title For Projections
Managers	111111	Executives
Managers	133111	Project Management Professionals (Office)
Managers	133112	Construction Managers (Site)
Managers	133211	Engineering Managers
Managers	133611	Procurement Managers
Managers	132000	Business Administration Managers (Finance, Human Resources, etc)
Professionals	234399	Community Engagement
Professionals	221100	Finance and Business Professionals
Professionals	232212	Surveyor
Professionals	233112	Materials Engineer
Professionals	233211	Civil Engineer
Professionals	233212	Geotechnical Engineer
Professionals	233213	Quantity Surveyor
Professionals	233214	Structural Engineer
Professionals	233311	Electrical Engineer
Professionals	233512	Mechanical Engineer
Professionals	263300	Telecommunications Engineers
Professionals	263200	IT Support and Test Engineers
Professionals	233999	Other Engineers
Professionals	234300	Environmental Professionals
Professionals	234400	Geologists, Geophysicists and Hydrogeologists
Professionals	251300	Environmental and Occupational Health Professionals
Professionals	220000	Other Professionals
Administrative staff	500000	Administrative Staff
Trades and Technicians	312611	Safety Officer
Trades and Technicians	312911	Maintenance Planner
Trades and Technicians	342400	Telecommunications Technicians (Field Staff)
Trades and Technicians	332211	Painting Trades
Trades and Technicians	341100	Electricians
Trades and Technicians	342211	Electrical Linesworkers (Transmission)
Trades and Technicians	312512	Mechanical Trades and Technicians
Trades and Technicians	342212	Technical Cable Jointer
Trades and Technicians	899914	Electrical Trade Assistants
Trades and Technicians	899915	Telecommunications Trade Assistants
Trades and Technicians	300000	Site Supervisor
Trades and Technicians	349900	Other Trades and Technicians
Machine Operators and Drivers	712111	Crane Operator
Machine Operators and Drivers	712211	Driller (Pilings, Foundations Etc)
Machine Operators and Drivers	721200	Earthmoving Plant Operators and Forklift Drivers
Machine Operators and Drivers	733100	Truck Drivers

ANZSCO 1 digit classification	ANZSCO 6 digit code	Employment Title For Projections
Machine Operators and Drivers	712112	Elevated Work Platform Operators
Machine Operators and Drivers	712900	Other Machine Operators and Drivers
Labourers	821100	Construction Labourers (Certificate 2 Level)
Labourers	821211	Concreter
Labourers	821711	Rigger and Dogmen
Labourers	821714	Structural Steel Erector (Steel Fixer)
Labourers	899900	Other Labourers

Material indicators – methodology

Introduction

Material indicators for the energy generation by renewable technologies utilising wind generation, solar or hydro power were developed using international and national literature, environmental impact statements/reports, installation standards and consultation with industry experts. A special consideration was taken for the Australia specific technology installation trends as well as the technological advancement direction. The focus materials of this study are concrete and steel, the materials playing a significant role in all renewables.

Zepf et al. (2014) showed materials pathways along the supply chain for the energy generation technologies including wind power, solar and hydro focus of this study. [36] While that work illustrated the pathways for materials along the whole supply chain, we focused on the final product and not on extraction.

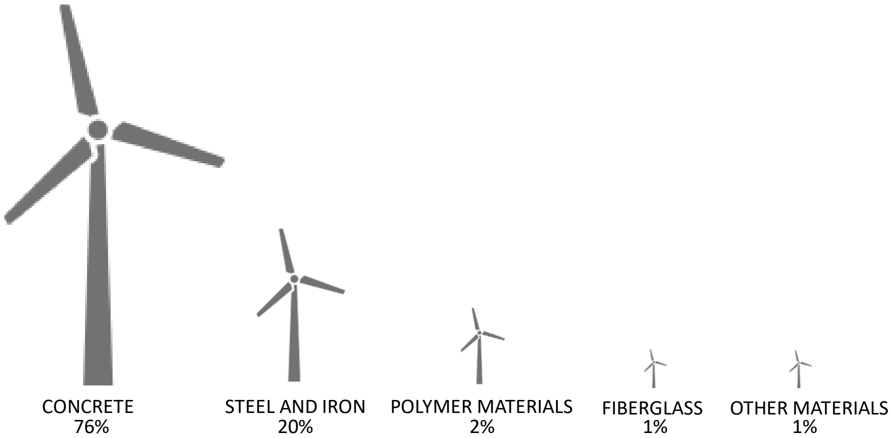
In this section we describe the method used to estimate the material indicators for concrete and steel for wind generation, solar and hydro as well as transmission lines and for the supporting infrastructure. We have listed estimates of material indicators for rooftop solar, coal, oil and gas as stated in the literature but have not analysed them for the Australian context.

Utility-scale wind power

Scaling up electricity from renewables is crucial for decarbonisation of world's energy system. Wind and solar power would lead the way with wind power to supply more than one third of total electricity demand by 2050, which represents nearly a nine-fold rise in the wind power share in the total generation mix by 2050 compared to 2016 levels.[37] It is predicted that onshore wind generation will play a significant role worldwide in renewables installations for the next few decades. Offshore installations, predicted to be a fifth of yearly onshore capacity installations, will also increase significantly over the next few decades. Most of the offshore wind power installations so far have been on the North Sea and nearby Atlantic Ocean and there are only a small number of installations projected for Australia by 2050. Therefore, this study focuses on onshore wind generation only.

Wind turbines are predominantly made of steel, fiberglass, resin or plastic, iron or cast iron, copper and aluminium, with concrete as a foundation (Figure 6). Onshore wind turbines use concrete as a foundation and concrete and steel is used in the foundations of the offshore wind turbine installations. Concrete and steel are the most prominent materials required for wind turbines and foundations. Manufacturing of the main components of the wind turbine requires specialised equipment and welding, lifting and painting machines that are also used in other industries such as construction and aeronautics. The foundations also require specialised equipment for rolling, drilling and welding. Special equipment is also needed to move these big structures.

Figure 6: Proportion of materials used to build a wind turbine

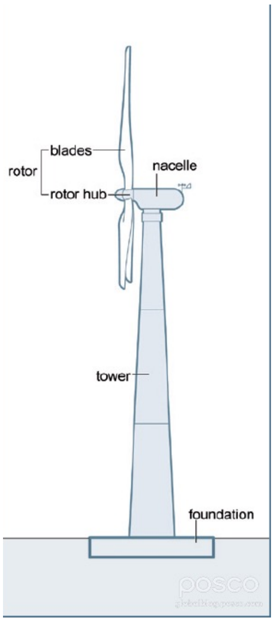


Note: Based on a 50 MW onshore wind plant. Adapted from International Renewable Energy Agency (2019). [38]

Wind turbines convert kinetic energy of moving air to electrical energy, with incoming air flow activating the rotation of rotor blades that in gearbox transfers to higher speed spinning the electricity producing generator. There are a number of variations in the designs of wind turbine and consequently the material requirements. One of the main distinctions is between geared and gearless converters, with further variations within each of the options. Gearless generators offer greater reliability and require less maintenance but are bigger and heavier (nacelle of direct drive synchronous generator (DDSG) is approximately one third higher than that of geared generator). However, the weight of the gearless generator is significantly reduced with the use of the rare earth elements (as in the direct drive permanent magnet synchronous generators' nacelles which are two thirds lighter than DDSG's).[39]

It is estimated that wind turbines require around 200 kg/MW of rare earths, which have been a driving force for innovation in the wind technology due to an increase in the rare earth prices. Lighter nacelles have also lower material requirements for the tower and foundations. Breakdown of components and material requirements for a typical 2.5 MW turbine is shown in Figure 7.

Figure 7: Material distribution in wind turbines based on onshore 2.5 MW turbine

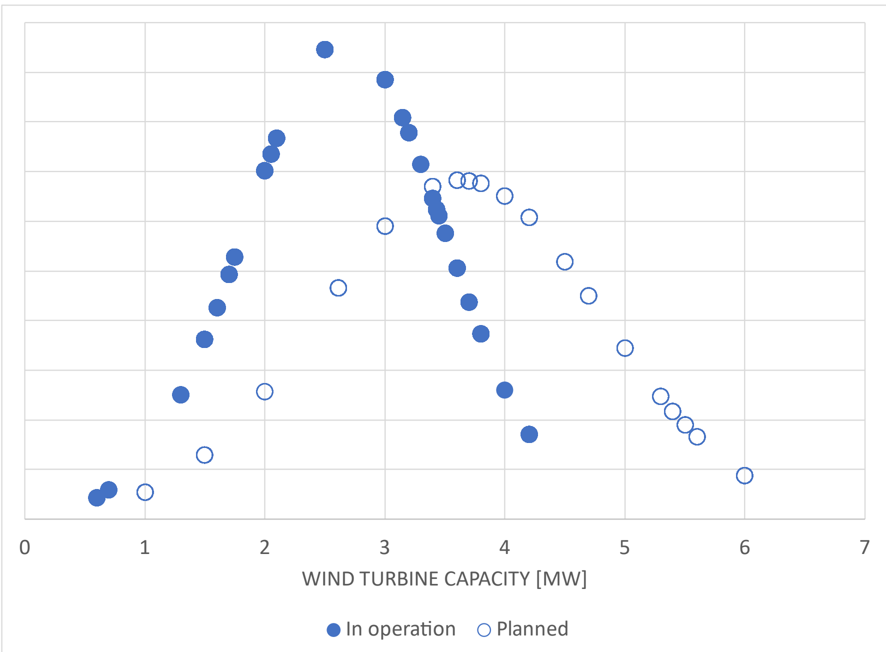


COMPONENT		MATERIAL	[%]
Rotor	Blades	Glass-reinforced plastics	100
	Hub with nose cone	Cast iron	62
		Low-alloy steel	35
		Glass-reinforced plastics	2
Nacelle	Generator	Aluminium	1
		Copper	30
		Electrical steel	69
	Gearbox	Aluminium	1
		Cast iron	49
		High-alloy steel	49
	Housing	Glass-reinforced plastics	100
	Main frame	Cast iron	65
		Low-alloy steel	35
	Main shaft	High-alloy steel	85
		Low-alloy steel	15
	Transformer	Aluminium	1
		Copper	31
		Electrical steel	68
Tower	Tubular steel	Low-alloy steel	100
	Tower internals	Aluminium	67
		Copper	33
Foundation	Concrete	Concrete	100
	Reinforcement	Reinforcement steel	100

Source: United Nations Environment Plan (2016)[40]

The capacity of the wind turbines has been increasing over the years. At the same time there has been a development towards lighter nacelle unit for the same capacity lowering the material requirement of the supporting tower and foundation. Therefore, while the turbine capacity is increasing over the time (Figure 8), the material requirements per MW capacity have remained similar (Figure 9).

Figure 8: Current wind turbine capacity in MW in operation and planned based on NEM



Source: AEMO, Generation Information (2021)[41]

Material indicators for steel and concrete for wind generation (

Table 21) were determined based on the data published in literature and are plotted as a function of wind turbine capacity in Figure 9.[42] [43] [44] [45] [46] [47] [48]

Figure 9: Material indicators for steel and concrete as a function of wind turbine capacity

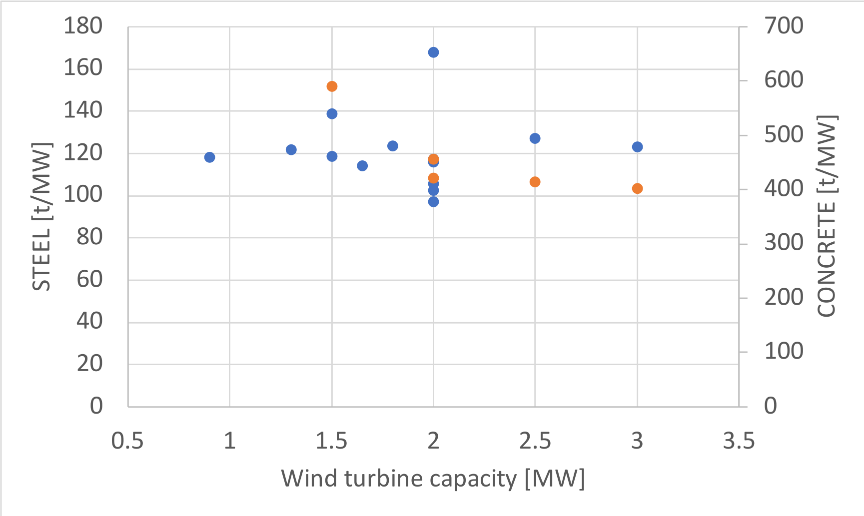


Table 21: Material indicators for wind power

Technology	STEEL [t/MW]	CONCRETE [m^3/MW]
Wind power	120	190

Utility-scale solar

Utility-scale solar farm constitutes of an array of **solar modules** (PV panels) arranged in strings. Modules include cells organised in a series on the panels. They differ in cell type, ranging from monocrystalline cells, polycrystalline cell, thin-film cells etc., using different materials. With the aim of increasing the efficiency and reducing costs, the technology has been evolving over time and will continue so in the future.

Modules are either mounted on fixed angle frames or sun-tracking systems. Mounting structures are typically fabricated from steel or aluminium, although there are examples of wooden beams.[49]

Fixed frames are simpler to install, cheaper, and require less maintenance. However, the tracking systems can increase yield up to 45%.[50] Single-axis track system better matches the grid energy profile and stability of the grid but requires 35% more steel as oppose to the fixed frame system.[51] In addition to the single-axis tracking systems there are also dual-axis tracking systems on the market. Dual-axis tracking maintains the optimum alignment to the sun, but is technically more complicated and requires more materials than single tracking system.[52]

Foundation options for ground mounted PV systems include:

- Concrete piers cast in-situ – small systems and uneven sloping terrain.
- Pre-cast concrete ballasts – large systems, grounds difficult to penetrate, low tolerance to uneven and sloping terrain.
- Driven piles – low-cost, quick, large scale installations.
- Earth screws – large-scale installations, tolerant to uneven or sloping terrain.
- Bolted steel baseplates – existing concrete ground slabs.[53]

Australian solar farms use predominantly single axis tracking technology and the driven piles for foundations.

The direct current electricity produced by the modules is converted to alternating current (AC) with the inverters to the voltage and frequency that are compatible with the AC grid. The inverters vary whether they are connected at the modular, string or sub-array level and whether they include a transformer.

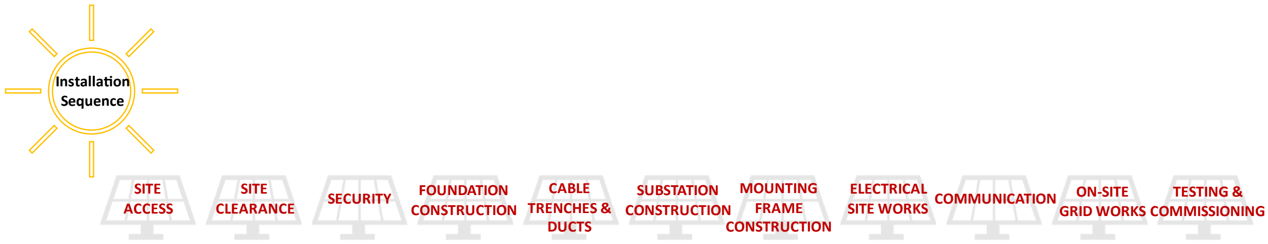
In addition, there are two different types of transformers at the utility-scale solar farm: the distribution transformer, installed after each inverter, and a substation transformer, used to set up voltage for transmission. They are both housed in a metal container and placed on a concrete foundation.

The panels and other components are connected with cables (copper or aluminium).

A solar farm also includes supporting equipment such as electrical protection devices (overcurrent protection, disconnection protection, lightning/surge protection), junction/combiner boxes (connecting cables from modules to the inverter). Equipment for metering as well as system monitoring, known as the Supervisory Control and Data Acquisition (SCADA) system is important in the operation of the solar farm.

Stages and sequence of solar farm installation are summarised in Figure 10. In addition, a temporary infrastructure is established, including laydown, storage and site compound for which the materials are not accounted in this study and the components are generally leased for the duration of the construction.

Figure 10: Installation sequence works for utility-scale solar farm



Solar farms use only minimal quantities of concrete in Australia due to use of driven piles for foundations. Concrete is predominantly used in foundations for the substation construction.

Solar farms use only minimal quantities of concrete in Australia due to use of driven piles for foundations. Concrete is predominantly used in foundations for the substation construction.

Most of utility-scale solar farm components are imported from overseas but some are produced locally.

Imported from overseas:

Solar panels

- Tracking system – integrated onshore but components are predominantly manufactured in China.
- Mounting structure, including the piles – the metallic part could be manufactured anywhere, including Australia, but a competitive cost is the barrier.
- Inverters – include a more sophisticated technology and it is less likely that the suppliers would open manufacturing facilities in Australia. European and US companies that dominate the market set offshore facilities in China to lower the costs.

Electrical equipment, combiner boxes

- Cables and conduits – can be supplied from Australia but are normally supplied from India or SE Asia due to cost

Components manufactured in Australia:

- Transformers - some of the big companies have manufacturing facilities for transformers in Australia and supply smaller transformers from Australia.
- Monitoring systems – supplied from Australia or overseas, depending on the design origin
- Security system
- Weather stations

- Fencing – predominantly steel
- Site Facilities

Most components of the solar farm last the lifetime, except for the inverters and other electrical devices that have 25 year warranty.

Figure 11 is showing the mass breakdown for a utility-scale solar farm. Steel is the main component by mass. From the global consumption of steel in 2017, only 0.4% were used for PV and the authors concluded that steel production far exceeds the demand for steel in PV systems.[54]

Figure 11: Component mass breakdown for utility-scale 100 MW solar farm system including 295 W panels mounted on single-axis tracking system

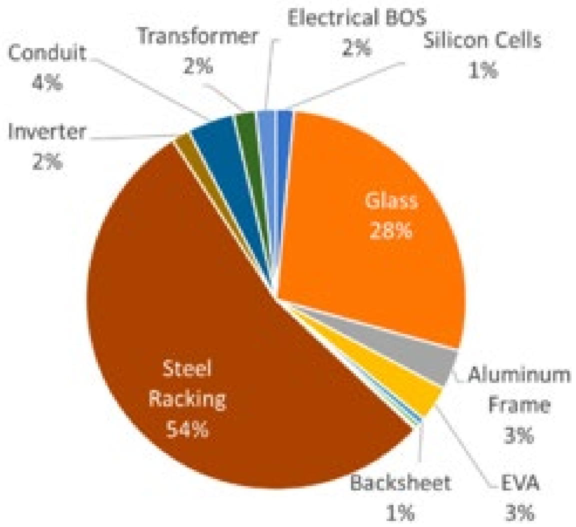
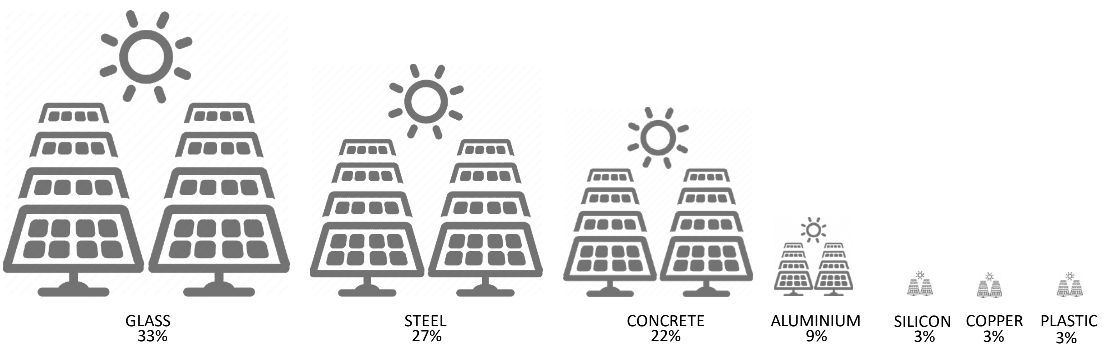


Figure 12 illustrates the proportion of materials used to build a solar farm. The main component is glass that is used for the solar panel and steel, a supporting structure for the panel and as listed above in the other supporting infrastructure on the solar farm. See Table 22 for the material indicators for solar.

Figure 12: Proportion of materials used to build a solar farm



Note: Adopted from (IRENA, 2019b).[55] Based on a 1 MW solar PV plant (Si-wafer).

Table 22: Material indicators for solar

STEEL [t/MW]	CONCRETE [m^3/MW]
96 [56]	-
56 [57]	20
- [58]	4
169 [59]	-
69 [60]	38
120 [61]	-
67.5 [62]	25
82	**22**

Hydro and pumped hydro

Hydro and pumped hydro use a large quantity of concrete to construct dams and reservoirs. The required building material quantities are very project specific and depend on the local topographical features, such as naturally occurring reservoirs, porosity of the material lining the reservoirs and the hydrology features.

A wide range of literature was explored in an attempt to derive the material indicators for hydro and pumped hydro. Reported numbers for concrete requirements in literature differ widely and indicate a large uncertainty in the numbers.

As hydro and pumped hydro are mature technologies and are not predicted to significantly evolve in the future, use of the data from historical installations was thought that could be used to predict material requirements. However, the majority of the currently installed hydro technologies in Australia are dams (Table 23) but the future planned projects are almost exclusively pumped hydro (Table 24).

Table 23: Current installed hydro and pumped hydro in Australia

STATE	Project	Type	Capacity [MW]	Storage [MWh]
NSW	Copeton	Dam	20	
	Glenbawn	Dam	5	
	Gutega	Dam	60	Does
	Hume Dam NSW	Dam	29	
	Jindabyne	Dam	1.1	
	Jounama	Dam	14.4	
	Keepit	Dam	7.2	
	Nymboida	Dam	0.686	
	Oaky	Dam	2.4	
	Pindari	Dam	5.772	
	The Drop	Run of River	2.5	
	Tumut	Dam	2116	
	Wyangala	Dam	24	

QLD	Kareeya	Run of River	84.6	
	Kareeya	Dam	7	
	Lake Somerset	Dam	4.3	
	Wivenhoe Small Hydro	Dam	4.5	
SA	Cultana	Pumped hydro	225	1800
	Baroota	Pumped hydro	250	2000
	Seacliff Mini Hydro	Dam	1.35	
	Terminal Storage Mini Hydro	Other	250	
TAS	Catagunya/Liapootah/Wayatinah	Dam	170.1	
	Cethana	Dam	85	
	Cluny	Dam	19	
	Devils Gate	Dam	60	
	Fisher	Dam	43.2	
	Gordon	Dam	432	
	John Butters	Dam	144	
	Lake Echo	Dam	32.4	
	Lake Margaret	Dam	8.4	
	Lemonthyme/Wilmot	Dam	81.6	
	Lower Lake Margaret	Dam	3.2	
	Mackintosh	Dam	79.9	
	Meadowbank	Dam	40	
	Midlands	Dam	6	
	Paloona	Dam	28	
	Poatina	Dam	300	
	Reece	Dam	131.2	
	Repulse	Dam	28	
	Rowallan	Dam	10.5	
	Tarraleah	Dam	90	
	Trevallyn	Dam	93	
	Tribute	Dam	82.8	
	Tungatinah	Dam	125	
VIC	Bogong/Mackay	Dam	150	
	Clover	Dam	29	
	Dartmouth	Dam	185	
	Eildon	Dam	135	
	Eildon Pondage Power Station	Run of River	4.5	
	Glenmaggie	Dam	1.9	
	Hume Dam VIC	Dam	29	

	Belgrave-Hallam Rd	Dam	0.25	
	Mount Waverley Mini Hydro	Dam	0.355	
	Murray	Dam	1502	
	Rubicon Mountain Streems	Dam	13.5	
	Wantirna Mini Hydro	Dam	0.132	
	West Kiewa	Dam	68	
	William Hotel	Run of River	1.8	
	Yarrawonga	Dam	9.5	

Table 24: Planned projects for hydro and pumped hydro in Australia

STATE	**Project**	**Type**	**Capacity [MW]**	**Storage [MWh]**
NSW	Bells Mountain	Dam	250-500	
	Oven Mountain Pumped Storage	Pumped Hydro	600	7200
	Armidale Pumped Hydro	Pumped Hydro	600	
	Snowy 2.0	Pumped Hydro	2040	349980
	Walcha Energy Project Storage	Pumped Hydro		
	Shoalhaven Expansion			3853
QLD	Kidston Pumped Hydro	Pumped Hydro	250	
SA	Baroota Pumped Hydro	Pumped Hydro	250	
	Kanmantoo	Other	250	
	Goat Hill Pumped Hydro	Pumped Hydro	230	1840
	Higbury Pumped Hydro	Pumped Hydro	300	
	Middleback Ranges	Pumped Hydro	90	390
TAS	Battery of the Nation	Pumped Hydro	3150	60000
VIC	Port Phillip Heads Tidal Energy Project	Tidal	34	

Source: AEMO, Generation Information (2021)[63]

The concrete requirements for pumped hydro will vary depending on whether there is one or two reservoirs and if they could be lined by natural material or if they need to be lined/build with concrete. Weather there is one or two reservoirs used depends on the location of the hydro station, if there is a naturally occurring reservoir and the penstock height to length ratio.

Steel is used for the pumps, equipment and pipes, which are usually coated with concrete, usually needing larger quantities when the pumped hydro is underground.

Due to the variation and uncertainty in concrete and steel requirement indicators for hydro and pumped hydro, the indicators used in Life Cycle Assessment (LCA) literature were applied based on a range of studies covering hydro, pumped hydro and underground pumped hydro and compared to the LCA database Ecoinvent (Table 25).

Table 25: Material indicators for concrete and steel for hydro and pumped hydro

Source	**Type**	**Steel [t/MW]**	**Concrete [m³/MW]**
Ecoinvent	Hydro	135	3542
(Vidal, O., 2017)	Hydro	96	3167
(Guo et al., 2020)	Pumped Hydro	35	64
	Pumped Hydro Underground	72	132
(Immendoerfer et al., 2017)	Pumped Hydro	44	1236
(Jiang et al., 2018)	Hydro	20	930
	Hydro	115	1064
	Hydro	111	1886
	Hydro	55	810
(Krüger et al., 2018)	Pumped Hydro	50	1249
ADOPTED	**Hydro**	**76**	**2027**
	Pumped Hydro	**43**	**850**
	Pumped Hydro Underground	**72**	**132**

Transmission lines and supporting infrastructure

High voltage and medium voltage transmission line assets were used to estimate the material requirements for transmission lines in Australia – low voltage lines were excluded due to the limited availability of data for these tower types and the high variability in material use (i.e. concrete, steel, wood).

Based on the literature available it was determined that high and medium voltage transmission line towers used in Australia are predominantly steel lattice towers with concrete foundations; projects featuring steel poles with concrete foundations appeared less frequently in literature sources and lacked available material intensity data.

The main differences between **single and double circuit transmission lines** are the tower height, foundation depth, and the frequency of towers built over a km of line.

See Figure 13 for a guide on transmission tower height and type according to voltage level taken from.[64]

Figure 13: Typical transmission tower design and height

Two main literature sources were used to derive estimates for steel per km of transmission line (Table 26). Some minor calculations were performed using the information provided by these sources to derive the final steel/km and concrete/km figures outlined in Table 26.

Table 26: Data sources used for transmission line infrastructure estimates

Transmission line type	Line type	Tower type	Tower height	Steel (tonnes)/km	Concrete (m^3)/km	Reference
330 kV Line	Double Circuit	Steel lattice tower	60-80m	46.2	71.3	(TransGrid, 2020a)
500kV/345kV Line	Double Circuit	Steel tower (lattice or pole)	60-80m	71		(Midcontinent Independent System Operator, 2019)
500kV/345kV Line	Single Circuit	Steel tower (lattice or pole)	60-80m	32.7		(Midcontinent Independent System Operator, 2019)
220kV Line	Double Circuit	Steel (lattice or pole)	50m	32.5	71.3	(TransGrid, 2020a)
230kV Line	Double Circuit	Steel (lattice or pole)	50m	33.6		(Midcontinent Independent System Operator, 2019)
220kV Line	Single Circuit	Steel (lattice or pole)	50m	17.3		(Midcontinent Independent System Operator, 2019)

TransGrid provided information on the total steel and concrete used for transmission lines over 135km for a 330 kV double circuit transmission line and over 22km for a 220 kV double circuit transmission line.[65] A weighting was applied to estimate the medium voltage and high voltage steel intensities for each tower type. This was achieved by averaging the total steel amount over the number of towers and then multiplying a height weighting of 62% for the high voltage transmission tower and 38% for the medium voltage transmission tower. These calculations provide estimates only and should be used as such.

Midcontinent Independent System Operator provided exact steel figures per tower type for 500 kV, 345 kV, and 230 kV double and single circuit lines.[66] Although the voltage between US transmission lines varies slightly, the 345 kV lines are treated as 330 kV equivalents and the 230 kV lines are treated as 220 kV equivalents. Tower types in the US study were classified as tangent, running and dead-end and the number of structure types per mile was provided per voltage class (see Table 27). These numbers were used to derive an average tonnage of steel per km of line, per voltage class.

Table 27: Number of structures per voltage class per mile

	A/C Transmission Structures per mile – steel tower and steel pole				Single circuit / Double circuit		
Voltage class	**69 kV line**	**115 kV line**	**138 kV line**	**161 kV line**	**230 kV line**	**345 kV line**	**500 kV line**
Tangent structures	9 / 9.5	8.5 / 9	8 / 8.5	7 / 7.5	5 / 7	4.5 / 6	3 / 5
Running angle structures	1 / 1	1 / 1	1 / 1	1 / 1	1 / 1	1 / 1	1 / 1
Non-angled deadend structures	0.25 / 0.25	0.25 / 0.25	0.25 / 0.25	0.25 / 0.25	0.25 / 0.25	0.25 / 0.25	0.25 / 0.25
Angled deadend structures	0.25 / 0.25	0.25 / 0.25	0.25 / 0.25	0.25 / 0.25	0.25 / 0.25	0.25 / 0.25	0.25 / 0.25
Total structures per mile	**10.5 / 11**	**10 / 10.5**	**9.5 / 10**	**8.5 / 9**	**6.5 / 8.5**	**6 / 7**	**4.5 / 6.5**

Concrete is used for **foundation of the transmission lines**. The amount of concrete required depends on the transmission tower size and weight. Double curcit towers are generally heavier and bigger than single cuircuit towers. Based on the Environmental Impact Statement for the Gateway West Transmission Line Project, USA (EIS, 2018), we estimated that the amount of concrete reqired for the average tower with single circuit was 45% less – 39.2 m^3/km – than for the tower with double circuit (71.3 m^3/km). Note that Dead-End structure referes to the position where the transmission line changes direction.

Table 28: Foundation excavation dimensions for transmission towers

500 kV	**SINGLE CIRCUIT**				**DOUBLE CIRCUIT**				
Tower Structure	*No of holes*	*Depth [m]*	*Diameter [m]*	*Concrete [m^3]*	*No of holes*	*Depth [m]*	*Diameter [m]*	*Concrete [m^3]*	*Difference [%]*
Tangent Lattice	4	6.7	1.2	31.3	4	7.9	1.5	58.1	***46***
Small Angle Lattice	4	7.5	1.2	35.2	4	8.7	1.5	63.5	***45***
Medium Angle Lattice	4	8.2	1.2	38.2	4	9.4	1.5	68.8	***44***
Medium Dead-End Lattice	4	9.0	1.5	65.8	4	10.2	1.8	107.0	***39***
Heavy Dead-End Lattice	4	9.8	1.5	71.1	4	11	1.8	115.4	***38***

Source: (EIS, 2018)

In addition to literature sources provided above, the American Iron and Steel Institute estimates between 18 and 30 tonnes of steel are used in high voltage transmission towers. At roughly two towers per km of line, this equates to between 36 and 60 tonnes of steel per km, confirming the estimates in Table 35 above.[67] [68]

Supporting infrastructure for transmission lines includes substations, transformers, capacitor banks, reactive plants and power flow controllers.

Only one source provided estimates of total concrete for a line project.[69] TransGrid provided total concrete figure of 11200 m^3 for the double circuit 157 km line (both medium and high voltage). An estimate was calculated per km based on this total figure of 71.3 m^3/km of line.

Supporting infrastructure is placed on concrete foundations. TransGrid estimated requirement of 448 m^3/ha of concrete for the supporting infrastructure[70]. Using AEMO indicative cost estimates for AC transmission assets for 2020 (Table 29) a concrete indicator was estimated to be 278 m^3/$mil.

Steel indicator was estimated based on average use of steel for steel frame in transformers. A 500 kV transformer requires 1.134t of steel for the frame (MISO, 2019) and based on the AEMO indicative cost estimates for AC transmission assets for 2020 (Table 29) a steel indicator was estimated to be 0.1t/$mil.

Table 29: AEMO indicative cost estimates for AC transmission assets for 2020

Plant	Number of units	Indicative cost estimates ($ millions)
500 kV double circuit transmission line (3040 MVA each)[a]	$/km	2.46
500 kV single circuit transmission line (3200 MVA each)[a]	$/km	2.05
330 kV double circuit transmission line (1200 MVA each)[a]	$/km	1.92
330 kV single circuit transmission line (1200 MVA each)[a]	$/km	1.54
275 kV double circuit transmission line (950 MVA each)[a]	$/km	1.79
275 kV single circuit transmission line (800 MVA each)[a]	$/km	1.49
220 kV double circuit transmission line (800 MVA each)[a]	$/km	1.66
220 kV single circuit transmission line (800 MVA each)[a]	$/km	1.41
500/330 kV 1000 MVA transformer	1	20.43
500/220 kV 1000 MVA transformer	1	20.28
100 MVAr 500 kV line shunt reactor	1	5.93
50 MVAr 330 kV line shunt reactor	1	4.01
100 MVAr 330 kV line shunt capacitor	1	4.06
100 MVAr 220 kV line shunt capacitor	1	3.16
330 kV 300 MVAr SVC	1	28.39
220 kV 200 MVAr SVC	1	23.14
3CB diameter 3CBS – 500 kV	1	11.18
3CB diameter 2CBS – 500 kV	1	8.73
3CB diameter 3CBS – 330 kV	1	7.48
3CB diameter 2CBS – 330 kV	1	5.77
3CB diameter 3CBS – 275 kV	1	6.25
3CB diameter 2CBS – 275 kV	1	4.83
3CB diameter 3CBS – 220 kV	1	4.25
3CB diameter 2CBS – 220 kV	1	3.32
New substation establishment (10,000m^2)[b]	1	16.12
New substation establishment (20,000m^2)[b]	1	23.34
New substation establishment (30,000m^2)[b]	1	31.42

Note: All costs are indicative and in 2020 dollars including project overhead.
a: For each transmission line longer than 150 km, an economy of scale factor of 0.95 is applied to $/km cost estimate.
b: Earth works, secondary systems building, DC supply, AC supply auxiliary transformers/cabling, fire protection and communication systems.

Other energy generation technologies

Other energy generating technologies such as gas, coal, oil and PV rooftop were not in the scope of this study. We have however included them in the model based on the values derived in the book review of energy production.[71]

The numbers in Table 30 are based on the international literature and have not been evaluated for Australian context. For PV rooftop it assumes use of concrete. The use of concrete in rooftop depends on the type of mounting type of mounting system and whether the PV system is ballasted. Ballasted systems are normally deployed on flat concrete roofs and where the penetration of the roof material is not possible. Flat roofs are used in commercial buildings and we have seen an increase in solar PV installations particularly on the commercial buildings in the recent year. In ballasted systems, concrete blocks are used to hold the system down and are limited to low wind regions (in Australia to Wind Region A).[72]

Table 30: Material indicators for other energy producing technology

Steel [t/MW] **Concrete [m³/MW]**	**Gas+CCGT**		**Coal**		**Oil**		**PV roof**	
	steel	concrete	steel	concrete	steel	concrete	steel	concrete
(Vidal et al., 2013)	-		52	75	-	-	169	494.2
Average lit data	-		56	65.4	51	29.6	217	-
min	-		68	30.8	51	29.6	250	-
max	-		40	81.3	51	29.6	200	-
(Hertwich et al., 2015)	77	54.2	72	85.4	-	-	24	29.2
min	-		103	130.8	-	-	35	30.4
max	-		48	57.1	-	-	19	23.8
Ecoinvent	-		106	135.4	73	100.8	24	-
min	-		92	104.2	73	100.8	18	-
max	-		120	166.7	73	100.8	35	-
ADOPTED	**77**	**54.2**	**70**	**80.4**	**70**	**80.4**	**88**	**14.6**

Adopted from (Vidal,O., 2017)

APPENDIX B – ACRONYMS AND KEY TERMS

Acronyms used in this report:

Alternating current	AC
Australia and New Zealand Standard Industrial Classifications	ANZSIC
Australian and New Zealand Standard Classification of Occupations	ANZSCO
Australian Bureau of Statistics	ABS
Australian Capital Territory	ACT
Australian Energy Market Operator	AEMO
Australian Institute of Health and Welfare	AIHW
Australian National Audit Office	ANAO
Central-West Orana Renewable Energy Zone	CWO REZ
Committee for Economic Development of Australia	CEDA
Compound annual growth rate	CAGR
Council of Australian Governments	COAG
Direct drive synchronous generator	DDSG
Engineering, Procurement and Construction firms	EPCs
Environmental, Social, and Governance factors	ESG
Fibre to the Node	FTTN
Full time equivalent	FTE
Gigawatt	GW
Gross Domestic Product	GDP
Implicit price deflator	IPD
Input Output	IO
Integrated System Plan	ISP
Integrated System Plan	ISP
International Construction Measurement Standards	ICMS
Life Cycle Assessment	LCA
Liquified natural gas	LNG
Medium and Long-term Strategic Skills List	MLTSSL
National Broadband Network	NBN
National Electricity Market	NEM
New South Wales	NSW
Northern Territory	NT
Operation and maintenance	O&M
Photovoltaics	PV
Plant labour equipment and machinery	PLEM
Regional Occupation List	ROL
Regional Sponsored Migration Scheme	RSMS
Renewable energy	RE
Science, technology, engineering and mathematics	STEM
Short-term Skilled Occupation List	STSOL
South Australia	SA
Subject matter expert	SME
Supervisory Control and Data Acquisition	SCADA
Transmission Network Service Providers	TNSPs
Transport Network Strategic Investment Tool	TraNSIT
Vocational education and training	VET
Western Australia	WA

Key terms used in this report:

Australian Skills Classification	The Classification systematically sets out the structure of, and relationships between, skills within occupations and across the labour market. The Classification offers a 'common language of skills', enabling stakeholders to identify and articulate the skills that underpin Australian jobs using a comprehensive and universal taxonomy. It provides a means to conceptualise the distribution of skills across the labour market at a 'deeper' level than occupation classifications or qualifications. As it continues to evolve, the data can be used alongside other contextual data and information to: • Help employers to better understand their current and future skills needs – enabling more effective workforce planning exercises. • Assist job seekers to better understand their current skill sets, job transition options and up skilling or re skilling needs. • Identify further opportunities to develop timely and targeted short courses or adapt curriculum. The Classification is updated twice yearly, and published on the NSC website at https://www.nationalskillscommission.gov.au/our-work/australian-skills-classification
Budgeted and Announced	Funding status – Project has been officially announced and budget has been formally allocated.
Completed (in Operations and Maintenance)	The status of the project from the handover of the asset to the operator, following the completion of all construction activities.
Cost breakdown	The allocation a project's total cost into categories of various levels of granular detail.
Equipment	Engineered equipment, such as air conditioners, large pumps, transformers, motor control units, rail signal and control, road traffic monitor and control equipment, etc.
Implementation	The period starting with and work on detailed construction drawings or start of main construction works (whichever is sooner), and ending with Mechanical completion of construction works.
Labour	All human resources required to deliver projects, including project management, design, and construction.
Major Public Infrastructure Pipeline	The collection of public infrastructure projects with values above $50 million in TAS, NT, and ACT and above $100 million in NSW, VIC, QLD, SA, and WA
Market Capacity Intelligence System	A comprehensive suite of analytical and system-based tools to interrogate and visualise capacity across sectors, by project type and resource inputs.
Market Capacity Program	The body of work undertaken by Infrastructure Australia to deliver insights and intelligence on Australia's capacity to deliver infrastructure projects. This report is a deliverable under that program.
Materials	Bulk construction materials that are broadly commodity materials, such as concrete, steel, rail track, and electrical bulks such as cabling and conduit.
Pipeline	The collective definition of projects as they are considered in aggregation.
Planning	The period starting from the initiation of work on development of business case, including consideration of scope, and ending with the completion of the business case, ready for investment.

Plant	Construction plant, for example cranes, excavators, and scaffolding, as well as temporary facilities such as site offices and lunchrooms.
Procurement	The period starting from the project's readiness for market sounding activities, ending with the final tender decision.
Skills Priority List	The Skills Priority List (SPL) is key deliverable for the National Skills Commission that provides a detailed view of shortages as well as the future demand for occupations across Australia. The SPL uses a range of inputs to deliver labour market assessments for occupations based on labour market data analysis, employer surveys, industry consultation and federal and state/territory government input. This list provides the backbone piece of labour market analysis on occupations that will be a key input to a range of Australian Government policy initiatives, including targeting of skilled migration, apprenticeship incentives and training funding. Noting that each of these measures will also need to consider other inputs relevant to their specific policy needs. Providing a single source of advice on occupations creates a direct line of input for stakeholders and ensures greater consistency and better targeting of resources across the various policy responses implemented by government. The SPL is reviewed and updated annually and is published on the NSC website at https://www.nationalskillscommission.gov.au/2021-skills-priority-list
Typecast	The classification of projects according to their scope.
Unbudgeted and Announced	Funding status – Project has been officially announced and budget has not been formally allocated.
Unbudgeted and Unannounced	Funding status – Project has not been officially announced and budget has not been formally allocated.

APPENDIX C – CRITICAL RISKS BY SECTOR

For the purpose of the risks and risk themes outlined in this section, we have used a simplified risk assessment based on the broader framework and items outlined above.

There are two components used within this report - a risk rating (based on likelihood and impact) and a trend (showing the direction of the risk). The risk ratings were identified based on risk likelihood and impact definitions that have been developed (see also Table 38).

Risks informed by research and market consultation

Broad review: Macroscopic Lens

- A macroscopic review of 'systemic' risks to the infrastructure pipeline was conducted.
- A review of 19 Australian risk-related datasets was undertaken.
- Analysis drawing on the Oxford Global Projects' global and Australian project dataset to benchmark cost and schedule overruns. The database includes over 11,000 projects valued at US$3 trillion
- Risks identified were examined for impact, likelihood, direction and manageability.

Detailed review: Microscopic Lens

- A detailed analysis of risk-related project documents to build the evidence base for recent project risks.
- Review of publications, recent project business cases, ANAO and state Auditor General reports and project risk registers across transport, energy, water, social, waste and digital projects.
- Risks were assessed, with more than 150 risks compiled in a risk repository under the risk framework.
- A digital mapping tool was developed to store the risk repository and to identify its geospatial dimensions where possible.

Market sounding and survey

- A consultation to test emerging views within the infrastructure sector on critical risks, risk appetite and risk sharing was undertaken.
- A market sounding was conducted, with 37 organisations in the infrastructure sector being interviewed.
- This was followed by a sector survey which collected the views of 40 senior infrastructure executives.

- In total, consultation was undertaken with banks, equity investors, Tier 1 and 2 contractors, and insurers to calibrate the identified risks to the current market.

Expert and data validation

- Initial consultation and findings validation were undertaken throughout the project.
- The validation tested informed risks and initial findings with sector-based, subject matter experts.
- Over 70 expert interviews were conducted with government executives and experts across renewables, transport, energy, water, social, waste and digital sectors.

The risks included in this report use the below risk rating and trend approach, based on the detailed risk management framework

As risks were identified through reviews of project registers, expert interviews and market soundings, we sought to test them against the five criteria aligned to the risk framework outlined earlier - Impact, Likelihood, Rating, Trend and Manageability.

For the purpose of the risks and risk themes outlined in this report, we have used a simplified risk assessment framework, comprising a risk rating (based on likelihood and impact) and a trend (showing the direction of the risk).

Risk ratings were identified based on risk likelihood and impact definitions that have been developed for IA. Importantly, different organisations have different risk appetites and definitions for what would constitute these ratings (i.e. Low, Medium or High). We have made an attempt to 'normalise' these for the purposes of a National Risk Identification framework.

The risk trend seeks to identify whether the risk in question will become more prevalent over the course of the next period. For example, contractor default risks are a known issue, but may become more relevant heading into next year given wage inflation and losses incurred by Tier 1s recently.

Table 31: Risk matrix

Likelihood					
Almost Certain	Medium	High	High	Critical	Critical
Likely	Low	Medium	High	High	Critical
Possible	Low	Medium	Medium	High	High
Unlikely	Low	Low	Medium	Medium	High
Rare	Low	Low	Low	Low	Medium
	Very Minor	Minor	Moderate	Major	Extreme
	Impact				

Table 32: Risk key

Risk Rating	Low	Medium	High	Extreme
Trend	Reducing	Stable	Increasing	

Transport sector

Our analysis identified the following key risks related to the transport sector:

Risks	0-5 year assessment	
	Rating	Trend
Increasing prevalence of tunneling in projects will require greater specialist capability nationally, to manage increasing risks on ground movements as well as geotechnical issues.	Critical	→
Land acquisition challenges will result in increased project costs due to underestimated compensation costs to landowners, and/or late changes affecting project scope and design	Critical	→
Increasing prevalence of social license issues as network disruption from multiple concurrent projects heightens impacts in urban areas.	High	↑
Greater attention required to cost scoping of environmental and land contamination, which may result in costs and delays.	High	↑
Project based rather than corridor approach, resulting in re-work and benefits underachievement.	High	→

The forward pipeline for transport is significant and compromises the majority of projects in the national infrastructure pipeline. There has been a major increase in the number of megaprojects in the future pipeline, including metro development, transcontinental freight corridor development, and major rail and road upgrades.

The large program of major urban projects suggests that contamination, in-ground and utilities risks, community opposition and interface risks, are likely to be amplified in the next 5 to 10 years, with more tunnelling projects and connections to existing networks. While the COVID-19 pandemic continues in 2021, it is unlikely to be a major risk factor in future.

Tunnelling and ground movement risks

There will be a 25% increase in the number of tunnels in Australia's major cities over the next 5 years.

There is an emerging risk associated with tunnelling relating to geotechnical issues both during and after construction. For example, as water levels shift with rains, ground movements caused by subsurface changes such as expansion of clay may impact surface properties, potentially resulting in compensation requirements.

Limitations in geological surveys to accurately determine the exact geological conditions under the ground is a large challenge to tunnelling. The uncertainty of ground conditions can lead to project delays as engineers revise technical plans. A major aspect of the $2 billion cost blow out of the Melbourne Metro was attributed to encountering an unexpected soil density, resulting in digging delays. [73]

Land acquisition

Incorrect or ineffective processes, including the use of Restrictive Assessments, can lead to difficulties with land market valuation.

This has led to overcompensation for land for the Western Sydney Airport, where ANAO found the $30 million price paid by the Australian Government for land in Bringelly was almost 10 times its fair value. [74]

This risk is particularly prominent in transport projects where large tracts of land potentially with contamination issues need to be purchased. The Parramatta Light Rail project announcement led to the price of land in Camellia skyrocketing, for which the NSW Government paid three times the estimated price of land. Further, according to a 2015 contamination study, Camellia had a "high likelihood of significant soil and groundwater contamination", including carcinogenic chemicals which could add additional remediation costs of up to $200 million.[75]

Urban and community disruption

Social licence issues can arise where urban project delivery conflicts with existing economic and social uses. Infrastructure Australia estimates that over the past 10 years, community opposition resulted in $20 billion in infrastructure delays and cancellations. [76]

The recent Sydney Light Rail projects paid $31 million of compensation to small businesses due to construction delays. [77]

Contamination and cost to remediate

Contaminated land can have a high impact on planning delays, with health, safety and related approvals processes required – affecting the budget and timeline of the project.

Uncertainty around the level and volume of contamination risk in urban areas is an extreme risk to new infrastructure projects, specifically asbestos, per- and polyfluoroalkyl substances (PFAS) and alkaline soils. Uncertainty around the quantity of contaminated materials may manifest in time delays and the costly remediation poses a risk to budget settings.

For example, the estimated cost of all remediation works for contamination for the M4 widening in Western Sydney was $200 million, from a total project cost of around $500 million.

Case study: West Gate Tunnel Project
The discovery of harmful contaminants in the soil resulted in lengthy disputes between contractors and the Victorian Government, delaying the project by at least 12 months, and led to both cost overruns and stoppages due to work on the project being halted while the contaminated soil was removed.

Project-based approach is resulting in re-work and benefits underachievement

Across the sector there is risk associated with the delivery approach for individual projects over taking a corridor approach to infrastructure development. For example, the replacement or updating of signaling equipment in a part of the rail network as part of a general maintenance or improvement program may not factor in a change to metro-style service planned for the future.

In this example, the impact of this approach would include the replacement of very new infrastructure (re-work) to support the metro trains, potentially costing hundreds of millions of dollars.

Taking a broader corridor or network approach to transport infrastructure ensures that portfolio-level benefits are achieved through considering the interdependencies and enabling projects.

Energy sector

Our analysis identified the following key risks related to the energy sector:

Risks	0-5 year assessment	
	Rating	Trend
Underlying connection and transmission infrastructure to support renewable energy is underdeveloped, creating potential for low grid resilience and 'orphan infrastructure' unable to connect into the network.	Critical	→
Lack of policy coordination is disbursing investment focus, leading to lower investment effectiveness and less efficient investment parameters.	Critical	→
Complex projects like hydroelectric dams are at risk of cost overrun.	High	↑
Consumer preference is changing type of energy demanded, with consumers preferring energy produced through renewables.	Medium	↑

Renewable energy connection to the grid is problematic

Energy represents a significant proportion of the national infrastructure pipeline, and has had a large increase in projects relative to previous years. Large-scale renewable hubs, which are a combination of 'green' energy sources, will form the majority of energy projects over the next five years.

There is a need for funding in grid infrastructure in support of in renewable energy assets. A significant and growing challenge limiting investment is achieving connection to the grid. Market proponents from northern Australia have noted this is particularly challenging in remote areas, which has created uncertainty for renewable energy developers through significant delays in connecting to the grid.

Similar issues are being experienced in other regions across Australia, including in the West Murray region nicknamed the "Rhombus of Regret" due to significant volumes of renewable projects attempting to connect to weak grid infrastructure. [78] In response to these challenges, policy and regulatory changes imposing output constraints, marginal loss factor reductions and the imposition of additional technical requirements on new generators has had further impact on the attractiveness of new renewable energy investment and general confidence in the sector.

Policy uncertainty is disbursing investment

Concerns have been expressed during industry engagement that current policy settings may not be sufficient to attract the level of the investment required to deliver additional renewable energy capacity to replace what will be lost via coal plant retirements.

Several states have set their own renewable energy generation targets. However, three out of eight states, including NSW, currently do not have a renewable energy target.

A lack of consistent direction in the transition of Australia's national electrical grid to renewables has therefore created investment uncertainty, disbursing investment focus in renewable energy assets.

Complex projects like hydroelectric dams are at risk of cost overrun

Data from Oxford Global Projects suggests that larger and more complex energy projects tend to go over budget as compared to smaller projects. When comparing Energy Asset Type from the same data set, solar projects were the most likely to meet the expected construction timeframe as compared to wind, hydro and thermal energy.

Solar and wind power projects tend to have the least cost variance and limited cost blowouts, while hydroelectric dams had a strong tendency to run over budget. Causes of hydroelectric dams cost overruns include greater development lead time and high upfront costs from engineering and construction requirements. Furthermore, market proponents have highlighted there is a knowledge gap due to limited experience with large scale hydroelectric development projects built in Australia in the past 30 years. There is additional complexity with selection of development sites and environmental impacts which may add to additional cost. This risk will likely to be reduced as there is potential for exponential growth in the industry and transfer of knowledge from historical projects in the long term horizon.

Consumer preferences are changing

There is a significant shift globally to focus on Environmental, Social, and Governance (ESG) issues with banks and equity investors indicating during market soundings that future energy investments will need to comply with clear ESG requirements and published trajectories. As a result, Australia has seen a substantial increase in renewable projects in the future pipeline across solar, wind power, hydro and hydrogen, in line with the global shift.

Water sector

Our analysis identified the following key risks related to the water sector:

Risks	0-5 year assessment	
	Rating	Trend
Lack of national policy framework creates uncertainty for investment.	Critical	→
Complex governance issues with dispersed authority creates decision uncertainty for delivering the infrastructure pipeline.	High	↑

Uncertainty for investment

Climate change is impacting rainfall patterns, driving reconsideration of dam infrastructure. There is also significant shift in the way water is managed with a push towards a more distributed model of water and recycling management and delivery, similar to the shifts that are occurring in the energy sector.

The uncertainty and the associated financial risk of predicting water demand can be reduced by allocation of financial risks and returns that enables public and private sector to earn risk adjusted returns. This can be done by:

- Policy instruments to recover cost of investment and improve financial performance (e.g. sanitisation and water supply tax).
- Identification of permanent revenue streams such as charges on drinking, waste and industry usage.

Complex governance issues

Complex governance issues with dispersed authority are creating uncertainty in delivering the infrastructure pipeline. This has most recently been seen within regional water infrastructure and the program of work around new or improved dam infrastructure across NSW.

Social infrastructure

Our analysis identified the following key risks related to the social infrastructure sector:

Risks	0-5 year assessment	
	Rating	Trend
Business cases for social infrastructure are frequently without adequate O&M funding resulting in significant unscoped financial burden for governments.	Critical	→
Business case guidelines favour economic infrastructure projects compared to social projects.	High	↑
Over-reliance on health professionals rather than care models is resulting in infrastructure not meeting needs.	High	↑
Demand shifts and population growth may result in school infrastructure becoming redundant well within the asset life.	Medium	↑

Inadequate funding analysis

Social infrastructure is a major part of the national infrastructure pipeline, with the majority of those projects being hospital redevelopments or new builds. Recent experience with the impact of COVID-19 has caused an important rethink for future operating requirements.

Unfunded operations for new social infrastructure is an ongoing risk. Unlike transport, for example, where project construction represents over three-quarters of the cost, cost to service social infrastructure generally outweighs the cost of construction.

Poor understanding of benefits

Market proponents have identified challenges in submitting successful business cases for social infrastructure due to difficulties in quantifying the intangible benefits of social infrastructure initiatives. Proponents have suggested that business case guidelines favour economic infrastructure projects compared to social projects.

Under-focus on care models

In the health sector, over-reliance on health professionals rather than care models is resulting in infrastructure not meeting needs. There is a growing risk associated with the development of new hospitals relating to the balance of input from clinical staff over the design and build of infrastructure being driven by the model of care required. Traditionally clinicians have had strong involvement in health infrastructure, particularly hospitals, however evidence indicates that the often these clinicians have been in the same role for decades and may not be aligned to new models of care that are being developed to support the best health outcomes for the community. The impact of this is high, with infrastructure being built that may not properly support the operational requirements of the future hospital given the lack of alignment to new care models being introduced. This can lead to re-development costs of the hospital over time. This can be mitigated through the careful consideration of the model for design for new hospital infrastructure to ensure it focussed on future care models.

Poor asset life planning

Demand shifts and population growth can result in low asset utilisation of social infrastructure, which is problematic as the benefit of social infrastructure is directly correlated to its use by people in communities. Given the difficulties in predicting the changing demographics of suburbs, there is an increased risk of benefit underruns in social infrastructure developments. Proponent have suggested the need for flexible infrastructure to cater to unpredictable shifts in demand.

Waste sector

Our analysis identified the following key risks related to the waste sector:

Risks	0-5 year assessment	
	Rating	Trend
Inadequate infrastructure development coordination for all stages of the waste cycle, from collection to aggregation to treatment, will cause cost overruns and benefits underruns.	Critical	→
Ineffective community engagement continues to lead to social license problems causing project delays and increased costs.	Critical	→
Low levels of market and regulatory readiness.	High	↑
Security and scale of supply for waste to energy projects.	Medium	↑

With fewer waste projects developed in recent years, this underscore key challenges with developing circular economy infrastructure quickly enough. The future waste pipeline will benefit from a stronger national and state focus on circular economy infrastructure, with policies that increase market demand

This sector includes infrastructure projects that utilise waste to energy technology, anaerobic digestion and other biomass solutions to divert landfill and to retain value from waste are underway. Future waste infrastructure projects will continue to focus on the development of waste to energy recovery, with multiple facilities being developed across Australia in coming years, including both energy from waste and waste processing facilities.

Waste projects are a small proportion of the national infrastructure pipeline, however the number of waste projects in development is larger than at any point in recent years.

Primary risks identified from previous projects were:

- Apprehension from communities towards new projects.
- Lack of cohesive government policy.
- Lack of sufficient investment.

While policy uncertainty still exists but is being addressed by governments, the two remaining primary risks remain critical for near-term waste infrastructure development in Australia.

Unclear planning and regulations, alongside a lack of community support is creating uncertainty within the waste sector which is driving risks.

Inadequate infrastructure planning and development

In December 2020, the Australian Parliament passed legislation to ban the export of unprocessed waste overseas. The Act implements a COAG ban on exports of waste plastic, paper, glass and tires, building impetus for developing circular economy infrastructure, alongside policies being developed by all Australian Governments. Nonetheless, Australia remains far behind other countries such as Norway and Denmark on rates of resource recovery. Historically inexpensive landfill levies and waste exports reduced economic incentives for long term investment in onshore facilities.

Immature end markets also mean there is a lack of demand for the use of recycled materials. And the oversupply of materials that followed the ban drove down the price of materials for recycling, to zero for paper and less than 25% of the previous value for plastics, creating a significant challenge for local councils to fund their recycling programs. The risk is that continuing market failures will lead to a shortfall in the scaled planning and development of critical infrastructure, including waste to energy but also aggregation and collection facilities. This would lead to the diversion of a far great amount of landfill, and is pronounced given the length of time such projects take to develop. For example, Kwinana took 10 years to develop.

Ineffective community engagement

Ineffective community engagement continues to lead to social license problems causing project delays and increased costs.

Waste projects have failed due to community opposition, which has led to significant planning delays and failure. For example, the ACT introduced a ban on waste incineration in response, after a proposal to build a W2E projects in Fyshwick was withdrawn.

Even Australia's first waste management success story, Kwinana, took 10 years to develop. While waste technologies have improved to capture emissions released from combustion of materials such as plastics, continued effective community engagement continues to cause investment risks pending social license resolution.

Low levels of market and regulatory readiness

The Waste Contractors and Recyclers Association of NSW encapsulated this sentiment regarding Waste to energy technology in Australia in their submission to APH 2019 Inquiry into Australia's Waste Management and Recycling Industries: [79]

> *"A lack of clarity around planning laws, outdated waste management laws and a poorly educated community has long stifled innovative solutions in energy from waste across Australia. The industry requires clearly defined, agreed and acceptable timelines for the processing of planning applications for new waste [and] recycling facilities. The industry also requires Government support to progress suitable, best practice applications."*

In relation to the development of recycling infrastructure, factors such as contamination and low-quality materials collection inhibit the investment signals required. To help manage this risk and drive change, there needs to be greater certainty in the requirements for recycled materials, allowing for certainly in new investment in manufacturing plants. This is likely to require a great level of coordination across all levels of government, including some pricing components such as the 10% VAT increase that the UK will add to any products with insufficient recyclable components Technology and operator inexperience were also factors in the Australian context, described by Recovered Energy Australia in their submission to APH 2019 Inquiry into Australia's Waste Management and Recycling Industries as *"...there are many challenges that are faced in bringing 'new' technology to market in Australia and at best it will be 5 years for similar projects to go from conception to operation, larger projects will take twice that time. During this period there are great risks from regulatory and commercial factors that can mean projects are delayed or abandoned."* [80]

Security and scale of supply for waste to energy projects

A major challenge to the development of commercial scale waste to energy projects in Australia is the ability to secure bankable, reliable quantities of waste for energy production and/or other byproducts. Facility operators may also need to respond to changes in feedstock volume or composition over time. Municipal waste is typically contracted by councils from a larger regional or national private waste service operators. These service contracts are low margin, high volume contracts with varying contract lengths. Analysis of successful energy from waste markets, such as Europe, highlight examples of local councils combining waste quantities to achieve scale, and locating projects close to major waste sources, and to points of grid connection.

Digital infrastructure

Our analysis identified the following key risks related to digital infrastructure:

Risks	0-5 year assessment	
	Rating	Trend
Poor understanding of existing utility infrastructure, leading to scope growth and cost overruns.	Critical	→
Underinvestment in network improvements.	High	↑
Lack of market incentives for regional and remote access.	High	↑
Declining returns on private investment and 'free rider' issues for 5G investment.	Medium	↓

Poor understanding of existing utility infrastructure, leading to scope growth and cost overruns

There is significant risk associated with a poor understanding of utilities infrastructure, for example poor asset mapping for telecommunications lines causing rework, scope creep and cost overruns in the implementation of new technologies. Such issues have already contributed to the cost base increases of installing the NBN, and are likely to be an ongoing issue as the 5G network is rolled out across Australia.

Underinvestment in network

Australia's next stage of digital infrastructure development will need to address gaps in network performance, and regional and remote connectivity. The Australian Government has set clear objectives in the context of its second stage of its NBN infrastructure rollout, to be a digital top 10 economy by 2030. While the NBN (revised) build was completed in 2020, FTTN and speed caps on packages have meant that the portion of Australians able to access promised internet speeds remains relatively small, especially in regional and remote areas.

There is an emerging risk of underinvestment in digital infrastructure relating to the fibre and 5G infrastructure required to deliver against the Government's goal of being a leading digital economy by 2030 – and questions of whether investments needed to 'future proof' the network are affordable. The impact of this underinvestment puts at risk a potential $90 billion in GDP growth over the 5 years to 2025 and $230 billion over a 10-year horizon and the ~250,000 jobs enabled by this digital transformation and the supporting competitiveness of organisations. [81] Additionally, underinvestment in digital infrastructure is likely to impact through greater cyber security attacks, limiting the ability to combat them. This is partially being mitigated by the investment in future fibre to premise roll-outs by the NBN and state based investments, however this is unlikely to ensure complete coverage for all Australians, particularly those in remote areas and smaller towns.

Lack of market incentives

Significant issues remain in rural and remote areas for mobile and broadband services. Geography also matters. In rural and remote settings, the cost of providing telecommunications infrastructure increases and the returns reduce as population densities decline. While Australia's mobile footprint includes over 99% of the population (at their premises), it covers only one-third of total landmass, meaning little or no service for those working and travelling in rural and remote areas. [82] With introduction of 5G this gap will be wider as the new rollout prioritises high density/greater return areas over rural areas

Declining returns

There is a growing risk to the expansion of the 5G network in Australia relating to declining profits from investors from the network. Experts indicate that return on capital is now around 6-8% and declining, compared with double digits historically. The 5G network requires approximately 10x the density of infrastructure towers compared to 4G requiring significant investment by mobile operators. The impact of this risk manifesting could be significant, particularly for regional and remote areas where the return on investment for mobile providers is harder to achieve. This will adversely impact businesses unable to access applications and tools built for 5G speeds as well as communities who may need to access education or health services using the newer technology.

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