

Queensland's Renewable Future

Investment, jobs and skills

Full Report

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CEO's Foreword

Queensland is on the cusp of a renewable energy boom. The momentous amount of infrastructure required to reach domestic net zero by 2050 has been supercharged by a prospective hydrogen industry – one that could serve both the state's domestic needs and those of large export markets.

The biggest challenge in delivering the boom could be the scale of the construction workforce required. Now is the time to start thinking strategically about the long-term impact this future could have on labour and skilled trade provision. Then we can plan with eyes wide open to meet the challenge.

The purpose of this report is to estimate the size of that challenge – what could be required of Queensland's construction workforce from the early 2020s to 2050 to deliver the renewables boom?

To best answer this question we combined near-term and long-term streams of research. Take the more substantial long-term stream first. We commissioned CSIRO to model three possible renewable futures for Queensland out to 2050, mapping out the energy requirements needed for both domestic net zero and different sized hydrogen industries, and the associated capital expenditure (CAPEX) pathways. From these the demand profile for construction labour was estimated.

Headline findings over this long-term period include the following:

- Up to 26,700 construction workers from the early 2020s to 2050 could be required to realise Queensland's renewables boom
- This follows a CAPEX requirement approaching \$13.9 billion annually. This is what's required to meet the state's net zero 2050 target while building a strong hydrogen industry serving both domestic and export needs
- More than half of these construction jobs (13,800) would be in regional Queensland, namely the central and northern parts of the state

The hydrogen industry has a big role to play in this outlook. Up to 18,500 construction workers could be required to build out just this part of our renewables future through to 2050 – provided the fuel sees production cost breakthroughs, along with strong domestic and international uptake. An additional 8,200 construction workers will be needed to build out the non-hydrogen renewable electricity infrastructure to reach net zero in Queensland by 2050.

Most construction jobs emerging across the boom (around two thirds) will be related to new renewable generation capacity (ie solar, wind and battery storage). A grid capacity up to 12 times larger than the early 2020s is needed by 2050 according to our higher end estimates. This astronomical scale-up is because renewable power is critical to both decarbonise our domestic electricity network and produce clean forms of hydrogen, whether for use onshore or shipping overseas.

Our near-term analysis – a census of the state's already existing renewable projects pipeline – suggests that Queensland is already tracking well against these ambitions. We identified a record \$20.8 billion in projects are already confirmed for delivery by 2025. This could increase grid capacity by around 70% over the near-term, driving demand for 4,600 construction workers.

Brett Schimming
Chief Executive Officer



***Is Queensland
ready for the
renewables
revolution?***

1 | Is Queensland ready for the renewables revolution?

To answer this question we must first look at what underpins Queensland's imminent renewable energy boom. The 2030 state target of 30% less emissions is under a decade away. Promisingly, solar and wind project investment has doubled over the last few years. We estimate \$20.8 billion of green energy projects are already underway or confirmed to commence between 2021 and 2025 – the highest value for a 5 year period ever. Around 20% of Queensland's major project investment portfolio is now in renewables. The level of enthusiasm is unprecedented.

Yet out to 2050, the boom grows headier still. The twin prospects of a clean hydrogen industry and Queensland's ambition to be carbon net zero by 2050 carries unprecedented demand for renewable infrastructure. Projected capital investment will be in order of tens to hundreds of billions of dollars, catalysing construction activity on the scale of the largest industrial deployments ever undertaken in Australia. Metaphorically, Queensland is being asked to 'sprint a marathon' to deliver our renewables future.

One area of risk to this outlook concerns the size and availability of the construction labour force required. Any capital expenditure (CAPEX) phase on this scale carries significant construction labour demand, with workers often required in remote locations with thin labour markets. There are clear parallels with the significant labour demands catalysed by the mining and LNG build-out of recent years. The industry and broader economy endured substantial dislocations and disruptions as human resources were hurriedly mobilised, redeployed and trained to meet unanticipated demand. Labour costs escalated astronomically putting shareholder appetites at risk (Reid and Cann, 2016).

This time it can be different. The scale up of future renewables-related construction activity will require workforce planning frameworks and deployable skilling solutions to succeed. Now is the time to start thinking very carefully about the long-term impact this future could have on metropolitan and regional markets for labour and skilled trade provision. The paradigmatic reason being much of Queensland's future competitiveness in hydrogen export to markets like the Asia-Pacific is predicated on affordable labour costs pegged to long-term wage stability. Losing control of these costs through unplanned escalation, labour bottlenecks and skills shortages could erode our international competitiveness, undermining a core pillar of the boom.

“Building the infrastructure needed for the renewables boom will rely on strategic workforce planning to succeed. Now is the time to start thinking carefully about the long-term impact this future will have on labour and skilled trade provision.”

Assessing the impact of a renewables boom on construction labour demand

In this spirit, the ultimate purpose of this report is to engage deeply with one fundamental question, what will be required of Queensland's construction workforce from now to 2050 to deliver the renewable energy boom? To get there, we firstly map out expected installed capacity and CAPEX requirements across a range of time periods, scenarios and geographies. From this we estimate construction labour demand. Above all, the aim is to better position industry and policymakers to make evidentiary decisions about the types of jobs, skills and training responses needed to secure Queensland's prosperity throughout the energy transition.

Engaging with this question is predicated on understanding perhaps the most inherently complex and uncertain phenomena of all – the future. It's conceivable that as we look from the present through to 2050 the amount we can predict with any level of certainty recedes with each passing year. To best account for this, the project has been conducted over two separate time scales, which in turn carry different methodologies and leverage different degrees of collaboration with industry experts. These are outlined in more detail below.

Assessing the current pipeline of renewable energy projects in Queensland

Chapter two leverages our newly developed Queensland Renewable Energy Projects (QREP) Database to assess the near-term implications of the renewables boom.

QREP is a census of all major renewable energy projects currently in the pipeline across Queensland and includes all announced hydrogen projects. This enables direct measurement of CAPEX and the installed capacity scheduled in the existing pipeline. QREP data is then used to forecast construction labour demand. This pipeline analysis framework is well-suited to near-term time horizons where a degree of real-world certainty is known across a given portfolio of projects.

The chapter draws on two partnerships. Renewable project listings purchased through a collaboration between CSQ and Green Energy Markets – a consulting firm providing trusted green energy project intelligence to government. Workforce modelling parameters were purchased through a collaboration between CSQ and Turner and Townsend – a professional services company specialising in labour modelling for construction projects, including renewable energy projects like wind, solar and clean hydrogen. In both cases CSQ performed independent analysis of the results.

Assessing Queensland's renewable energy outlook to 2050

Chapter three uses scenario modelling to assess the longer-term implications of the renewables boom. The core focus was measuring variation in the size of the state's potential future hydrogen industry. CSQ consider this industry the 'game changer' for renewable infrastructure growth and construction labour demand over the longer-term in Queensland.

Three scenarios were modelled that vary the size of the export and domestic use of hydrogen for the state through to 2050. Scenarios were overlaid with the projected base renewables required to drive the other major pillar of the boom – our non-hydrogen domestic decarbonisation agenda (ie net zero by 2050). CAPEX and installed capacity requirements were key outputs and from these construction jobs were estimated. Scenario analysis of this kind is suitable over long-term time horizons in highly uncertain environments.

CSQ collaborated with industry specialists at CSIRO (Hydrogen Industry Mission and Energy Transition Pathways) on development of the three scenarios. CSQ then commissioned the scenario modelling and estimates of the number of construction jobs that may be required in future. CSQ conducted independent analysis and contextualisation of the results.

1.1 | Context of Queensland's renewable energy boom

What's driving Queensland's renewable energy boom?

Queensland is in the race to decarbonise yet the transformation required is profound. An unprecedented amount of renewable power is needed for Queensland to move towards a net zero economy by 2050.

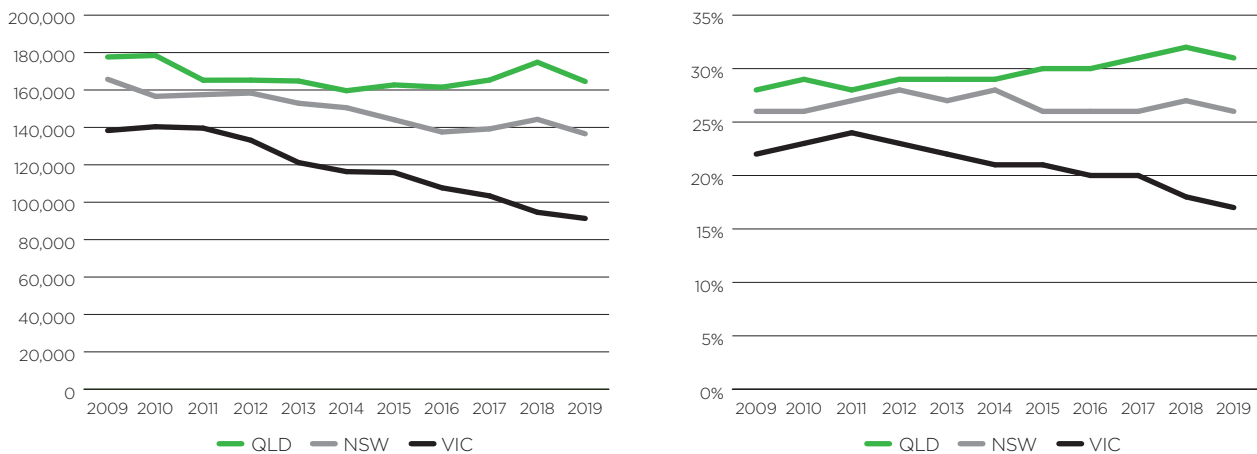
Queensland's emerging renewables boom is the result of clear forces. Climate change is driving a global economic transition. Nations are seeking to rapidly reduce carbon dioxide (CO₂) emissions to mitigate climate-related risks. The scientific consensus is to limit global temperature rises to between 1.5°C to 2°C (above pre-industrial levels).

This goal requires global net zero CO₂ emissions by 2050 (the 2015 Paris Agreement the first global deal for national commitments). That is, the complete removal of CO₂ – the backbone of our industrial age energy system and modern economy – in around three decades. Such deep decarbonisation requires a fundamental but rapid transformation of our energy ecosystem.

Nations and jurisdictions throughout the world have quickly mobilised around net zero ambitions and climate-related policy initiatives. By 2022, national net zero pledges worldwide covered around 96% of global CO₂ emissions (Clarke et al, 2022). In this context, Queensland announced a net zero emissions by 2050 target in 2017. This was in conjunction with an interim goal for 30% reduction in emissions by 2030, and 50% renewable energy penetration by 2030 (Queensland Government, 2021a).

This means Queensland is in the race to decarbonise. This is a meteoric task for any advanced economy, but this state in particular. According to the State Greenhouse Gas Inventory (2019), Queensland remains the top carbon emitting state in Australia accounting for around 31% of national emissions (**Figure 1a and 1b**). The generation of electricity from fossil fuels accounts for the largest share of these emissions, at around 30% (Queensland Government, 2020).

Figure 1a and 1b: Top three CO₂ emitting states in Australia, 2009-2019, (a) Emissions in gigagrams (b) % of Australian emissions



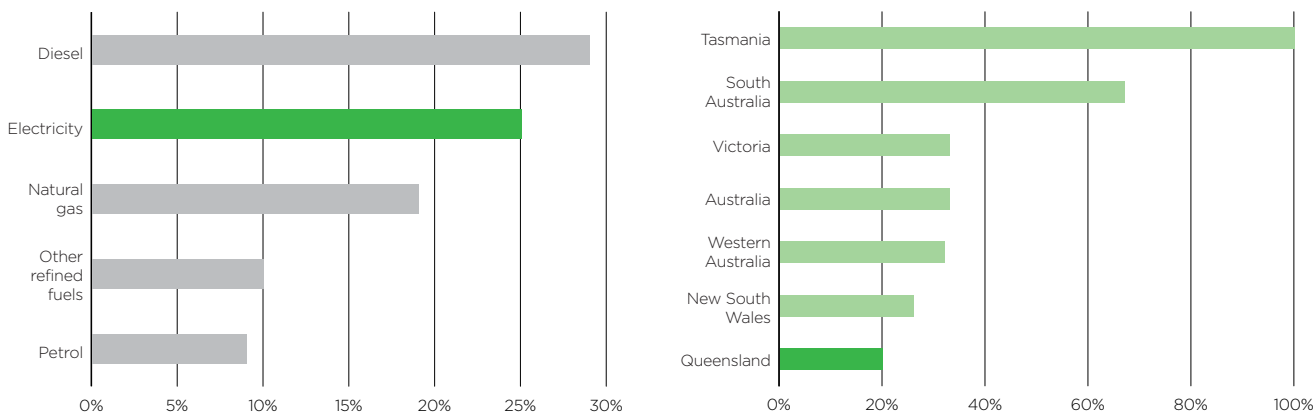
Note: 2019 the most recent year data available.
Source: State Greenhouse Gas Inventory (2019).

The key question is how to achieve net zero in this context. There are many legs of the journey. The first part is the fundamental shift to a carbon-free electricity system as the basis of domestic economies (ETC, 2021a). This part really has two movements – the direct electrification of traditionally fossil fuel sectors (eg moving to electric vehicles) and the equally fundamental shift in base electricity supply from fossil fuels to renewable power (eg solar and wind). Collectively, this could remove around up to 70% of emissions by 2050 (estimates vary) and account for the largest push towards net zero relative to later steps (Clarke et al, 2022).

The transformation required in Queensland is profound. Currently around a quarter of our economy is directly electrified, close to the average of all OECD countries (Figure 2a) (IEA, 2022). Queensland also has the lowest proportion of renewable power penetration in Australia (Figure 2b).

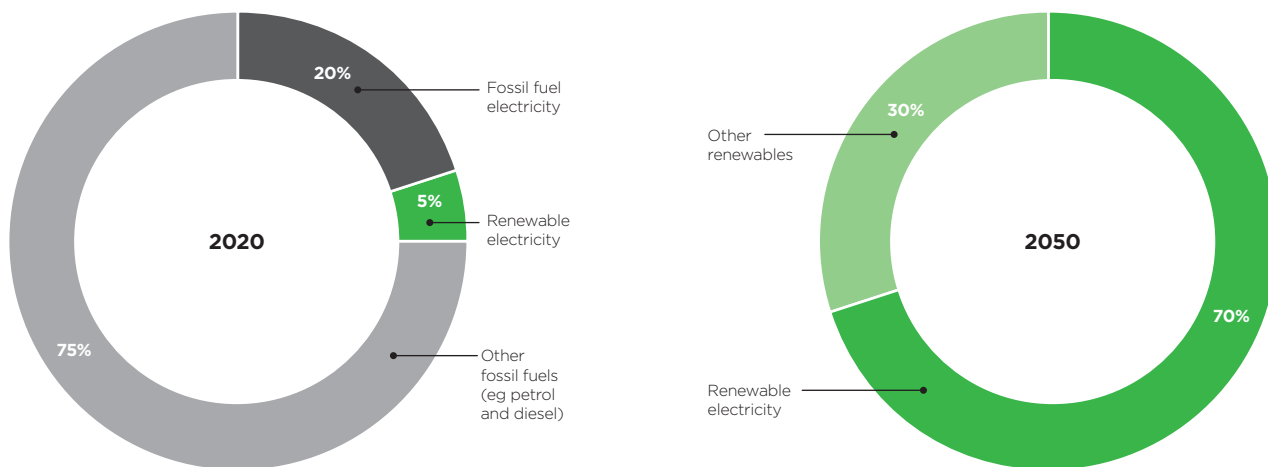
Assuming Queensland remains in line with global projections required for net zero (IEA, 2021; ETC, 2021a), direct electrification would need to double or more from around 25% today to up to 70% by 2050. Simultaneously, almost all that electricity would need to be sourced from renewables. Figures 3a and 3b provide a simplified view of what this could mean for Queensland’s energy use from 2020 to 2050.

Figure 2a and 2b: Proportion of direct electrification (2020) and renewable energy uptake (2022) in Queensland



Note: Direct electrification measured at point of end use for top five uses (and account for 92% of total energy used); renewable energy as proportion of total power generation. Source: ABS (2020); CEC (2022).

Figure 3a and 3b: Final energy use by source, Queensland, 2020 and 2050



Note: 2050 is indicative and based on a net zero scenario using ETC (2021a; 2021b) and IEA (2021). 'Renewable electricity' of 70% and 'Other renewables' of 30% based on ETC (2021a; 2021b) 2050 Indicative Scenario. A marginal proportion of fossil fuel electricity with CCS may also be used in future (not pictured). Source: ABS (2020), CEC (2022); ETC (2021a); IEA (2021).

1.1 | Context of Queensland's renewable energy boom (continued)

This transition pathway to net zero by 2050 has ultimately kick started Queensland's renewable energy boom. Vastly more electrification is expected coming from a vastly higher share of renewable supply. All from a relatively low base in a state with comparatively high emissions. A triple decade demand profile for the requisite renewable energy infrastructure (mainly wind and solar assets) is the result. As is the demand for construction labour to deliver this whole new generation of green energy projects.

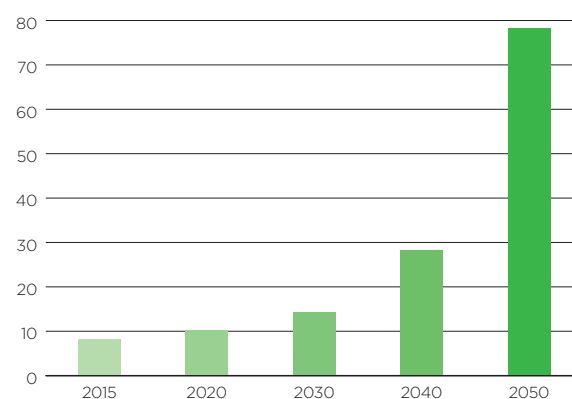
Unlike many other regions of the world Queensland has the natural capital required to unlock these renewables domestically. The state has some of world's best-endowed factors for large-scale renewable uptake, including extraordinary sunshine, wind and land resources (Blakers et al, 2019). Queensland experiences some of the best solar insolation in the world, the headline marker of solar PV potential (Burke et al, 2022; Sharma et al, 2021). The renewable boom awaits.

Clean hydrogen and Queensland's net zero goals

Two major questions remain. How could the remainder of net zero be achieved in Queensland? How could countries without this state's physical renewable potential reach net zero? The short answer to both is clean hydrogen. There is much recent hype and hyperbole around this clean fuel. Given its quick emergence - more than 30 governments worldwide have released national hydrogen strategies in the last two years (Clarke et al, 2022) - its place in a net zero future, and profound role in Queensland's renewables boom, requires some explanation.

The hype is not surprising, and much of it is well-founded. Beyond renewables and direct electrification it's clear that a proportion of emissions still needs to be removed (the remaining 30% from our estimates above). Hydrogen has quickly emerged as a critical fuel required for this second leg. Yet many countries have even more ambitious hydrogen plans. Japan and South Korea, for example, envision so called 'hydrogen economies' or 'hydrogen societies' where the fuel forms a larger and more primary part of their net zero plans (Government of Japan, 2017; Burke et al, 2022). This means some of the largest emitting economies in the world are considering hydrogen as their core net zero tool. As a result of this collective bullishness, global demand for the fuel has quickly surged, with estimates predicting a seven to ten-fold increase (**Figure 4**).

Figure 4: Projected global demand for hydrogen from 2015 to 2050, in exajoules



Note: In a > 2 °C global warming scenario from 2015 to 2050.
Source: Statista (2022).

What is clean hydrogen?

The fuel-of-choice for the second leg of Queensland's domestic net zero and a potential export to other countries to meet their decarbonisation goals. Two types of hydrogen come under the 'clean hydrogen' banner:

- 'Green' hydrogen is produced from 100% renewable energy (ie wind and solar) and is a zero carbon fuel.
- 'Blue' hydrogen is produced from fossil fuel sources like natural gas but uses carbon capture and storage technology (CCS) to achieve near zero emissions but is not completely carbon neutral.
- A major global market has emerged for clean hydrogen, which can be shipped and traded globally as a low carbon fuel.
- Hydrogen derived from fossil fuels has a long history. But it's emergence as a decarbonisation fuel has occurred because much cleaner types can now be produced.
- Cheaper renewable power and improved CCS technology underpin the emergence green and blue hydrogen respectively.

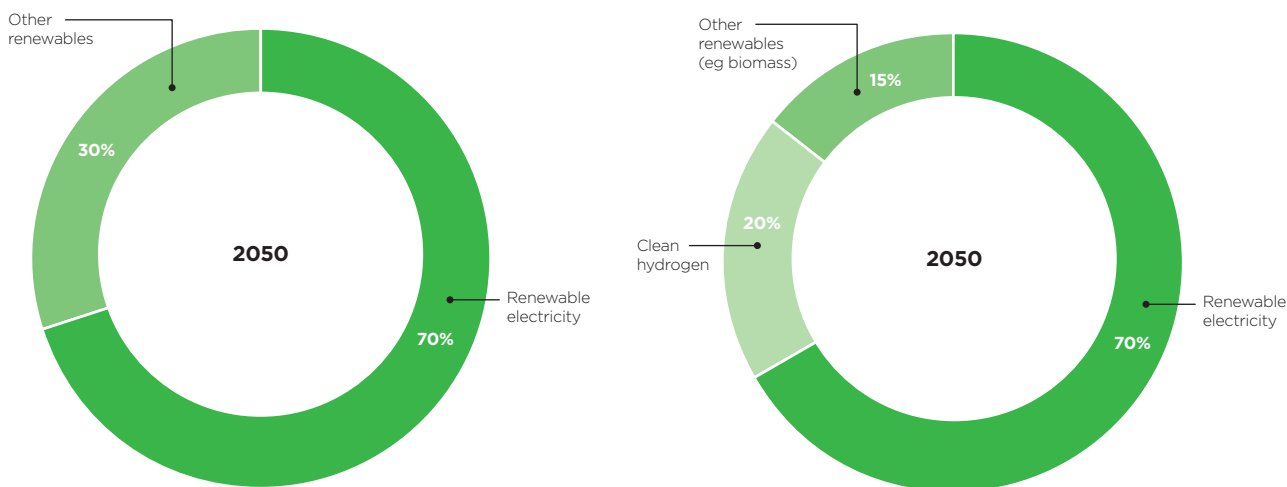
Hydrogen and domestic net zero

Clean hydrogen has at least two critical roles in a net zero future – one domestic and one global. Take domestic first. Even in places like Queensland, which have abundant renewable resources to power large-scale direct electrification, there remain parts of the economy where CO₂ is hard to abate using these methods. Other clean energy vectors are needed in this context if true net zero is to be achieved (IEA, 2019).

Clean hydrogen has emerged to fill much of this gap. Prospective use-cases include helping to reduce emissions from natural gas (by blending with hydrogen), transport (hydrogen-powered heavy vehicles and shipping, hydrogen-based aviation fuel) and manufacturing (high temperature industrial heat, steel production). Hydrogen also shows promise as a critical energy storage solution, alongside batteries, to ensure power supply reliability in the vastly larger renewables supply networks foreseen in future (AHC, 2021).

While hydrogen’s precise role in these hard-to-abate applications is inherently uncertain, sources suggest its use could remove an additional 15-20% of CO₂, although some suggest up to 34% (Clarke et al, 2022; ETC, 2021b; BNEF, 2020; Sharma et al, 2021). Returning to our charts from Figure 3b above, a 15-20% impact in a net zero 2050 future is shown (**Figure 5a and 5b**). The fuel is evidently shaping up as the fuel of choice for the second leg of domestic net zero in places like Queensland. This is driving the prospect of a clean hydrogen industry in the state, with the associated infrastructure adding another whole stream of demand to the renewables boom.

Figure 5 and 5b: Projected final energy use by source, Queensland, 2050, without and with hydrogen



Note: 2050 is indicative and based on a net zero scenario using ETC (2021a; 2021b) and IEA (2021). Clean hydrogen also includes hydrogen based ammonia and syngas. Source: CEC (2022); ETC (2021a); IEA (2021).

1.1 | Context of Queensland's renewable energy boom (continued)

Hydrogen and global net zero

Hydrogen's role in global net zero could be even larger. Clean hydrogen has the unique ability to be shipped and traded globally as a low carbon fuel (AHC, 2021). Import demand has emerged in countries without the natural capital inputs (mainly land, wind and solar) required to produce their renewable electricity or hydrogen domestically (like Queensland can). A major global market has therefore emerged for hydrogen, with distinct importing and exporting nations on either side of the ledger. Clarke et al (2022) estimates 30% of global clean hydrogen volumes have the potential to be involved in long cross-border trade, higher than for natural gas.

The resource therefore offers the prospect of a multi-decade and multi-billion dollar export play for renewables rich places like Australia, with Queensland at the forefront (ACIL Allen, 2018). The release of both the Commonwealth and Queensland Government hydrogen strategies clearly identified this extraordinary prospect (Commonwealth of Australia, 2019; Queensland Government, 2019). The race is on to become the critical upstream supplier of clean hydrogen to many parts of the world. The Asia-Pacific region in particular is promising, with Japan and South Korea the most likely destinations for Queensland (Burke et al, 2022). Parts of Europe, like Germany, are also increasingly possible (Van Leeuwen, 2022).

A pivot to clean hydrogen in the Asia-Pacific alone could catalyse extraordinary demand for the fuel. Japan and South Korea have the fifth and eighth highest CO₂ emissions globally (World Population Review, 2022). Energy imports currently account for an estimated 93% and 81% of total energy used in each country respectively (Global Economy, 2022). Both countries have ambitious net zero 2050 targets that see a primary role for hydrogen. There is large scope for both countries to become clean hydrogen importers longer term to reach net zero (Clarke et al, 2022).

Building a hydrogen export industry in Queensland

Australia – and Queensland in particular – is uniquely positioned to capture some market share. The largest proportion of natural gas and coal imports for Japan, for example, already come from Australia, with much of that from Queensland (Government of Japan, 2016). These flow via long established trade partnerships. Queensland's profile in South Korea's energy import portfolio is similar (Argus Media, 2021). Simply put, these existing trade partnerships could become 'green' in future with Queensland's clean hydrogen replacing the fossil fuels we already provide.

On the price side, recent modelling shows it is more cost-effective for Japan to import hydrogen from our shores than to produce in-country (Clarke et al, 2022). Parts of Northern Queensland are forecast to be the most cost-effective place to produce hydrogen in Australia (Percy, 2022). And Australia itself has been identified as having one the lowest hydrogen production costs in the world (Clarke et al, 2022).

Constructing a hydrogen export industry in Queensland – especially one focused on green hydrogen – introduces a profoundly larger prospect than just a domestic industry. It may even dwarf all the infrastructure required for Queensland to reach domestic net zero. Quantifying and conveying this point is one of the most critical goals of this report. An export industry changes the renewables game completely for Queensland – ratcheting up the boom to level not fathomable only a few years ago. There are several overlapping reasons why.

“Constructing a hydrogen export industry in Queensland – especially one focused on green hydrogen – would be a game-changer for renewables in the state. It could supercharge the already large renewables boom on a monumental scale.”

Much of the scale is to do with a series of compounding factors along the supply chain (not to mention the need for hydrogen production and storage assets). These factors include:

- Green hydrogen is created via 100% renewable electricity (ie wind and solar)
- It takes a relatively large amount of renewable energy to create a unit of green hydrogen
- The size of the export market is extraordinarily large
- An unprecedented amount of renewable electricity is already earmarked for Queensland to reach domestic net zero

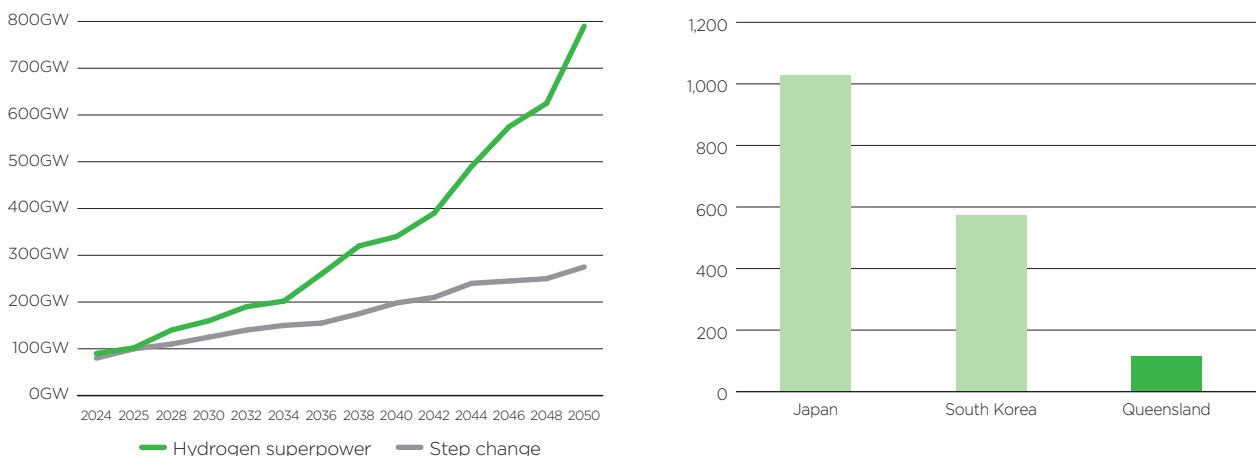
The implications for scale and growth are hard to grasp. As a proxy, in their so called 'hydrogen superpower' scenario, the Australian Energy Market Operator (AEMO, 2022) estimate the national electricity grid would need to grow eight times larger in capacity by 2050 to support an export-focused hydrogen industry in Australia (Figure 6a). This is in addition to a tripling in its size to reach net zero in Australia. So 11 times larger overall. Installed renewables would need to be 37 times higher than now just for hydrogen. Applying these trends to Queensland's power generation capacity, and the associated energy project pipeline required, shows how the development of a hydrogen export industry could momentarily supercharge the already large renewables boom.

This monumental scale has a lot to do with the potential size of the export market. Japan and South Korea's current CO₂ emissions are nine and five times larger than Queensland respectively (Figure 6b). In theory, assisting Japan alone to decarbonise by only 10% would be equal to decarbonising the whole of Queensland's economy. The development of clean hydrogen technology means much larger economies are looking to places like Queensland to help achieve their own ambitious climate policies.

Ultimately, we must remember that the possibility of a hydrogen industry – especially an export-orientated one – has emerged at the same time as the drive towards net zero in Queensland. Even without hydrogen, Queensland would be undergoing an unprecedented renewables boom to decarbonise. This boom has now been supercharged by the hydrogen prospect with two channels driving the state's renewable energy boom – radically more domestic electrification from renewable power and the use of hydrogen onshore or for export. Both are essentially predicated on the same infrastructure – large-scale renewable energy. This means an unprecedented pipeline of energy projects are about to be deployed in Queensland, both in the near-term and long-term. This will catalyse significant construction labour demand across the state.

It is quantifying this pipeline in the near-term, and the associated labour demand, that we now turn.

Figure 6a and 6b: Forecast capacity required for two AEMO scenarios; Metric tonnes of CO₂ emissions for Japan, South Korea and Queensland in 2020



Note: 'Step change' and 'Hydrogen superpower' are two of the four scenarios developed by AEMO that cover a broad range of plausible trends and developments related to the NEM and the energy transition. See AEMO (2022) for more about all four scenarios. Queensland emissions calculated based on ~30% proportion of Australia's total emissions. Source: Reproduced from AEMO (2022 pp.34); IEA Data Services (2022a).



Current pipeline of renewable energy projects in Queensland

2 | *Current pipeline of renewable energy projects in Queensland*

In this section, we use our newly developed Queensland Renewable Energy Project (QREP) database to analyse the size, likelihood and geography of the current renewable energy project pipeline in Queensland. QREP is the result of a census of major renewable energy projects conducted for this project (Chapter 5 contains the QREP methodology). Almost all projects in the database are scheduled to start at some point prior to the end of 2025.

We pay specific focus to the emerging hydrogen projects pipeline. A comparison of the rapid growth of the renewable pipeline to previous years is also offered. We then use QREP to model the construction workforce demand arising in the near-term, including for specific construction trades.

2.1 | *Major findings summary*

Pipeline of renewable energy projects: the boom has begun

- Queensland's renewable energy projects pipeline is accelerating with an estimated \$73.4 billion book of work over 215 projects – the boom has begun
- Around \$20.8 billion of this is already underway or confirmed to commence by 2025
- Half of the current pipeline is large-scale solar infrastructure
- Regional Queensland is home to more than 90% of the near-term pipeline of renewable energy projects
- The pipeline could foster a three-fold increase in renewable power generation for the state by 2025 and grow the electricity grid from 16.2GW to 27.2GW
- 20% of Queensland's major construction pipeline is now in renewables-related infrastructure – up from only 5% a few years ago
- Solar and wind project investment has doubled over the last five years
- Hydrogen projects have scaled up to around 8% of the renewables pipeline, with half of the 35 projects announced in 2021 alone
- The hydrogen projects pipeline is valued at \$5.7 billion and could enable 7.5GW of electrolyser capacity by 2030
- Queensland hydrogen projects pipeline includes some of the largest hydrogen projects announced in the world to date

Thousands of construction jobs needed: 90% in regional Queensland

- Renewable projects already confirmed for delivery in the pipeline could require 4,600 construction workers to 2025 – and up to 10,300 at peak
- Around a third of workforce demand will be for solar projects
- An estimated 90% of construction labour demand will be in regional Queensland
- Parts of Queensland – like the Darling Downs, Mackay and Central Queensland – are already developing a green energy niche in solar, wind and hydrogen respectively – dictating local channels of specific construction labour
- Highly skilled trades and technicians could account for one in five roles (22%) across the renewable construction workforce – but this could increase to almost 30% for hydrogen projects

2.2 | Unpacking the pipeline

Queensland's renewables pipeline: by status

Queensland's renewable energy projects pipeline is accelerating with an estimated \$73.4 billion book of work over 215 projects. The journey towards net zero has begun.

Conducting a census of the current pipeline of renewable energy projects in Queensland identified 215 projects in total. All projects with a known start date were scheduled to commence construction before the end of 2025. If all these projects went ahead in this timeframe this would equate to a \$73.4 billion capital investment in renewable infrastructure across the state.

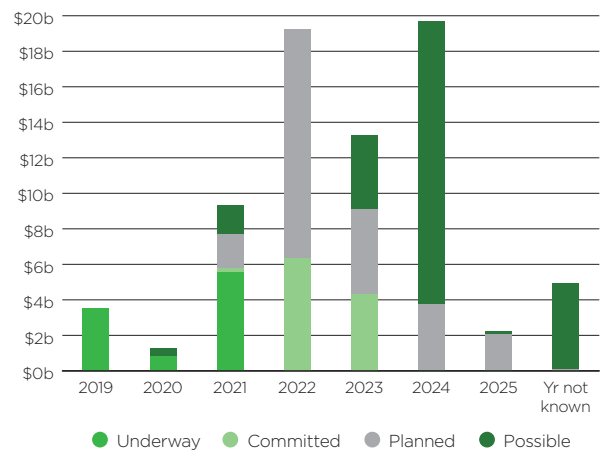
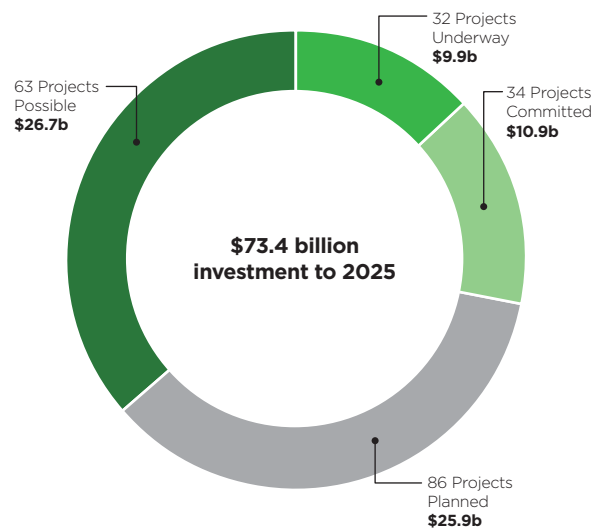
It's unlikely all these projects will eventuate in these timeframes or indeed at all. Some will be deferred, some modified and some re-sized. Others will be abandoned altogether. That said, many will move through to construction as time progresses. Taken at face value, the \$73.4 billion pipeline represents a real-world measure of the unprecedented enthusiasm for renewable energy projects in the state.

Yet, it's critical that projects in the pipeline are classified clearly to separate those projects most likely to go ahead from those less so. We do this by assigning QREP projects one of four statuses (see Chapter 5 for the criteria used for each stage). Projects with a status 'underway' or 'committed' are highly likely to progress and provide the most realistic measure of future construction activity. 'Planned' and 'possible' projects have a lower probability of moving through to construction, though this does not mean there is no chance.

Figure 1a below shows that underway projects (\$9.9 billion) and committed projects (\$10.9 billion) together account for 28% of the renewable project pipeline and constitute \$20.8 billion worth of confirmed construction work. The renewables boom has clearly begun. The remainder of the pipeline is either planned or possible (\$52.6 billion). Even with such a strong start, further potential upside for the renewables boom is also clear. If only half of these latter projects went ahead the pipeline would more than double.

Figure 1b shows the project pipeline by year and status. It shows the importance of time on status. As we move through future years, the prospect of planned and possible projects moving into construction grows. Some upside potential is therefore incredibly likely.

Figure 1a and 1b: Renewable project pipeline, Queensland



Note: By project commencement year and project status.
Source: QREP Database (CSQ, 2022). Last updated 15 December 2021.

Queensland’s renewables pipeline: by energy sector

Half of Queensland’s renewable energy project pipeline is large-scale solar infrastructure projects (50%) – the highest of any group.

Dividing the renewable pipeline across energy sectors revealed that around 81% of projects (regardless of status) were either solar or wind (\$59.0 billion). The third largest group was the nascent hydrogen industry, already accounting for around 8% of total project value (see **Figure 2a**).

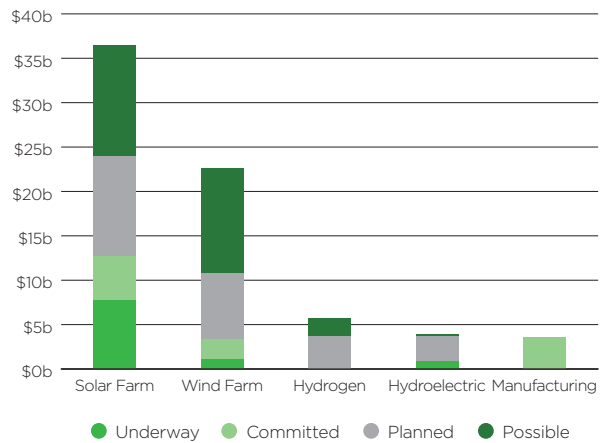
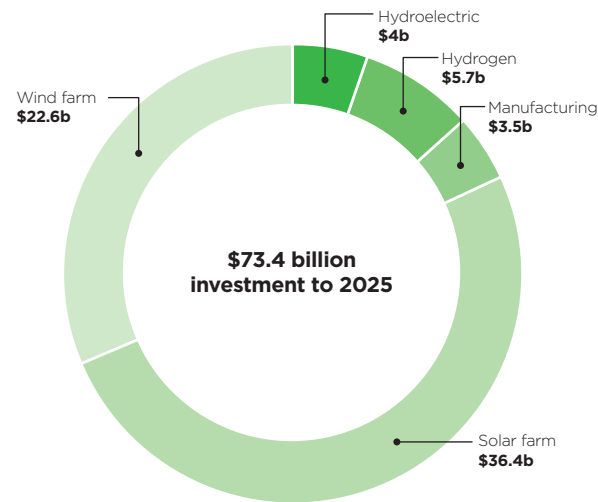
Solar infrastructure is by far the largest sector of the current renewables pipeline. These projects account for 50% of all projects – valued at \$36.4 billion in total across 120 projects. Every second renewable project deployed in the state in the near-term could be a solar project. This reflects Queensland’s world-class natural solar potential (Burke et al, 2022). Almost a third of these projects are already underway or committed – a strong sign of momentum in the solar sector. Solar make up 50% of the total pipeline, but account for close to 80% of underway projects.

Wind infrastructure then accounts for around a third of renewable projects – valued at \$22.6 billion in total across 33 projects. Much less of this sector is underway or committed at present, only around 15%. A stunning 85% of wind projects remain at the planned or possible stage, providing substantial upside to this sector in future (see **Figure 2b**).

Close to \$5.7 billion of hydrogen infrastructure has been announced to date across 35 projects and constitutes an impressive 8% of the project book. However, close to all these projects (98%) remain in the planned or possible stage at present. This makes sense given the infancy of this industry. We focus exclusively on the hydrogen projects pipeline the following Section 2.3 of this chapter.

The remaining share of the project pipeline is constituted by hydroelectric power and manufacturing projects – accounting for around 5% of projects across all statuses respectively. Manufacturing in the renewables context refers to the construction of facilities that will in turn manufacture renewable technologies for the industry at large – eg hydrogen electrolyser factories and lithium battery manufacturing hubs.

Figure 2a and 2b: Renewable project pipeline, Queensland



Note: Some sub-sectors of the renewable energy pipeline have been excluded due to smaller values (battery storage, transmission, biogas). Solar and wind projects are large scale projects, doesn't include domestic solar installation. Source: QREP Database (CSQ, 2022). Last updated 15 December 2021.

2.2 | Unpacking the pipeline (continued)

Queensland’s renewables pipeline: by region

Regional Queensland is home to more than 90% of renewable energy projects in the pipeline – with hotspots in Central Queensland, Mackay and the Darling Downs.

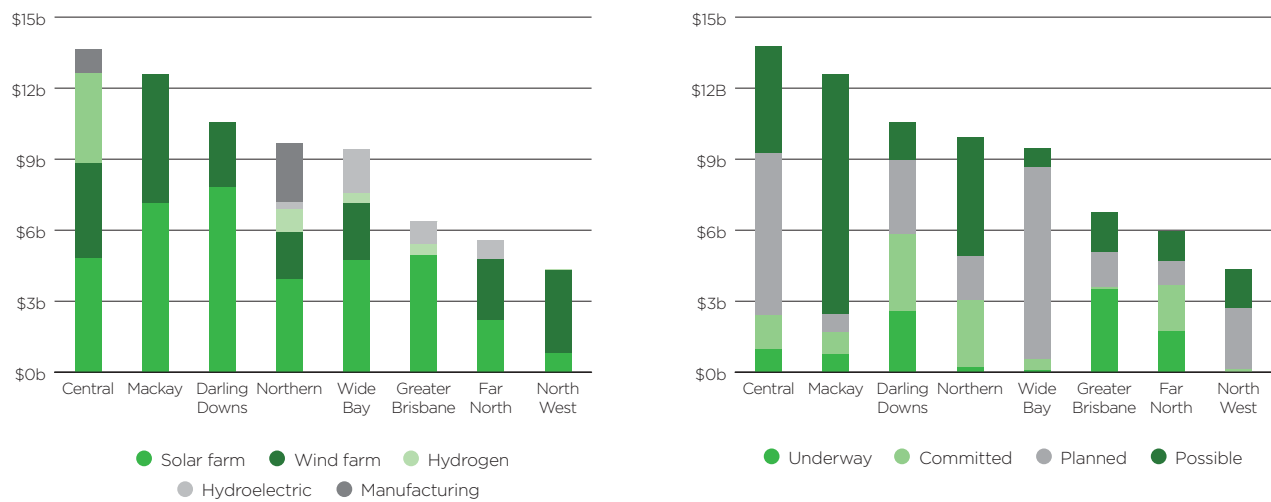
A major finding generated by our pipeline analysis is that the lion’s share of renewable energy infrastructure will be built outside the South-East Queensland corner. Currently 190 (\$66.6 billion) of the 215 total renewables projects (\$73.4 billion) in the pipeline are across regional parts of Queensland – around 90%.

Figure 3a shows that while several regions will benefit from Queensland’s renewable energy boom, certain regions will dominate. Central Queensland (\$13.8 billion), Mackay (\$12.6 billion) and Darling Downs (\$10.6 billion) account for an estimated 50% of the projects in the pipeline when combined (under all statuses). Central Queensland alone accounts for close to 20% (or one fifth) of the state’s renewables boom by value.

This dominance reflects a unique profile of renewable energy projects in these regions – which suggests early competitive advantage for certain jurisdictions in the renewable industry. Central Queensland leads due to diverse project mix across solar, wind, hydrogen and manufacturing infrastructure. Mackay accounts for the largest share of the state’s wind projects (close to 25% of all wind projects are in the region), while the Darling Downs comprises the highest solar share across the state (21% of all solar projects).

Figure 3b shows the extent to which these findings depend on project likelihood. The vast share of projects (around 85%) in both Central Queensland and Mackay are only at planned or possible at this point. If only underway and committed projects were considered, the most dominant region for renewable energy projects at present would be the Darling Downs. The highest share of solar projects is in this region, and as mentioned, a high share of solar projects is either underway or committed.

Figure 3a and 3b: Renewable project pipeline, Queensland



Note: Some regions of Queensland have been excluded due to smaller investment in renewables projects (eg Sunshine Coast, Gold Coast and South-West). Mackay includes Whitsunday, Darling Downs includes Toowoomba. Some sub-sectors of the renewable energy pipeline have been excluded due to smaller values (battery storage, transmission, biogas projects).
Source: QREP Database (CSQ, 2022). Last updated 15 December 2021.

Queensland’s renewables pipeline: by capacity

An estimated 11GW of renewable generation capacity will likely be added by the project pipeline by 2025 – a three-fold increase on the total installed renewables capacity of Queensland in 2020 (3.8GW).

Aggregating installed capacity for projects that generate energy (solar, wind and hydroelectric infrastructure) indicates substantial renewable power could be brought online via the infrastructure in the current pipeline.

For underway and committed projects alone – those most likely to go ahead on current timelines – a cumulative 11GW of generation capacity could be added to Queensland’s energy system by 2025. Three-quarters of this capacity would come from solar sources (around 74%), followed by wind (19%) and hydroelectricity (7%).

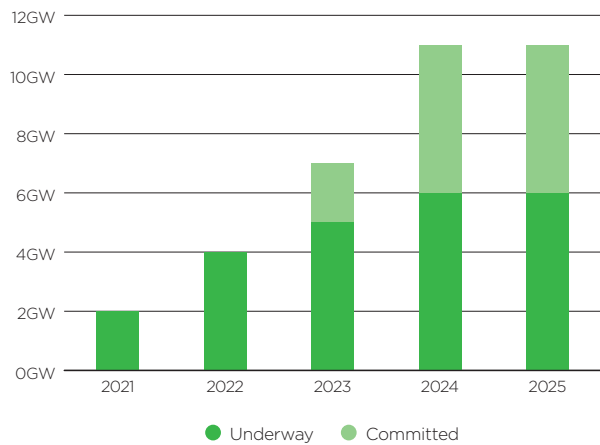
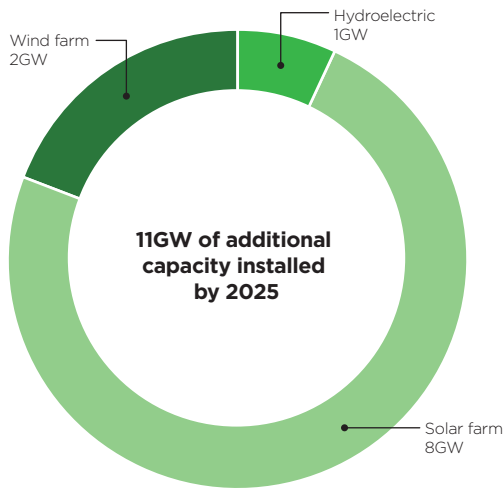
Certain regions are set to become renewable generation powerhouses in this context based on the location of current projects. The Darling Downs region, for example,

accounts for the largest share of expected installed capacity additions in the pipeline (adding 40% of the total). Again, this reflects the region’s strong solar play mentioned earlier.

According to the Queensland Government (2022) the state’s current grid capacity is 16.2GW (including fossil fuels). Around 3.8GW of this from renewable sources. The current pipeline of 11GW from confirmed projects could therefore provide a cumulative capacity of 27.2GW by 2025. It would also represent a three-fold increase of the renewable component of the grid, climbing from 3.8GW today to 14.8GW. If zero fossil fuel generation comes online during this period, around 54% of Queensland’s power would be from renewables by 2025. This far exceeds the interim target of 50% by 2030.

Beyond this, if planned and possible projects in the renewables pipeline were to go ahead as well, a staggering 44GW of additional renewables capacity would be added in Queensland in the near-term. While this is unlikely, it again shows the unprecedented level of enthusiasm for renewable energy projects in the state, and the strong upside in the outlook for the industry.

Figure 4a and 4b: Renewable project pipeline, Queensland (cumulative installed generation capacity)



Note: By project commencement year. Only for project types that aim to generate electricity. Source: QREP Database (CSQ, 2022). Last updated 15 December 2021.

2.3 | Special focus: Queensland’s hydrogen projects

The growth of hydrogen in Queensland

Queensland’s nascent clean hydrogen industry is expanding at an unprecedented pace with 35 projects already announced – almost half of these in 2021 alone. This pipeline is valued at \$5.7 billion and could enable 7.5GW of electrolyser capacity by 2030.

Quantifying hydrogen’s role in the renewables boom in Queensland is a key goal of this paper. This industry has the potential to become the largest driver of renewable generation demand in future, especially if an export industry is established. In this context we provide a special focus on the hydrogen projects pipeline in Queensland to date¹.

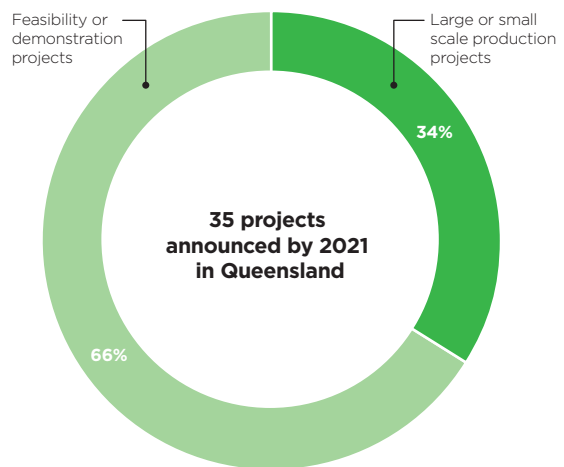
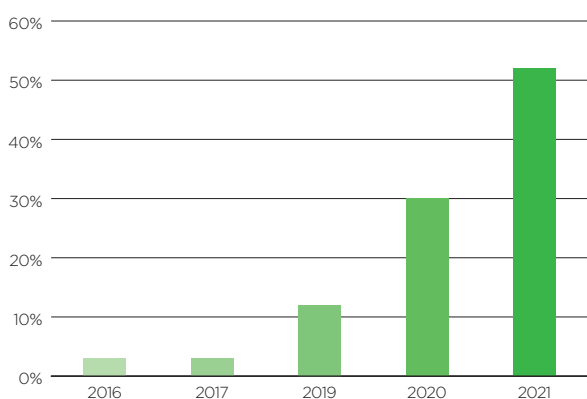
Our major finding is that 35 hydrogen projects have already been announced in the state, valued at \$5.7 billion. Almost all these projects are green hydrogen (rather than

blue hydrogen), and the majority of projects plan to utilise renewable solar electricity for electrolysis (rather than wind power).

Second to this is the pace at which this industry has emerged. It seemed that 2021 was ‘the year of hydrogen’ in Queensland with almost 50% of current projects were announced in that year alone (see **Figure 5a**).

Projects could be further characterised as a promising mix of early phase pre-competition and mature phase commercial orientation. Most projects (66%) are in the pre-competition phase, which includes a range of research, feasibility studies, pilots and demonstration plants (see **Figure 5b**). These projects are smaller scale (ie in the Megawatt, MW, range) but represent much potential upside to the hydrogen projects pipeline provided market activation parameters are met.

Figure 5a and 5b: Hydrogen project pipeline, Queensland



Note: Figure 5a is % of all hydrogen projects in Queensland by announcement year. Figure 5b is by number of projects, rather than value (\$AUD) of projects. Source: QREP Database (CSQ, 2022). Last updated 15 December 2021.

¹ Less is known about the hydrogen projects pipeline at present relative to other projects, mainly due to how rapid projects have been announced (eg the value of 14 of the 35 projects is currently unknown). The figures presented here are likely an underestimate.

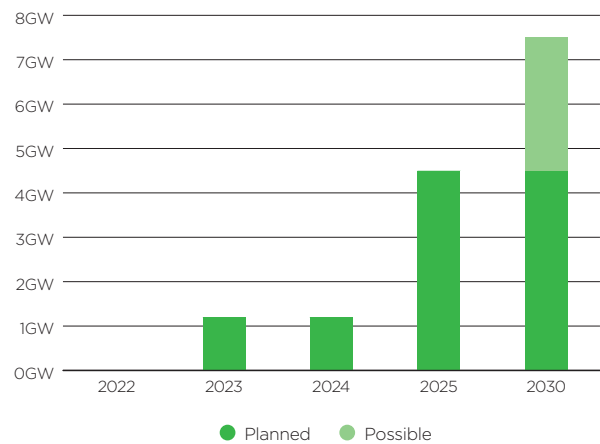
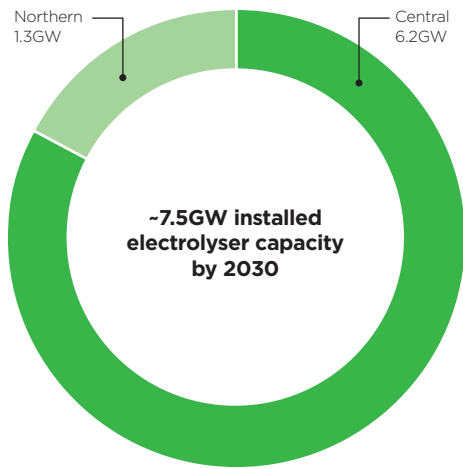
The remaining third of projects are in a more mature phase and represent the early promise of Queensland’s hydrogen export industry. Queensland now has three giga-scale projects in the pipeline (named after an electrolyser above 1GW), collectively valued at \$3.8 billion. There have only been 17 giga-scale projects announced globally, according to the World Hydrogen Council (2021). These giga-scale projects in Queensland are all export orientated and aim to be operational by 2030.

In total, the current hydrogen projects pipeline could provide a total installed electrolyser capacity of around 4.5GW by 2025 and 7.5GW by 2030 (Figure 6a).

Like the broader renewables boom, the hydrogen industry will most likely be concentrated in certain regions. Access to a deep water port for example will be critical to export activation. To date, more than 80% of projects by installed capacity are in Central Queensland, particularly around Gladstone, with the remainder in Northern Queensland (see Figure 6a).

Almost all hydrogen projects remain in the planned or possible stages at present, likely reflecting the pace at which the industry has emerged (see Figure 6b).

Figure 6a and 6b: Hydrogen project pipeline, Queensland (cumulative installed electrolyser capacity)



Note: MW scale projects have been announced in the Darling Downs and Greater Brisbane but are not included in the above due to scaling differences. By estimated project completion year. Source: QREP Database (CSQ, 2022). Last updated 15 December 2021.

2.4 | The renewables project pipeline in context

Estimating the scale of renewables-related construction activity

An estimated 20% of projects in Queensland’s overarching construction pipeline are now in renewables-related infrastructure – a figure that scales dramatically for certain parts of the state.

It’s important to put the renewables boom in the context of overall major project construction activity, especially for different regional areas. In this section, we integrate our renewables project pipeline into CSQ’s larger Major Projects Database which contains all significant construction projects in the pipeline across the state.

The major finding from this integration is that 20% of the future construction project pipeline for the state across major residential, commercial and civil works is now in renewable infrastructure. In other words, one in every

five dollars invested in major construction projects in Queensland is now going towards renewables. This has increased from around 5% (or one in every twenty dollars) on average per year during the 2015-2020 period.

Second to this is how this proportion scales dramatically for different parts of the state – hinting at the profound impact the renewables boom could have on regional construction industries (see **Figure 7a**). For the Wide Bay region, we estimate a staggering 60% of future major project delivery could be in renewables and around 35% for Northern Queensland. **Figure 7b** shows how dramatically the proportion of major construction works dedicated to solar and wind projects in particular has grown in recent years.

This shift could be fundamental and transformative for the local construction industries in those regions as they leverage their competitive advantage in renewables.

Figure 7a and 7b: % of major projects pipeline in renewables-related infrastructure



Note: All status are included.
Source: QREP Database (CSQ, 2022). Last updated 15 December 2021. Major Projects Database (CSQ, 2022).

Comparing renewables infrastructure investment: past and present

Investment in renewable infrastructure projects has doubled over the last few years – driven by intense investment in solar projects.

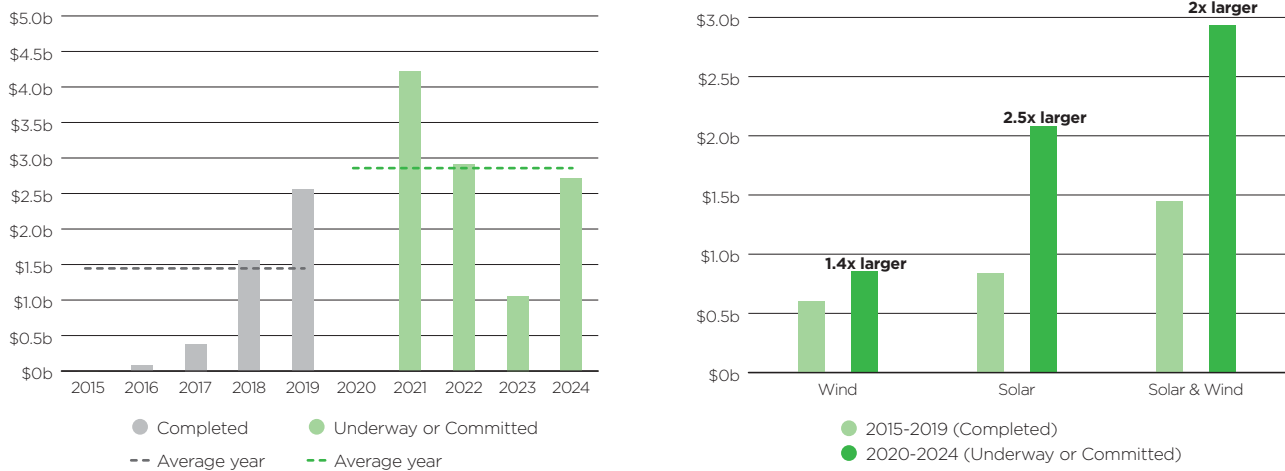
Contextualising the pipeline of investment in renewables projects relative to past green energy projects is also important.

Figures 8a compares the annual capital investment in solar and wind projects completed from 2015 to 2019 against those underway or committed from 2020 to 2024. An upward trend is clearly discernible, with the average year from 2020 to 2024 (\$2.9 billion) around double that from the preceding five years (\$1.5 billion).

Figure 8b shows that this growth has been driven primarily by increased investment in solar projects, which have ballooned by 2.5 times on average over this same period, growing from around \$850 million per annum to \$2.1 billion.

These growth estimates would be substantially higher if projects at earlier stages of the investment cycle were included, keeping in mind that just over 85% of wind infrastructure remain at the planned or possible stages at the time of publication.

Figure 8a and 8b: Investment in wind and solar projects, Queensland



Note: By project completion year (real or estimated). Figure 8a: there no projects ending in 2015 or 2020 in the project pipeline. Figure 8b: the average annual project value for 5-year groups.

Source: QREP Database (CSQ, 2022). Last updated 15 December 2021. Major Projects Database (CSQ, 2022).

2.5 | Construction labour demand arising from the pipeline

What size will the workforce for renewables be in the near-term?

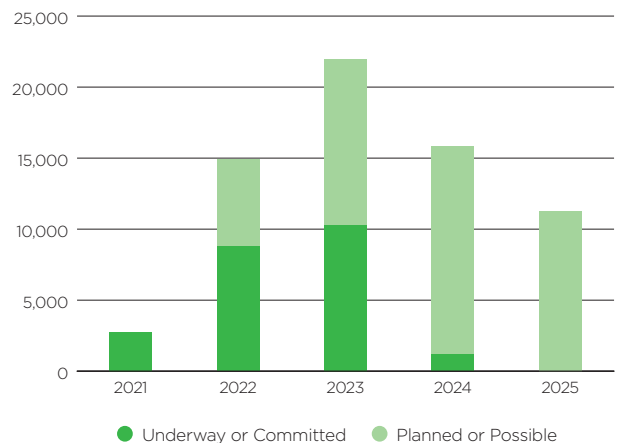
Renewable projects already underway or committed to delivery in Queensland could require around 4,600 construction workers through to 2025 – and up to 10,300 at peak times.

The fundamental question of this paper is, what will be required of Queensland’s construction workforce to deliver the renewables boom? In this section, we model the construction labour demand, both in aggregate and at the occupational level, arising from the near-term projects pipeline. To remain conservative in our estimates, we focus mainly on underway and committed projects (See Chapter 5 for the modelling methodology used).

Our major finding is that approximately 4,600 construction workers would be required (on average) from 2021 to 2025 to deliver these projects (**Figure 9a**). This would vary from year to year, but offers a standard mid-point measure of labour demand. Yet, construction workforces are rarely deployed in a uniform manner. **Figure 9b** shows peak demand of workers for these projects in 2023 at just over 10,300.

Figure 9b also overlays the estimated workforce demand emerging if all projects in the pipeline went ahead given current timetables. Such a prospect could catalyse demand for almost 22,000 workers at peak in 2023, and an average of 13,500. While complete deployment is unlikely, this shows the workforce impact of any substantial upside in the pipeline.

Figure 9a and 9b: Projected renewables-related construction jobs based on current pipeline, Queensland



Note: Figure 9a adds up to 4,700 rather than 4,600 due to rounding.
Source: Modelled using QREP Database (CSQ, 2022). Last updated 15 December 2021.

“From a workforce point of view, the interaction between hydrogen, solar and wind jobs will be important. As more upstream solar and wind assets are used to produce commercial volumes of hydrogen, the construction jobs required to build these may become part of the hydrogen industry jobs count, blurring the lines between the true size of renewables sector workforces.”

Which renewables sector will have the most jobs in the near-term?

Around a third of workforce requirements could be in solar infrastructure - with demand increasing dramatically if planned and possible projects proceed.

Modelling construction labour requirements across the various energy sectors revealed over 80% of jobs demand for confirmed projects were in one of three sectors (**Figure 10a**). The construction of renewable manufacturing facilities (35%, 1,600 jobs), solar farms (33%, 1,500 jobs) or wind farms (14%, 650 jobs).

The build out of facilities that in turn manufacture renewable technologies servicing domestic or international green energy supply chains tops this list. This reflects two major projects, the billion dollar hydrogen electrolyser factory confirmed for delivery in Gladstone, combined with a billion dollar lithium battery manufacturing project in Mackay.

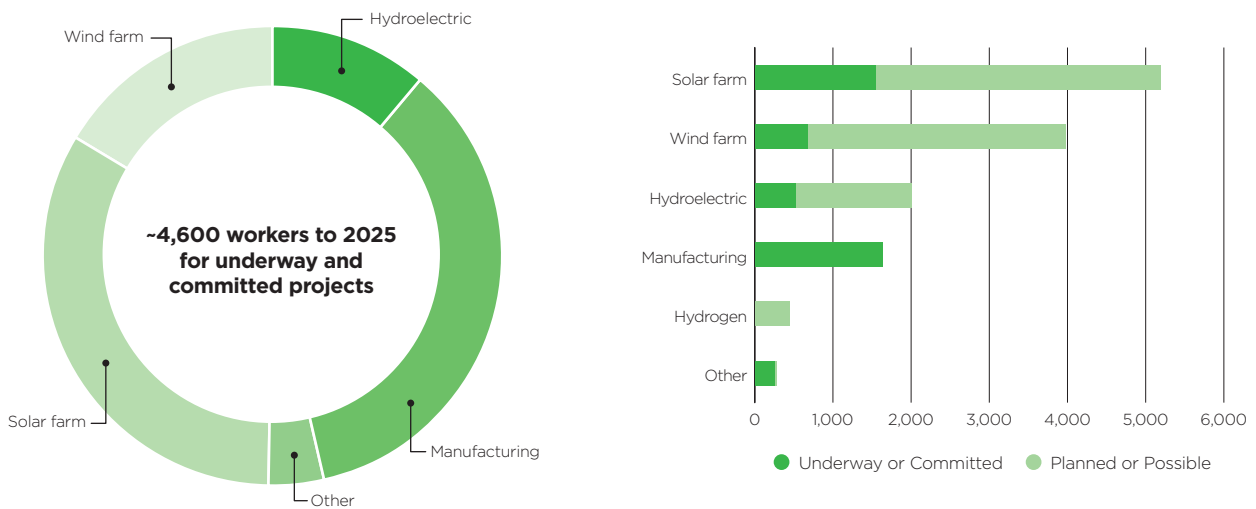
Yet, construction demand for solar projects may be the one to watch in the near-term. These already constitute a third of jobs for confirmed projects. Yet **Figure 10b** show the potential upside workforce impact if the remaining projects in the pipeline went ahead according to schedule.

Whilst a scenario of complete deployment of the entire pipeline is unlikely, even a proportion of solar projects moving to construction could come to dominate labour requirements. A similar yet less pronounced possibility is also discernible for planned and possible wind projects.

Hydrogen construction jobs don't feature in **Figure 10a** because almost all work in that sector is only at the planned or possible stage at present. Hence, hydrogen facility construction demand appears in **Figure 10b** and could range from around 400 on average through to 2025.

From a construction workforce point of view, it's important to mention an emerging interaction between hydrogen jobs, and solar and wind jobs. In future, an increasing share of upstream solar and wind generation will likely be utilised to produce commercial volumes of green hydrogen. Although this prospect remains in the future, it would mean (at least in theory), that the construction labour required to build these upstream solar and wind assets might best be counted as part of the 'hydrogen industry construction workforce'. The hydrogen figures in **Figure 10b** below do not account for these upstream labour requirements, and only refer to the direct construction of hydrogen processing facilities. These figures may therefore be an underestimate of the true size of the hydrogen construction workforce.

Figure 10a and 10b: Projected renewables-related construction jobs based on current pipeline, Queensland



Note: Average number of construction jobs from 2021 to 2025. Figure 10a 'Other' includes battery storage, transmission lines, hydrogen and biogas projects. Hydrogen workforce is then split out from 'Other' in Figure 10b. Source: Modelled using QREP Database (CSQ, 2022). Last updated 15 December 2021.

2.5 | Construction labour demand arising from the pipeline (continued)

Where will the most renewables jobs be in the near-term?

More than 90% of construction labour demand for renewable energy projects will be in regional Queensland – led by Northern Queensland.

Our modelling of regional construction labour demand shows that of the eight regions with material labour needs arising from the renewables boom in the near-term, Greater Brisbane is the only jurisdiction not in regional Queensland (**Figure 11**).

This finding did not change whether the labour demand from confirmed projects only or the entire pipeline was modelled – with more than 90% of demand in regional Queensland under either condition. This suggests a large regional labour footprint is a defining feature of the renewable construction workforce.

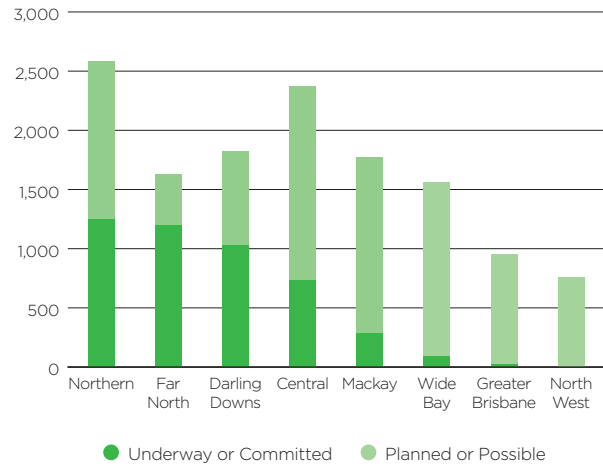
Another major finding was Northern Queensland as the lead locality of workforce demand for renewable projects. For confirmed projects, over a quarter (27%) of all renewables construction workforce demand (or 1,250 jobs) could be required in that region alone.

Other notable regions with strong demand in the near-term for confirmed projects are Far North Queensland and the Darling Downs region, requiring 1,200 (26% of all) and 1,000 workers (22% of all) respectively.

The potential upside in the renewable pipeline for regional jobs demand is also clear (**Figure 11**). This is the loaded gun of the outlook, which if even only partially fired could lead to a step change in the demand profile for almost every region.

Chief among these is Central Queensland, which has the largest worker demand for planned and possible projects (at 1,600). Even if a share of projects went ahead it would put Central towards the top region for near-term renewable construction jobs. Other regions of note here are Wide Bay and Mackay, who would see an 18- and 6-fold increase in demand.

Figure 11: Projected renewables-related construction jobs based on current pipeline, Queensland



*Note: Average number of construction jobs from 2021 to 2025. Other regions have been excluded due to a comparatively small level of construction labour demand (Sunshine Coast, Gold Coast, South-West). Mackay includes Whitsunday, Darling Downs includes Toowoomba.
Source: Modelled using QREP Database (CSQ, 2022). Last updated 15 December 2021.*

Developing a regional ‘green energy niche’

Parts of Queensland are already developing their green energy niche - which will likely dictate flows of construction labour.

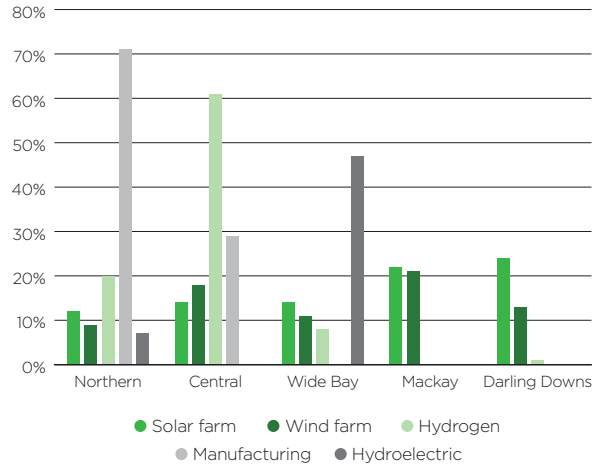
Our labour modelling of the full pipeline indicates a remarkable pattern of labour demand when we combined region and renewable sector. It appears regions could come to specialise in the construction and installation of particular types of renewable infrastructure.

This finding is represented in **Figure 12** which shows the proportion of each renewables sector workforce in Queensland by five major regions.

Northern Queensland, for example, will demand the highest proportion of construction jobs in renewable manufacturing generated across the state in the near term with around 70% of construction jobs in that sector given all pipeline projects. Central Queensland will be the hotspot for construction jobs related to hydrogen with 60% of all hydrogen construction jobs in that region alone. While the Darling Downs will be home to the most solar jobs with around 24% or one in four of all solar construction jobs in Queensland. Meanwhile Mackay leads demand for wind construction labour with around 21% of all wind jobs.

Even at this early stage of the boom, it appears these regions have their own point of differentiation, or green energy niche when it comes to the type of construction labour in demand for the renewables boom.

Figure 12: Projected demand for construction workers (%), based on current renewable projects pipeline, Queensland



Note: Average number of construction jobs from 2021 to 2025 (as %). All statuses. Several regions have been excluded due to smaller number of renewables jobs across these measures (Greater Brisbane, North-West, Sunshine Coast, Gold Coast, and South-West). Source: Modelled using QREP Database (CSQ, 2022). Last updated 15 December 2021.

2.5 | Construction labour demand arising from the pipeline (continued)

What type of construction jobs will be needed in the near-term?

Just over a third of construction labour arising from the renewables pipeline could be for low skilled and semi-skilled labourers. While high skilled trades could make up one in five roles.

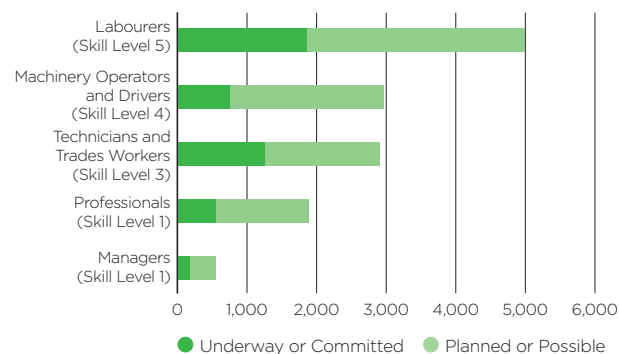
Our modelling of construction labour demand arising from the renewables pipeline also enables deeper profiling of broad occupational groups, skills compositions and specific occupations (see Chapter 5 for modelling methods). This can enable more sophisticated skilling pathways and training frameworks to be developed.

In this section we again split projects confirmed for delivery (underway, committed) compared to those less certain (planned, possible). Although occupational demand varied systematically across these groups (most comes via the latter group) we found little difference between the proportion or profile of occupations demanded by project likelihood. We therefore comment mainly about occupations arising across all project stages. When breaking down occupations by renewable sector we focus only on the three major project areas most critical to this report – solar, wind and hydrogen.

Our first finding is at the occupational group level which aggregates individual construction roles into one of five major areas (see **Figure 13**). These five areas also represent various skill levels² which could impact training and lead times (see ABS 2009 for more information on skill level). We estimate that the largest demand for construction workers will be for general Labourers, which account for around 37% of all jobs (around 5,000 on average from 2021 to 2025 for all projects). These are generally low skilled or semi-skilled, with a skill level of 5. Less lead time is required for these roles relative to more skilled positions.

Machinery Operators (22%) and Technicians and Trade roles (22%) account for the next two largest groups, requiring almost 3,000 roles respectively on average from 2021 to 2025. These roles both require more intense certification and training, with trade roles the more advanced of the two. This means highly skilled trades could make up one in five roles.

Figure 13: Forecast average demand, construction occupation groups, all renewable projects, Queensland, 2021-2025



Note: Average workers required for renewables projects in the pipeline from 2021 to 2025. Source: Modelled using QREP Database (CSQ, 2022). Last updated 15 December 2021.

Which renewables sectors will need which skills?

Building out the hydrogen industry could require a much higher share of skilled construction trades relative other types of renewable energy projects – a critical insight for this emerging sector.

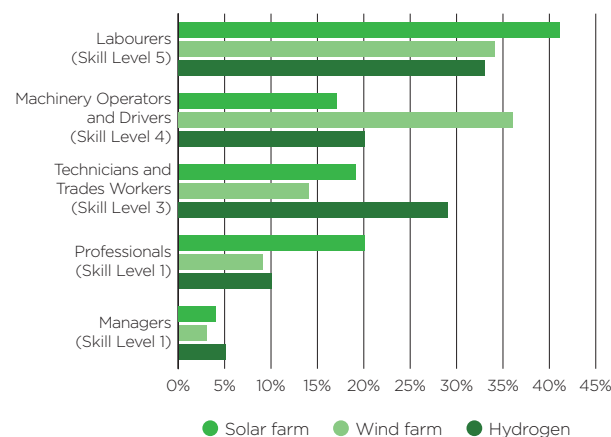
In the figure below (**Figure 14**) we provide the proportional demand profile for these five occupational groups within solar, wind and hydrogen construction projects.

This provides several insights. Firstly, the solar construction workforce has a higher demand per head for general Labourers (41% of solar workers) than wind (34%) or hydrogen workforces (33%). This suggests that well over one-third of the solar construction workforce is semi-skilled. This should be considered in the context of the dominance of solar projects in Queensland’s renewable energy pipeline (accounting for 50% of all projects).

Secondly, the highest occupational group for the construction of wind assets is Machinery Operators and Drivers (36% of the wind construction workforce). This is different to both solar and hydrogen, which have labourers as the most common workforce group.

Finally, and perhaps most importantly, almost 30% of hydrogen roles are for Technicians and Trade Workers. This is a significant concentration of highly skilled roles, much higher than solar (with 19% of workers from this group) and more than double that required to deliver wind projects (14%). This finding could have broader implications for skilling pathways as the hydrogen industry scales. Developing or attracting more skilled trades people requires longer lead times, and they are often in high demand across the industry.

Figure 14: Forecast average demand, construction occupation groups (%), selected project types, Queensland, 2021-2025



Note: Proportion of occupational group required to deliver specific sub-sectors of renewable projects in the pipeline (ie Labourers account for 41% of the average solar construction workforce required to deliver all solar projects in the pipeline). Source: Modelled using QREP Database (CSQ, 2022). Last updated 15 December 2021.

² In ANZSCO, skill level is defined as a function of the range and complexity of the set of tasks performed in a particular occupation. The greater the range and complexity of the set of tasks, the greater the skill level of an occupation with 1 being the highest. More information on skill level is contained in Chapter 5 of this report

Which jobs will dominate Queensland's renewables boom?

Certain roles will dominate the construction workforce required for renewables projects – including General Labourers (17%), Concreters (9%), Truck Drivers (8%) and Electricians (7%) – but this varies by project type.

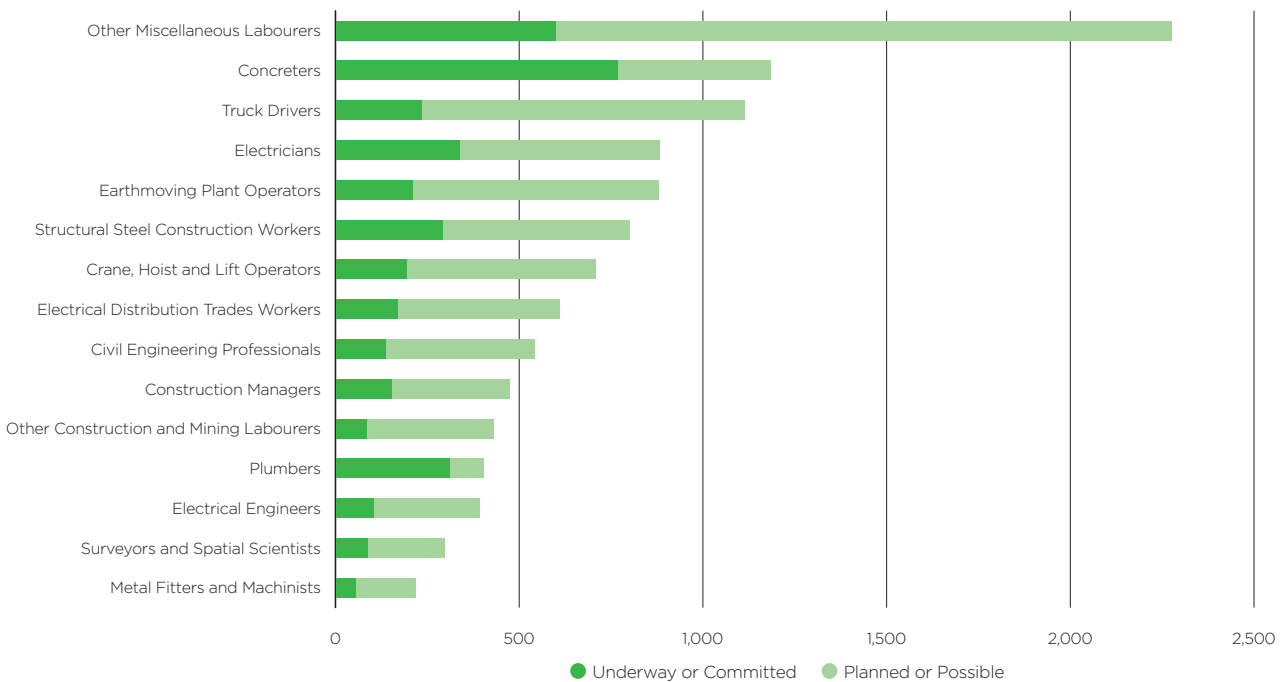
In this section we unpack the full occupations and skills composition of the construction workforce required to deliver Queensland's near-term renewable energy pipeline (Figure 15).

This profiling represents a breakdown of our earlier estimates of aggregate workforce demand. That is, an occupational breakdown of the 4,600 (confirmed projects) or the 13,500 (all projects). It is also, in essence, a breakdown of the occupational groups into their respective occupations. We do this first for the full renewables pipeline, then by solar, wind and hydrogen projects respectively.

Across the full suite of renewables projects, Other Miscellaneous Labourers (also known as General Labourers) and Concreters constitute the most in demand construction roles, accounting for 17% and 9% of occupations respectively. When combined with Structural Steel Construction Workers (6%), these roles account for the highest overall Labourer occupational groups needed to deliver renewables projects. These roles will form the base of the renewables workforce in Queensland.

The most in demand high skilled trades roles across the demand profile are in the electrical domain. Electricians and Electrical Distribution Trades Workers accounting for 7% and 5% of roles respectively. These roles will constitute the main technical requirements of the renewable energy build out. This makes sense given that decarbonisation, for the most part, is about increasing renewable electricity supply.

Figure 15: Forecast average demand, construction occupations, all renewable projects, Queensland, 2021-2025



Note: Average workers required for renewables projects in the pipeline from 2021 to 2025. The occupations listed cover 85% of the renewable construction workforce. Source: Modelled using QREP Database (CSQ, 2022). Last updated 15 December 2021.

2.5 | Construction labour demand arising from the pipeline (continued)

Workforce demand: solar projects

Solar projects have the highest aggregate construction labour needs at present in Queensland’s renewables pipeline. The occupational breakdown of this demand is outlined in **Figure 16**.

Four roles make up more than half (56%) of the construction workforce required for solar projects (Other Miscellaneous Labourers, Electrical Distribution Trades Workers, Truck Drivers and Earthmoving Plant Operators). Notably, around a third of solar construction workers fall into the first role and almost one in ten are from the electrical distribution trades which is the most in-demand skilled trade required onsite.

Workforce demand: wind projects

The construction workforce required for wind projects is more diverse than solar but share many similarities (**Figure 17**). Truck Drivers (16%) and Earthmoving Plant Operators (12%) are the highest roles in demand. Much of this would be to clear prospective sites and transport commercial sized turbines.

Associated with this work are roles for Structural Steel Construction Workers (10%) and Laborers (10%). Electrical workers are again the top skilled trades required on site, this time with Electricians accounting for 9% of construction labour demand.

Figure 16: Forecast average demand, construction occupations, solar projects, Queensland, 2021-2025

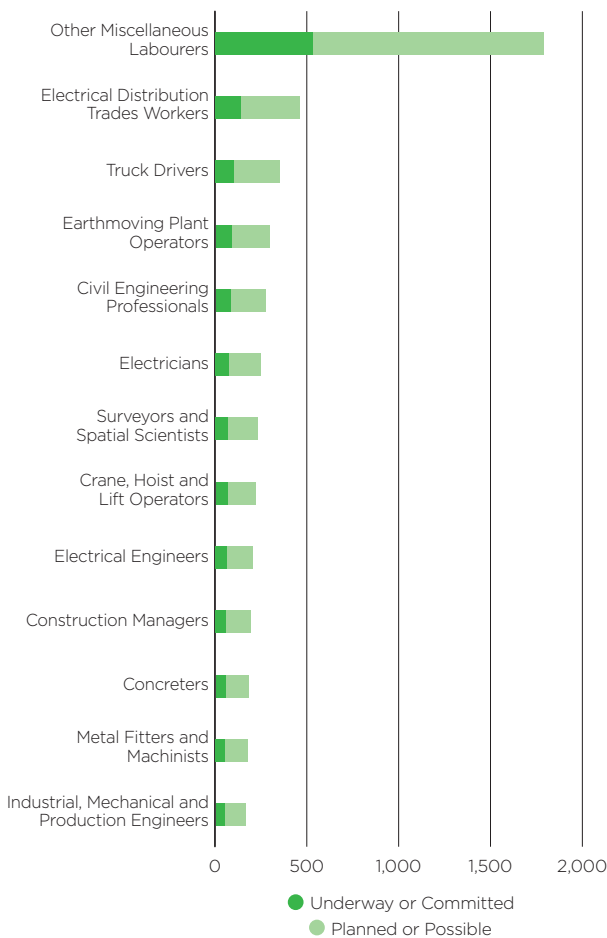
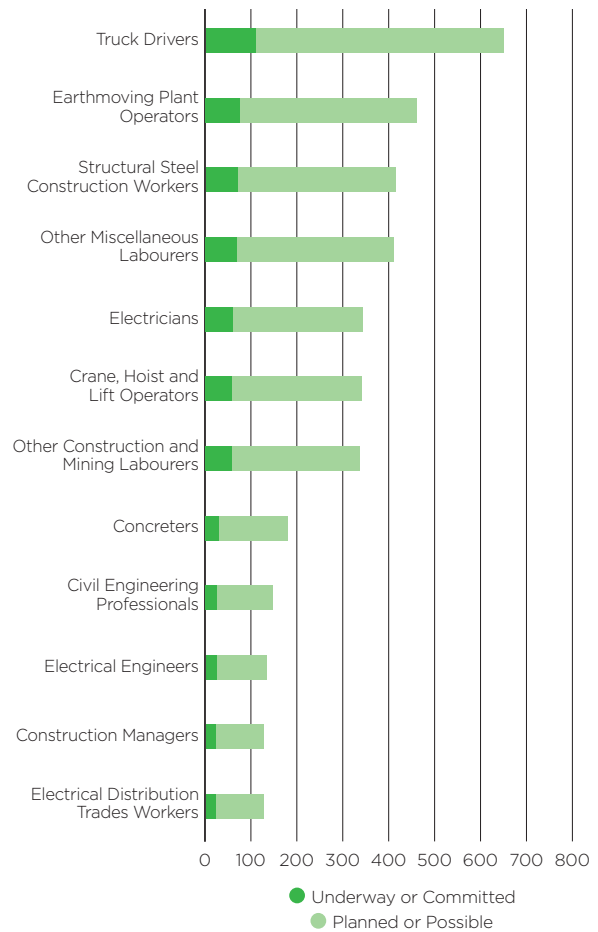


Figure 17: Forecast average demand for construction occupations, wind projects, Queensland, 2021-2025



Note: Average workers required for solar projects (left) and wind projects (right) in the pipeline from 2021 to 2050. The occupations listed cover 90% of each sector’s renewable construction workforce.
Source: Modelled using GREP Database (CSQ, 2022). Last updated 15 December 2021.

Workforce demand: hydrogen projects

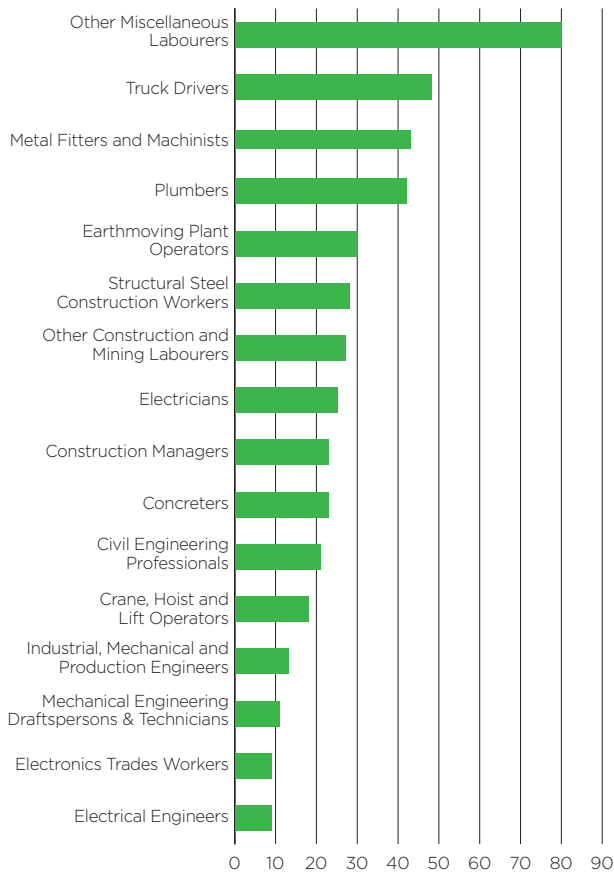
Metal Fitters and Plumbers will be critical roles for the build out of green hydrogen infrastructure – constituting almost 20% of the workforce mobilised to build processing facilities.

The construction workforce required for hydrogen has important differences from solar and wind projects – especially for highly skilled trade roles with long lead times. Our modelling suggests that both Metal Fitters and Machinists (9%) and Plumbers (9%) are key trades for hydrogen infrastructure.

These roles could become critical in future as the hydrogen industry scales up, suggesting pathways into these trades are a key supply point for the build out of the industry. Notably, these roles are not featured in either solar or wind construction projects and are unique to the hydrogen sector.

That said, the remaining workforce requirements are consistent with the broader classes of renewables. General Labourers (16%), Truck Drivers (10%), Earthmoving staff (6%) continue to be the most in demand roles in the semi-skilled domain.

Figure 18: Forecast average demand for construction occupations, hydrogen projects, Queensland, 2021-2025



Note: Average workers required for hydrogen projects in the pipeline from 2021 to 2050. The occupations listed cover around 90% of the hydrogen construction workforce. Source: Modelled using QREP Database (CSQ, 2022). Last updated 15 December 2021.



Queensland's renewable energy outlook to 2050

3 | Queensland's renewable energy outlook to 2050

Beyond Queensland's near-term project pipeline, a much larger renewables boom awaits. Even by 2025, we will be just starting two overlapping energy journeys to get to net zero by 2050.

The first of these journeys is the continued decarbonisation of the state's economy via a scale up of renewable powered electrification. The second is the simultaneous production of clean hydrogen, whether for Queensland's hard-to-abate sectors or for export to assist other countries pursue their own climate ambitions. Significant construction labour demand over a number of decades will result.

Here we present what could be required in Queensland to realise these larger ambitions out to 2050. We do this across three different scenarios – or 'futures'. In all futures Queensland achieves net zero.

But what makes these scenarios vary is crucial. We introduce strong variation in the 'game changing' feature likely to dictate just how large the renewable boom could be for the state over the longer-term. This variation is the size of the export and domestic markets for hydrogen produced in Queensland.

Three hydrogen-centric scenarios out to 2050 were modelled:

- export volume high, domestic use high ('Export & Domestic')
- export volume high, domestic use low ('Export-led')
- export volume low, domestic use high ('Domestic-led')

Importantly, all scenarios were overlaid with a standard estimate of the 'base renewables' required to deliver the other major part of the boom. That is, the parts of Queensland's decarbonisation pathway that don't depend on hydrogen (eg increased electrification from more renewable electricity). Adding this to each hydrogen scenario provides insights into the total requirements for Queensland to reach net zero, while varying the future size of the hydrogen industry.

We report findings across three main dimensions through to 2050 to realise these futures:

- the associated CAPEX pathways of all required infrastructure
- the installed capacity and output volumes
- the number of construction workers required to deliver each future

Particular focus is paid to geography, with these dimensions reported for zones across regional and South-East Queensland for each scenario.

After a brief summary of findings, this section begins with an explanation of the modelled scenarios, including the underlying assumptions. Following this we explore the results more comprehensively across CAPEX, installed capacity and output volumes, and construction jobs.

3.1 | Major findings summary

Capital expenditure (CAPEX)

- Annual average CAPEX required to meet Queensland's renewables boom (including all base renewables and hydrogen industry infrastructure) to 2050 could range from \$6.7 billion (Domestic-led) to \$13.9 billion (Export & Domestic)
- Regardless of scenario, most annual CAPEX will be hydrogen-related – ranging from 60% to 80% of annual costs – with the remainder in base renewables
- Regardless of scenario, most renewables boom CAPEX will be deployed in regional Queensland – from 62% to 96% of CAPEX costs per year – with Northern Queensland the highest amount of investment
- Annual average CAPEX for Queensland's hydrogen industry to 2050 could range from \$4.0 billion (Domestic-led) to \$11.2 billion (Export & Domestic)
- Across all scenarios, the largest component of hydrogen industry CAPEX is the upstream supply of renewable electricity rather than direct processing and storage of the fuel
- Upstream supply accounts for well over half (56% to 67%) of yearly hydrogen-related CAPEX – ranging from \$2.7 billion (Export-led) to \$6.4 billion (Export & Domestic) per annum
- Most hydrogen CAPEX will be deployed in regional Queensland, from 55% up to a notable 99% depending on scenario

Installed capacity and output volumes

- Cumulative renewable generation required to meet Queensland's boom by 2050 (including all base renewables and hydrogen industry infrastructure) could range from 105GW (Export-led; Domestic-led) to 192GW (Export & Domestic)
- This would be 6.5 to 12 times larger than the total installed generation capacity currently in Queensland, which includes fossil fuels (16.2GW)
- An extraordinary share of this capacity would become the upstream source for hydrogen production – ranging from 44% (46GW) to almost 70% (133GW) added by 2050
- Cumulative installed electrolyser capacity of the hydrogen industry could range from around 50GW (Domestic-led) to 270GW (Export & Domestic) by 2050 – spanning a possible 6- to 36-fold growth from QREP 2025 pipeline estimates (7.5GW)

- Scaling up the hydrogen industry in Queensland could see from 3.1 million (Domestic-led) to 8.0 million (Export & Domestic) tonnes produced per year by 2050 – with more than 70% bound for export regardless of scenario
- By 2050, across all scenarios, most of the state's hydrogen will be produced in regional Queensland – from 66% to 96% of total output by volume – with most of this produced solely in Northern Queensland

Construction jobs

- Construction jobs arising from Queensland's renewables boom (including all base renewables and hydrogen industry infrastructure) to 2050 could range from 14,500 (Domestic-led) to 26,700 (Export & Domestic)
- Regardless of scenario, most construction jobs generated by the boom will be in regional Queensland, spanning from 13,600 (Domestic-led) to 16,200 (Export-led)
- A large share of renewable boom construction jobs would be required solely for hydrogen-related infrastructure – accounting for 43% to 69% of jobs demand – the remainder would be delivering base renewables
- This means Queensland's hydrogen industry could require from 6,300 (Domestic-led) to 18,500 (Export & Domestic) construction workers from 2021 to 2050, while base renewables requires an estimated 8,200 over the same period
- Developing the state's hydrogen industry will generate substantial construction jobs in regional Queensland – from 6,400 (Domestic-led) to 9,000 (Export-led) on average from 2021 to 2050
- Most construction jobs emerging from Queensland's renewables boom (including all base renewables and hydrogen industry infrastructure) will be in the deployment of the staggering amount of renewable energy infrastructure required – accounting for 68% to 92% of all renewables boom construction jobs

3.2 | Developing future renewable energy scenarios for Queensland

How we developed the hydrogen industry scenarios

Based on preliminary research and industry liaison, CSQ firstly hypothesised that a hydrogen industry in Queensland could be the major driver dictating the size of the renewable energy boom over the long-term. Secondly, that the fault line shaping the size of a hydrogen industry will likely be the relative sizes of the export and domestic markets.

CSQ also identified that the uptake rate of hydrogen in these markets may also differ. While a strong domestic sector may prove key to export success, there is a material chance that these markets diverge. These two paths could therefore carry very different capacity and CAPEX requirements - and therefore workforce implications.

Exploring different yet plausible extremes in hydrogen uptake in these markets within a series of long-term scenarios was therefore prioritised. This would provide strong variation along the fundamental axis likely to dictate future pathways of installation capacity, CAPEX and construction workforce requirements for the most critical part of Queensland's renewables boom.

CSQ then conducted a review of hydrogen scenario modelling in Australia to determine if any precedent work had been conducted on the role that variation in domestic-export market capture could have (CSQ, 2021). Most studies overlooked this crucial variation, assuming rates of export and domestic uptake would scale identically. Other studies focused only on either domestic or export markets, rather than modelling both. No prior studies had been conducted specifically for Queensland. There was a clear need to understand how different rates of export and domestic hydrogen uptake could impact Queensland.

Following this, three scenarios were developed for Queensland during a Hydrogen Scenario Workshop with attendees from CSQ and CSIRO. The scenarios were based on variations in the export and domestic uptake of hydrogen through to 2050 (**Figure 1**). A standard estimate of Queensland's non-hydrogen requirements (eg renewable power needs) to get to net zero 2050 in the state are built into each scenario. Therefore each scenario gets Queensland to net zero, but the size of the hydrogen industry varies given different levels of domestic and export uptake. These scenarios were then modelled by CSIRO in Aus-TIMES (see Chapter 5 for more about Aus-TIMES).

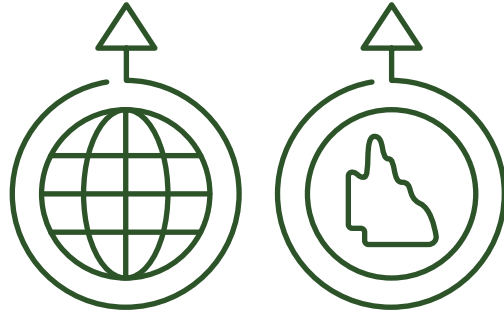
Figure 1: The schematic location of our three scenarios along the export-domestic fault line



Source: CSQ (2021).

Scenario 1: Export & Domestic

- In this scenario, global temperature rise is limited to $< 2^{\circ}\text{C}$ as ambitious net zero climate policies are realised, including in Australia
- The hydrogen production cost curve declines substantially, resulting in the potential scale-up of domestic use as one of the clean energy vectors essential to aid carbon neutrality
- A strong export market for clean hydrogen opens globally, including the Asia-Pacific region, as other nations chase a low price fuel to reach their own net zero vision
- Queensland develops a strong hydrogen export market to meet this demand



Scenario 2: Export-led

- This scenario sees global temperature rise limited to 2°C . Most, but not all, countries reach net zero emissions by 2050
- Clean hydrogen production costs remain comparatively high. This limits widescale adoption as a major vector in the transition to net zero in Queensland, and more land-based offsets are pursued to meet the state's target
- A strong export market for clean hydrogen still opens up globally, including the Asia-Pacific region, but hydrogen production to meet this demand could move to remote locations away from main grids, including the National Electricity Market (NEM)
- Queensland develops a strong hydrogen export market to meet this demand



Scenario 3: Domestic-led

- In this scenario, global temperature rise is $> 2^{\circ}\text{C}$. Some countries reach net zero emissions by 2050
- The hydrogen production cost curve declines substantially, potentially scaling-up domestic use as a clean energy vector aiding carbon neutrality
- A strong export market for clean hydrogen in the Asia-Pacific fails to materialise
- The commercialisation of offshore wind generation allows countries with access to the ocean (like our potential trading partners, Japan and South Korea) to meet their hydrogen needs cheaper onshore (see Cheng et al, 2022 for deeper analysis)



Overall, these scenarios include assumptions developed in the workshop which shape the energy sector modelling outcomes (**Table 1**). The percentage-based values shown are maximums and the scenario modelling method used may find it more cost-effective to use another fuel besides hydrogen, for example.

3.2 | Developing future renewable energy scenarios for Queensland (continued)

Parallel scenario: base renewables

In addition to these scenarios is the projected 'base renewables' required to support our domestic decarbonisation agenda – ie non-hydrogen renewable infrastructure that is the first leg of the renewables boom for Queensland.

This same scenario remains constant across all hydrogen scenarios and is added to each scenario independently to provide the total capacity required in Queensland to support not just hydrogen production (export or domestic) but overall electrification to reduce domestic emissions and achieve net zero 2050 in Queensland.

This base renewables scenario is similar to AEMO's (2021) Steady Progress Scenario which was their most likely or 'central' scenario when this modelling was done. It contains current CO₂ reduction targets, retirement capacity estimates and increased electrification of vehicles. It's noted that AEMO (2022) has since moved to a more aggressive 'central' scenario called Step Change. For this reason the base renewables outputs in this report, including construction labour demand, may be an underestimate.

Table 1: Assumptions by scenario for modelling

Hydrogen assumption	Export HIGH Domestic HIGH		Export HIGH Domestic LOW		Export LOW Domestic HIGH	
	2030	2050	2030	2050	2030	2050
H2 export*	1	18.1	1	18.1	0	4.9
Green ammonia product export*	1	49.1	1	49.1	0	39.3
Green steel*	Output	Output	Output	Output	Output	Output
Transport fleet share (%)						
- Long haul trucks	15%	70%	10%	50%	15%	70%
- Buses	2%	10%	0.40%	2%	2%	10%
- Shipping	Output	Output	Output	Output	Output	Output
- Light vehicles	1%	5%	0.20%	1%	1%	5%
- Aviation	Output	Output	Output	Output	Output	Output
Natural gas replacement (%)						
- Buildings	10%	100%	0%	10%	10%	100%
- Chemical manufacturing	10%	60%	10%	30%	10%	60%
- Alumina refining	10%	30%	10%	30%	10%	30%
Other	10%	30%	10%	30%	10%	30%
Grid services	Output	Output	Output	Output	Output	Output

Note: * Mt/year. Hydrogen can be exported as a liquid or as green ammonia. The assumption listed are for the whole of Australia and Queensland's share of this will be determined by the model. Source: CSIRO (2022) for CSQ.

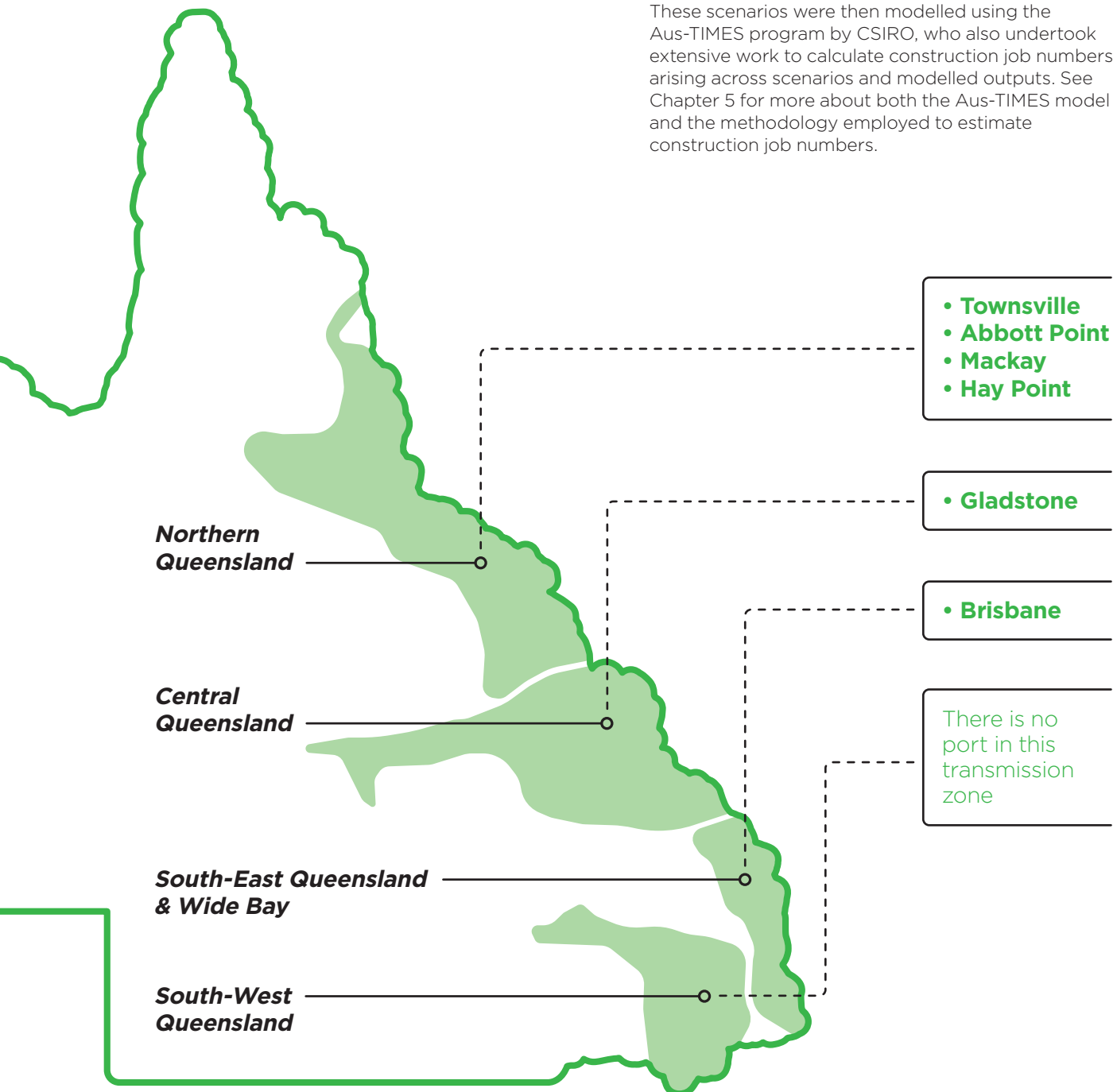
Queensland regions: all scenarios

The regional footprint of the renewables boom, and the associated call on construction labour, is a critical feature of any future that emerges. Across all scenarios (where possible), outputs are presented by one of the four Queensland transmission zones. These include the associated ports from where commercial volumes of hydrogen could be exported and were selected due to the berth sizes required for Panamax sized ships.

These four transmission zones and ports include:

- **Northern Queensland:**
Townsville, Abbott Point, Mackay and Hay Point
- **Central Queensland:**
Gladstone
- **South-East Queensland (including Wide Bay):**
Brisbane
- **South-West Queensland:**
there is no port in this transmission zone

These scenarios were then modelled using the Aus-TIMES program by CSIRO, who also undertook extensive work to calculate construction job numbers arising across scenarios and modelled outputs. See Chapter 5 for more about both the Aus-TIMES model and the methodology employed to estimate construction job numbers.



3.3 | Capital expenditure (CAPEX) outlook

Annual average CAPEX for all renewable-related infrastructure in Queensland (hydrogen-related and base renewables) to 2050 could range from \$6.7 billion to \$13.9 billion (depending on scenario).

To report projected CAPEX results we focus primarily on the average annual investment required in \$AUD (in 2021 prices; not adjusted for inflation) across five-year intervals starting from 2021-25 through to 2046-50. We do this for each scenario. This is followed by an indication of the yearly average across this entire three decade period (2021-2050) again for each scenario.

We start by reporting CAPEX at the highest level possible – combining infrastructure costs for both hydrogen-related and base renewables – then break this down into the various components. This will clarify the total potential expenditure required for Queensland’s renewables boom over the long-term, while outlining the primary drivers of this expenditure. We also focus on where in Queensland this infrastructure will likely be built.

At this highest level of aggregation, we estimate that the CAPEX required to meet the infrastructure demands arising from the entire renewables boom through to 2050 are substantial for Queensland – and could range from \$6.7 billion to \$13.9 billion per year on average from 2021 to 2050 (**Figures 2a and 2b**).

Our estimates of aggregate CAPEX vary fundamentally by scenario. An Export & Domestic hydrogen future, combined with the base renewables required for

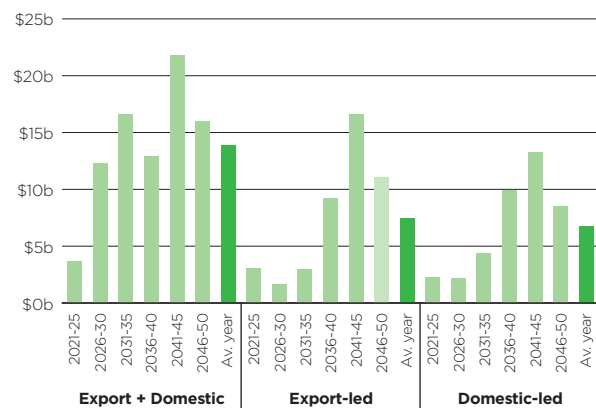
domestic electrification, requires almost double the yearly CAPEX (at \$13.9 billion) than a future in which either of those markets fails to fire materially. A future of high exports but low domestic uptake (Export-led), or vice versa (Domestic-led), results in a roughly equivalent annual CAPEX (\$7.4 billion, \$6.7 billion respectively). Such CAPEX variation across scenarios provides some cursory support for our original claim that variations in the size of these markets could have a material impact on CAPEX.

Such a long-term average covers substantial variation from one five year interval to the next, with a clear ramp up across all scenarios from mid-2020s to early 2030s. This is followed by a CAPEX peak in 2041-45, with the high point of \$21.7 billion on average each year over that period in the Export & Domestic scenario (**Figure 2a**). Across scenarios this peak appears to be driven by intense investment and build out of major hydrogen production and storage technology, particularly in Northern Queensland.

How does the renewables boom compare?

For comparison, annual CAPEX in the Queensland mining boom period (from 2010 to 2016) was an estimated \$19.7 billion (ABS, 2021f). The approximate yearly CAPEX for all of Queensland’s civil construction work done from 2016 to 2021 was around \$20.5 billion (ABS, 2021c). **Table 2** below outlines these comparisons. In either case, the renewables boom can be considered a capital intensive prospect on the scale of some of Queensland’s largest industry developments to date.

Figure 2a: Renewables-related annual CAPEX, Queensland, average for 5 year intervals



Source: CSIRO (2022) for CSQ.

Figure 2b: Renewables-related annual CAPEX, Queensland, average 2021-2050

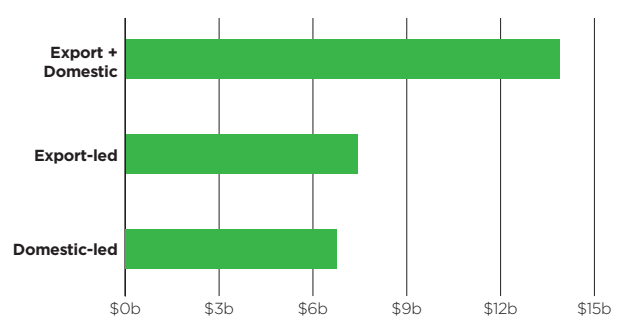


Table 2: Annual CAPEX comparisons, Queensland

Period	Mining boom (2010-2016)	Civil construction (2016-2021)	Renewables Export + Domestic (2021-2050)	Renewables Export-led (2021-2050)	Renewables Domestic-led (2021-2050)
Annual CAPEX (\$b)	\$19.70	\$20.50	\$13.90	\$7.40	\$6.70

Source: ABS, 2021f; ABS, 2021c. CSIRO (2022) for CSQ.

Hydrogen and non-hydrogen infrastructure investment

A remarkable share of annual renewables CAPEX will be specifically for hydrogen-related infrastructure and technology – an estimated 60% (\$4.1 billion) to 80% (\$11.2 billion) of the overall cost structure.

The second area of CAPEX we report on is the division between hydrogen and non-hydrogen types of infrastructure investment required over the forecast horizon. As mentioned, each hydrogen scenario also includes a standard amount of base renewables required to support our non-hydrogen related domestic decarbonisation agenda (ie more electrification from a higher share of renewables).

Figure 3a below overlays the CAPEX required for these base renewables on top of hydrogen-related CAPEX projections. This shows the capital intensive nature of hydrogen infrastructure – which absorbs most annual CAPEX requirements in each time-interval regardless of scenario. This provides direct support for our preliminary hypothesis – that a hydrogen industry in Queensland would be the major driver dictating the size of the renewable energy boom over the long-term.

Earlier periods do however see CAPEX outlays channelled more heavily on base renewables than hydrogen-related projects. This is likely driven by higher market security and current demand for domestic renewable power,

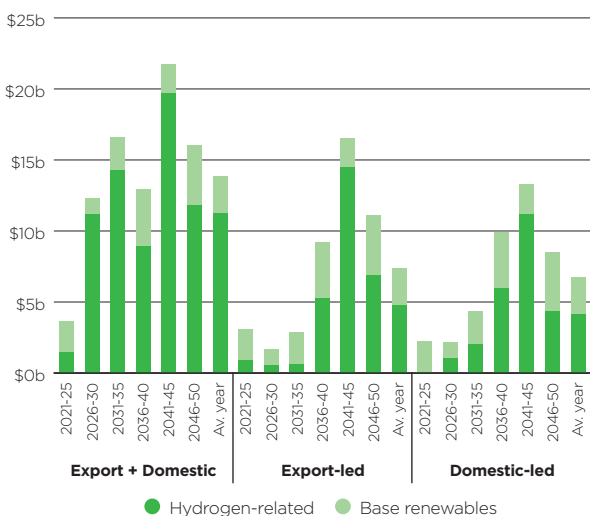
compared to the lesser certainty of hydrogen. This is also consistent with our QREP analysis (2021 to 2025) with solar and wind projects vastly outweighing hydrogen infrastructure announced to date.

In average annual terms, we report that hydrogen CAPEX could account for 60% (\$4.1 billion) to 80% (\$11.2 billion) of all renewables-related CAPEX through to 2050 (**Figure 3b**). This varies again by scenario, with an Export & Domestic hydrogen future requiring more CAPEX and therefore accounting for the upper limit of all costs (80% or \$11.2 billion per year).

The other two scenarios are again very similar in their CAPEX requirements, despite specialising in opposite ends of the future hydrogen market. Hydrogen-related CAPEX in both require between \$4 billion to \$5 billion per year on average to 2050, and each account for around 60-65% of total CAPEX (Export-led, \$4.7 billion, 64%; Domestic-led \$4.1 billion 61%).

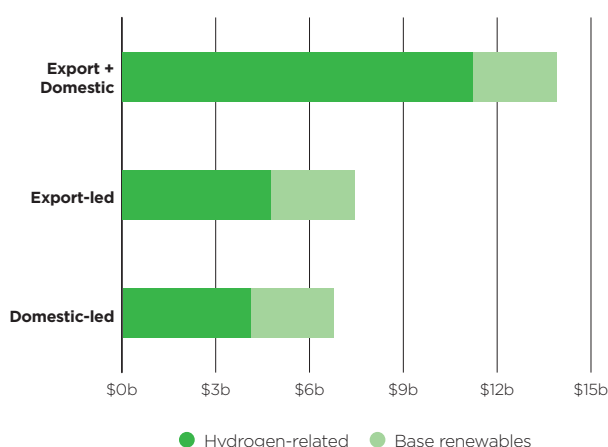
Across all three scenarios, we find that even without the hydrogen industry there would still be substantial CAPEX investment for domestic decarbonisation of electricity use. This is estimated at \$2.7 billion on average per year. The largest component of base renewables (made up of generation and transmission infrastructure) is generation, which constitutes an estimated 79% (\$2.1 billion) of the \$2.7 billion CAPEX annually from 2021 to 2050 (not pictured).

Figure 3a: Renewables-related annual CAPEX, Queensland, average for 5 year intervals



Source: CSIRO (2022) for CSQ.

Figure 3b: Renewables-related annual CAPEX, Queensland, average 2021-2050



3.3 | Capital expenditure (CAPEX) outlook (continued)

Where renewable-related CAPEX will be spent across Queensland

Most renewable-related CAPEX will be spent on infrastructure in regional Queensland - from 62% to 96% of CAPEX per year - with Northern Queensland accounting for the highest amount of investment.

Assessing the locality of future renewables infrastructure in Queensland is a critical component of our study. Past infrastructure booms in Queensland (like the mining and LNG booms) have shown the large impacts concentrated industry development can have on regional communities and economies. Even at this early stage, our QREP analysis indicates how diversely renewables projects are spread across Queensland and are likely to have a sizable impact on regional levels of construction activity in the near-term.

Given this context, we separated our long-term scenario analysis for the whole of Queensland across four regions (or transmission zones) of Queensland. All regions expect South-East Queensland and Wide Bay were in regional Queensland.

We found that, regardless of scenario, the vast majority of CAPEX will be spent on infrastructure in one of the three zones in regional Queensland - from 62% to 96% of CAPEX per year (**Figure 4b**). Arguably, the renewable boom is primarily a regional boom, especially in the second and third scenarios. Given that most of this CAPEX is hydrogen-related, this also means the hydrogen industry will likely be a regional industry.

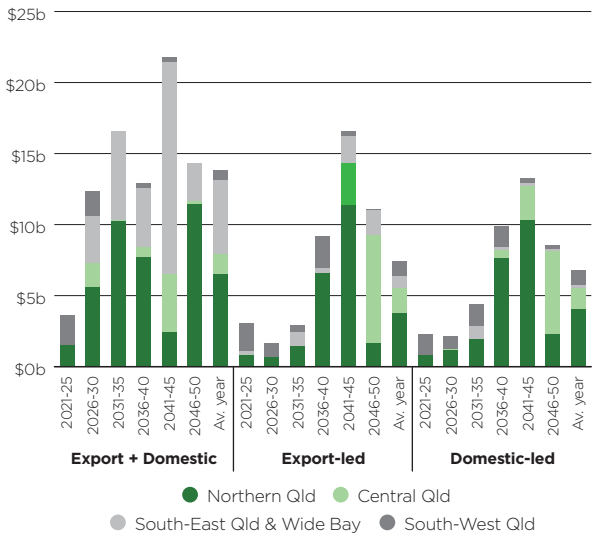
More specifically, we found that Northern Queensland accounts for the largest share of annual average CAPEX across most five year intervals (**Figure 4a**). This was standard across all scenarios, meaning the region is likely to become the home of renewable-related infrastructure in Queensland in future.

Beyond this, the regional picture changes dramatically by scenario and by time-interval. We found that a large export and domestic market for hydrogen in future (ie Export & Domestic) would require concentrated CAPEX in South-East Queensland and Wide Bay, particularly in the peak CAPEX years of 2041-45. Most of this is in investment in renewable generation (solar) and transmission infrastructure to produce green hydrogen in the region. In both other scenarios, a similar result emerged, but with Central Queensland playing this supporting role rather than the South-East corner.

The average annual results over the three decades from 2021 to 2050 help tell these regional stories more clearly. **Figure 4b** shows the regional concentration of CAPEX. Regional Queensland could need from \$6.5 billion to \$8.7 billion per year on average, compared to \$250 million to \$5.2 billion in South-East Queensland and Wide Bay. **Figure 4c** shows Northern Queensland leads CAPEX across scenarios, requiring from \$4.0 billion to \$6.5 billion per year.

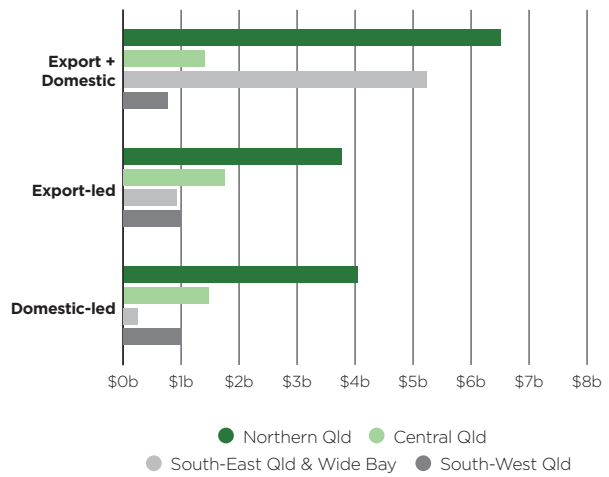
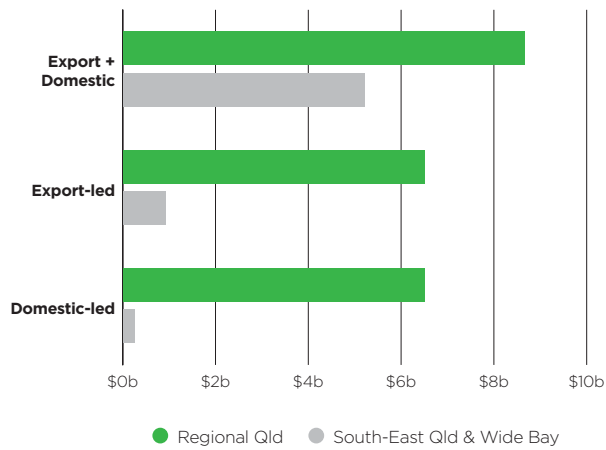
Most base renewables are also delivered in Northern Queensland accounting for 46% of annual CAPEX costs. This is followed by South-West Queensland and accounts for most of that region's renewables-related investment. South-West Queensland has very little role in the hydrogen industry, as will be shown later.

Figure 4a: Renewables-related annual CAPEX, Queensland, 5 year intervals



“The renewables boom is primarily a regional boom. Which means the hydrogen industry will likely be a regional industry – with most CAPEX being spent on hydrogen-related projects in regional areas.”

Figure 4b and 4c: Renewables-related annual CAPEX, Queensland, average 2021 to 2050



Source: CSIRO (2022) for CSQ.

3.3 | Capital expenditure (CAPEX) outlook (continued)

CAPEX for hydrogen-related infrastructure

Annual average CAPEX for all hydrogen-related infrastructure in Queensland from 2021 to 2050 could range from \$4.0 billion to \$11.2 billion – but will likely ramp up dramatically as the industry scales.

Hydrogen is clearly the core driver of CAPEX investment in the long-term renewables outlook for Queensland, so it's critical to report specifically on the CAPEX requirements of hydrogen-related infrastructure.

Importantly, these estimates includes both the direct production and storage of hydrogen (ie electrolyzers and holding tanks), but also the CAPEX required for upstream supply assets (ie renewable generation and transmission infrastructure). Whilst these four areas are possibly not all the major components of the hydrogen-related CAPEX stack (eg hydrogen pipelines, water desalination plants and port infrastructure are not included), they are arguably constitutive of the vast majority of CAPEX, and are the main ones reported here under the banner of 'hydrogen-related' CAPEX. That said, the exclusion of these other elements suggests any reported figures could represent an underestimate.

We estimate that the CAPEX required to meet the infrastructure demands arising from various hydrogen-related futures through to 2050 are substantial for Queensland – and could range from \$4.0 billion to \$11.2 billion per year on average from 2021 to 2050 (**Figures 5a and 5b**).

These estimates vary fundamentally by scenario – suggesting CAPEX requirements do indeed depend on material variations in the market activation rate across

export and domestic domains. Specifically, an Export & Domestic hydrogen industry is more than double the size in yearly CAPEX terms (at \$11.2 billion on average) of either other scenario where only one part of the market activates (\$4.7 billion, Export-led; \$4.0 billion, Domestic-led).

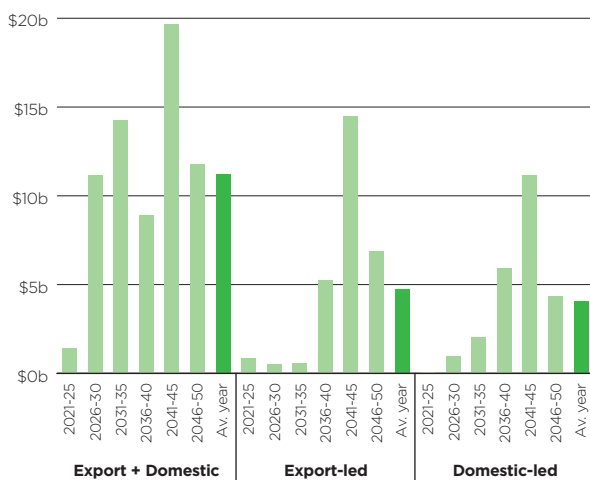
For comparison, yearly CAPEX for all of Queensland's civil construction work done from 2016 to 2021 was around \$20.5 billion. The yearly CAPEX requirements from 2021 to 2050 for Export & Domestic hydrogen capability in Queensland would be equal around 50% of all current civil construction CAPEX undertaken across the state. Both other scenarios equal around 25%.

In either case, any commercial hydrogen industry in the state can be considered a remarkably capital intensive prospect, on the scale of some of Queensland's largest industry developments to date.

Such a long-term average also covers substantial variation from one five year interval to the next (**Figure 5a**). Across all scenarios the 2041-45 period is the most CAPEX intensive – and represents a major period of investment in hydrogen production technology as the industry ramps up. The highest point is for Export & Domestic requiring \$19.7 billion each year on average over this five year period.

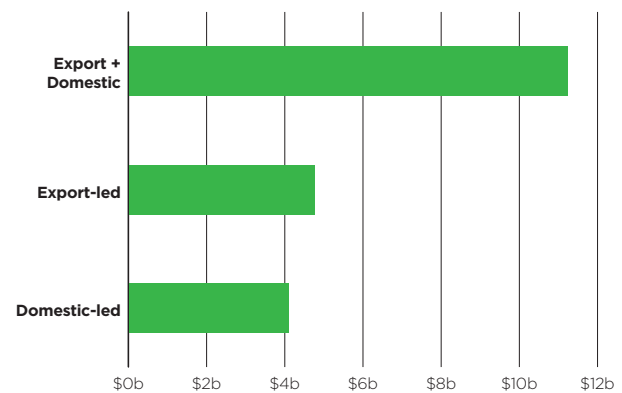
In addition, more than 85% of CAPEX is invested in the later part of the forecast period (from 2036 to 2050) in the second two scenarios (93% in Export-led and 87% in Domestic-led). This is compared to a much more uniform CAPEX spend profile in Export & Domestic. This is driven mainly by vastly more early upstream supply requirements for renewables for Export & Domestic, compared to the other futures modelled (more on this later).

Figure 5a: Hydrogen-related annual CAPEX, Queensland, 5 year intervals



Source: CSIRO (2022) for CSQ.

Figure 5b: Hydrogen-related annual CAPEX, Queensland, average 2021 to 2050





3.3 | Capital expenditure (CAPEX) outlook (continued)

Hydrogen-related CAPEX: by infrastructure type

Across all scenarios the largest component of hydrogen-related CAPEX is the upstream supply of renewable energy rather than the direct production and storage of the resource – upstream supply accounts for an extraordinary 56% to 67% of average annual CAPEX through to 2050.

Hydrogen-related CAPEX can be split into two discrete functional groups. One is the upstream power supply infrastructure and includes both the renewable generation assets and transmission infrastructure. We've called this component of CAPEX 'hydrogen renewables'. This is the core input for the industry and represents a critical supply chain. The process to create green hydrogen – electrolysis – is incredibly energy intensive, and by definition this energy must be sourced from renewables.

The second functional group is the direct infrastructure required to safely synthesise and stockpile commercial volumes of hydrogen. For green hydrogen this includes electrolyser plants, and for blue hydrogen this includes CCS facilities. In both instances, hydrogen may then need to be stored in pressurised tank or other storage systems. This CAPEX grouping therefore includes 'hydrogen production and storage'.

We estimate that while the production and storage component of hydrogen CAPEX is substantial – and in some five-year intervals accounts for most CAPEX – it only accounts for 33% to 44% of annual average CAPEX costs across scenarios (ranging from \$1.4 billion to \$4.8 billion per annum). See Figures **6a and 6b** for details.

The implication is clear. Upstream supply (ie hydrogen renewables) accounts for well over half (56% to 67%) of hydrogen-related annual average CAPEX (ranging from \$2.7 billion to \$6.4 billion). This was a surprising finding and illustrates in clear terms the energy intensive nature of hydrogen production and the flow on effects this has for the CAPEX composition of any future industry.

In addition to this we found an important time-phase dimension to this CAPEX grouping. The proportion of CAPEX required for upstream supply is highest at the early part of the forecast period, and decreases systematically as production and storage investment ramps up, particularly for the Export & Domestic and Export-led scenarios (**Figure 6c**).

This provides a potential insight into the future build out profile and sequencing of the development of Queensland's hydrogen industry. A vast amount of supply infrastructure is required first over the next ten to fifteen years, followed by a ramp up in hydrogen production and storage facility investment.

Again, almost double the CAPEX will be required for both hydrogen renewables and hydrogen production and storage for Export & Domestic compared to either an Export-led or Domestic-led industry.

“In developing Queensland's hydrogen industry, a vast amount of power supply infrastructure will be required first over the next 10-15 years – with a second wave of investment in hydrogen production and storage facilities after that.”

Figure 6a: Hydrogen-related annual CAPEX, Queensland, 5 year intervals

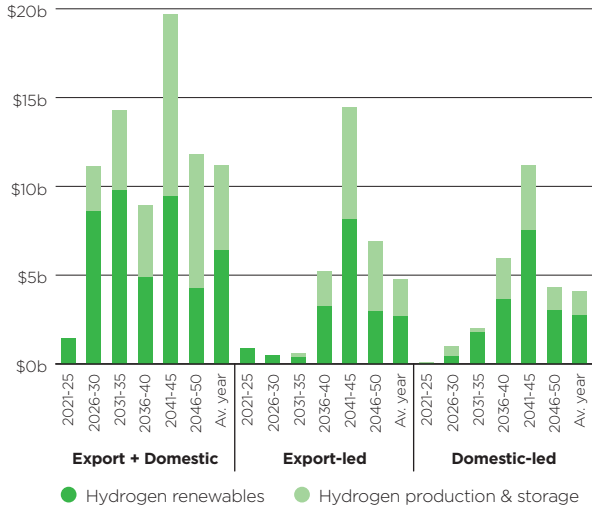


Figure 6b: Hydrogen-related annual CAPEX, Queensland, average 2021 to 2050

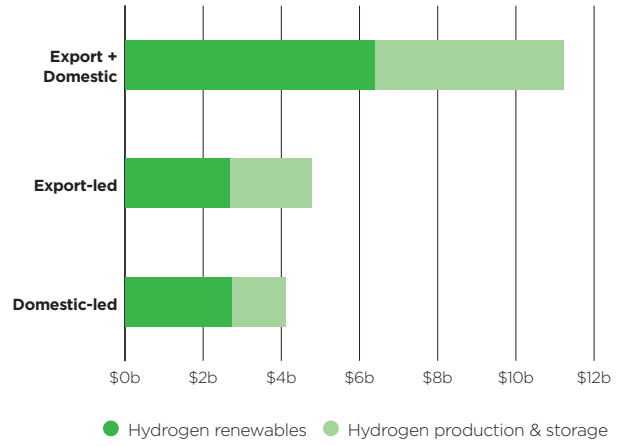
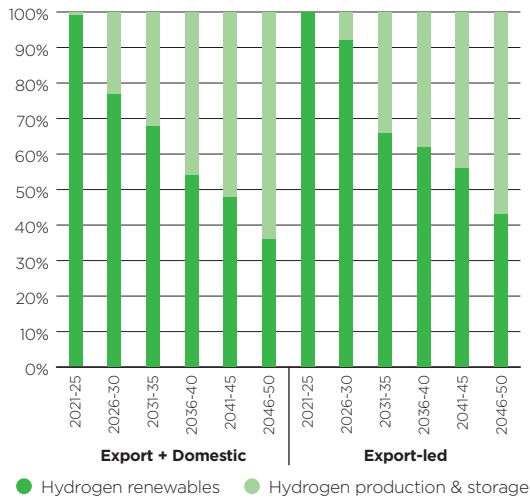


Figure 6c: Hydrogen-related annual CAPEX, Queensland, 5 year intervals, % of costs for two scenarios



Source: CSIRO (2022) for CSQ.

3.3 | Capital expenditure (CAPEX) outlook (continued)

Hydrogen-related CAPEX: generation, transmission, production and storage costs

The majority of upstream supply CAPEX is, in turn, solely for renewable generation infrastructure (eg solar and wind assets) – which accounts for 38% to 55% of all annual hydrogen-related CAPEX, the largest single cost base for the industry.

Even deeper CAPEX profiling is possible by splitting 'hydrogen renewables' into generation and transmission asset costs; and 'hydrogen production and storage' into separate production and storage costs.

This process revealed a set of standard findings across all scenarios. Firstly, a remarkable share of hydrogen renewables CAPEX is specifically in generation infrastructure (ie wind, solar and battery asset deployment) rather than transmission line infrastructure (**Figure 7a and 7b**). Annual generation costs alone could range from \$2.1 billion (Export-led), \$2.3 billion (Domestic-led), to \$4.3 billion per year (Export & Domestic). Across all scenarios, generation CAPEX is the largest single cost base for the industry given these four parts of the hydrogen infrastructure portfolio.

It should be noted that substantial investment in transmission infrastructure is also required, especially in Export & Domestic with an estimated \$2.1 billion per year. A shortfall of transmission infrastructure is considered a potential bottleneck to increased renewable power integrated into the grid. And given its notorious difficulty in being approved, this shortfall could become a risk to the hydrogen futures envisaged (Geiger, 2022; Major, 2021; Wood, 2020). The recent approval of the environmental assessment of the Copperstring 2.0 transmission project in Queensland is a positive sign that large decisions can be made to facilitate progressive development of this critical power infrastructure (Barry, 2022). Yet more work will need to be done.

The majority of hydrogen production and storage CAPEX is, in turn, for hydrogen production facilities and infrastructure (rather than storage) – which accounts for 26% to 35% of total annual hydrogen-related CAPEX. This is second largest cost base for the industry.

Figure 7a: Hydrogen-related annual CAPEX, Queensland, 5 year intervals

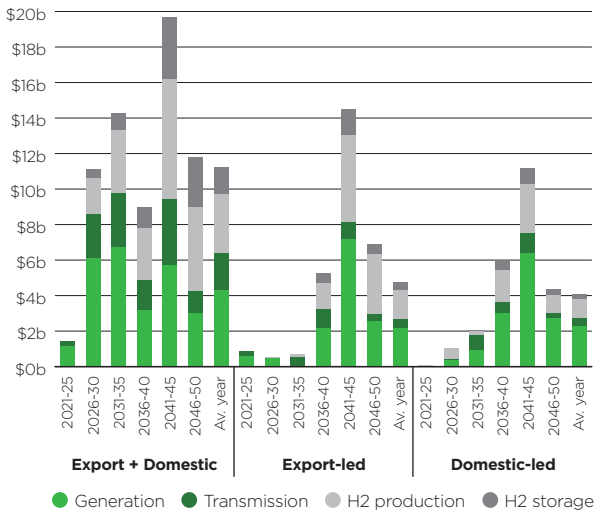
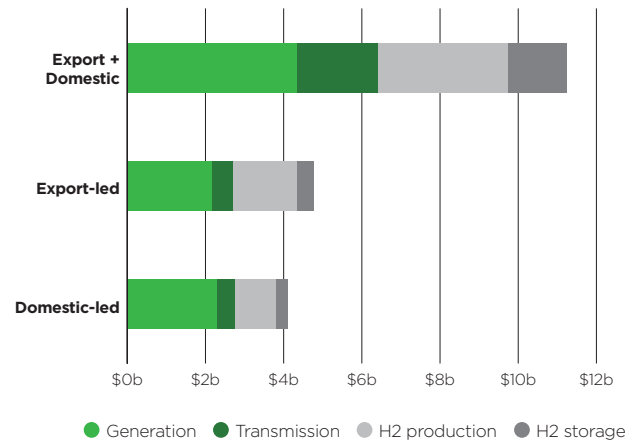


Figure 7b: Hydrogen-related annual CAPEX, Queensland, average 2021 to 2050



Source: CSIRO (2022) for CSQ.

Hydrogen-related CAPEX: upstream renewables infrastructure

Most renewable generation CAPEX will be in wind and solar PV infrastructure - but wind CAPEX is expected to be higher, particularly in certain scenarios.

Upstream renewable generation infrastructure inputs for the hydrogen industry fall into three technologies - solar power, wind power and battery storage. Queensland is fortunate enough to have excellent solar and wind energy resources, which when combined with battery storage systems can be used to supply reliable and affordable renewable power for hydrogen production.

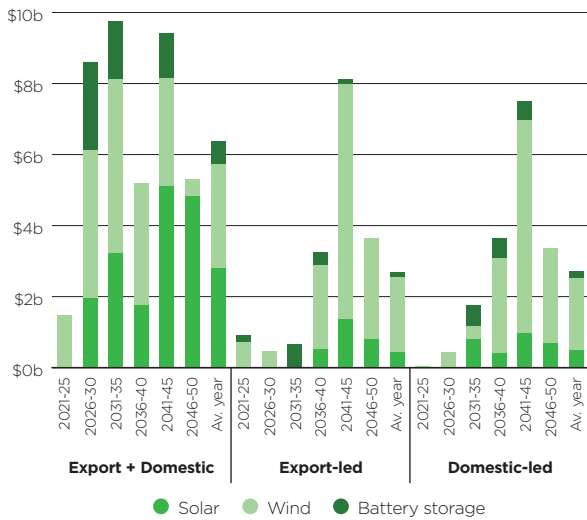
Substantial investment in all three technologies will therefore be essential for each hydrogen future (**Figure 8a**). It's clear that most CAPEX will be for wind or solar - but this composition changes dramatically by scenario. Almost equal investment in upstream wind or solar would be required within Export & Domestic, with \$2.9 billion and \$2.8 billion per year required respectively (**Figure 8b**).

Wind CAPEX is expected to be remarkably higher as a share of generation CAPEX in both Export-led and Domestic-led futures - accounting for a staggering 74% to 80% of renewable generation investment. This is equivalent to an estimated \$2.0 billion to \$2.1 billion per year. Solar CAPEX in real terms is much lower in both these scenarios (around \$450 million).

By implication this means that a similar CAPEX range for wind investment is needed regardless of scenario - between \$2.0 to \$3.0 billion per annum. This adds up to around 26GW of wind power installed by 2050. The major difference for Export & Domestic is that almost the same amount of solar CAPEX is then added on top. This shows the upstream CAPEX impact of having both an Export & Domestic market for hydrogen.

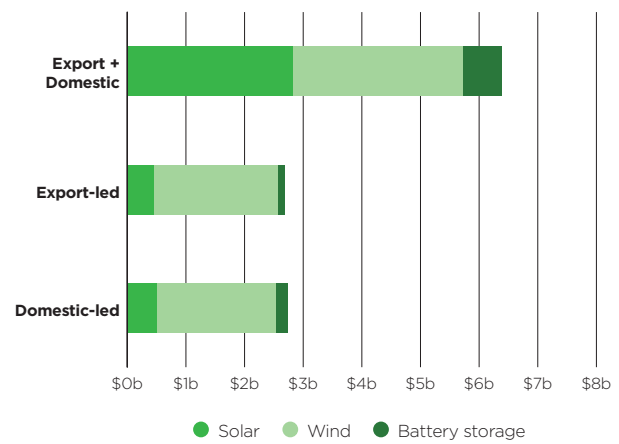
Less than 10% of annual average CAPEX across scenarios are likely to be required for battery storage - from \$100 million to \$700 million per annum.

Figure 8a: Hydrogen-related annual CAPEX, Queensland, 5 year intervals, renewable generation



Source: CSIRO (2022) for CSQ.

Figure 8b: Hydrogen-related annual CAPEX, Queensland, average 2021 to 2050, renewable generation



3.3 | Capital expenditure (CAPEX) outlook (continued)

Hydrogen-related CAPEX: green and blue scenario differences

The CAPEX required for hydrogen production facilities could vary dramatically by scenario between green and blue infrastructure investment.

We estimate that facilities to produce green hydrogen via electrolysis will be a fundamental driver of hydrogen production CAPEX across all three scenarios (**Figure 9a and 9b**). Indeed, virtually all production-related CAPEX in Export & Domestic and Domestic-led scenarios will be for green hydrogen infrastructure (from 91% or \$4.7 billion per year to 98% or \$1.3 billion per year in each scenario, respectively).

But this composition changes dramatically for Export-led where the major hydrogen production CAPEX driver will be for blue hydrogen infrastructure, accounting for 66% of investment (\$1.3 billion). The significant share reflects the scenario assumptions. This scenario has a higher global climate ambition target, thus renewable technology costs are higher. It also has a lower gas price. These two factors combined mean that blue hydrogen is a cost-effective hydrogen production technology in this scenario. More detail on green and blue hydrogen use across scenarios is provided later.

Very little role is foreseen in CAPEX for grey hydrogen production technologies. Accounting for less than 10% of hydrogen production investment. For this reason it has been excluded from the graphs below

Figure 9a: Hydrogen-related annual CAPEX, Queensland, 5 year intervals, hydrogen infrastructure

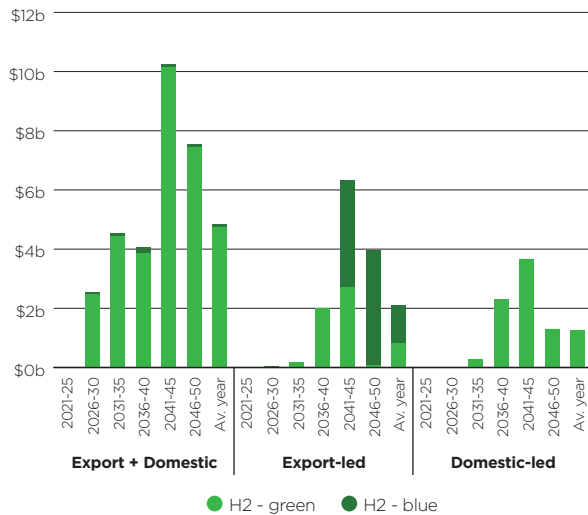
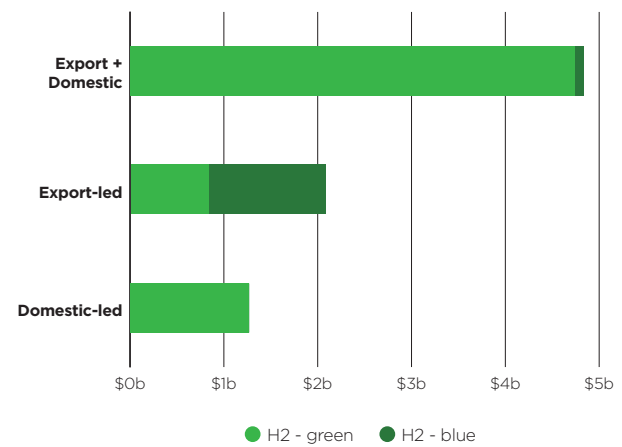


Figure 9b: Hydrogen-related annual CAPEX, Queensland, average 2021 to 2050, hydrogen infrastructure



Source: CSIRO (2022) for CSQ.

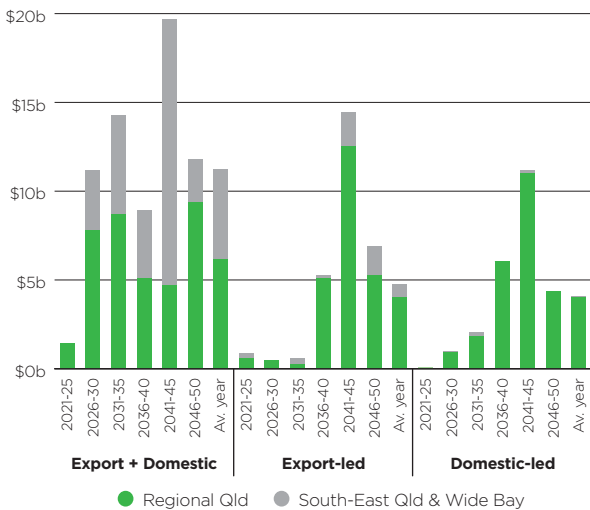
Hydrogen-related CAPEX: by Queensland region

Most hydrogen-related CAPEX will be deployed on infrastructure in regional Queensland - ranging from 55% to a notable 99% of average yearly costs - with Northern Queensland accounting for the highest amount of investment.

As shown in our QREP analysis, certain parts of regional Queensland are already emerging as hotspots of commercial interest in hydrogen production and renewables more broadly. This regionality is likely to continue over the long-term.

We forecast that regional Queensland will play the frontline role in the deployment of hydrogen-related CAPEX infrastructure (**Figure 10a**). Although the size of that role will change by scenario. In Export & Domestic, an estimated 55% of CAPEX will be deployed in regional Queensland (an estimated \$6.2 billion per year). The concentration of the industry in regional parts of the state is much higher in Export-led and Domestic-led scenarios, although the industry itself is smaller in CAPEX terms. In Export-led, 85% (\$4.0 billion) of yearly hydrogen-related CAPEX is spent in regional Queensland, this increases up to a notable 99% (also \$4.0 billion) in Domestic-led.

Figure 10a: Hydrogen-related annual CAPEX, Queensland, 5 year intervals



Source: CSIRO (2022) for CSQ.

3.3 | Capital expenditure (CAPEX) outlook (continued)

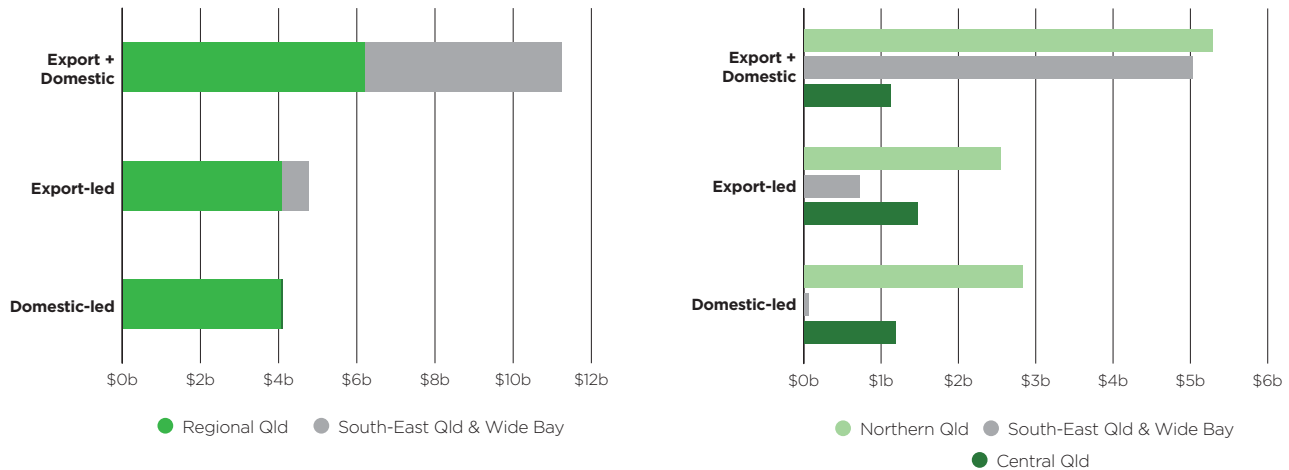
It's clear that any major role for South-East Queensland and Wide Bay in the industry could depend heavily on the emergence of both a strong export and domestic market for hydrogen (ie Export & Domestic). The impact on CAPEX is substantial in this scenario, resulting in around 45% of average annual infrastructure investment through to 2050 in South-East Queensland and Wide Bay, equivalent to \$5.0 billion per year (**Figure 10b**) and staggering \$15 billion on average from 2041-45 (**Figure 10a**).

Looking into specific regions, we found that Northern Queensland accounts for the largest share of annual average CAPEX in all scenarios – and is the likely home of the hydrogen industry (**Figure 10c**). Across scenarios, Northern Queensland accounts for 46% (\$5.3 billion), 53% (\$2.5 billion) and 69% (\$2.8 billion) of average annual hydrogen-related CAPEX from 2021 to 2050 respectively. Beyond the aforementioned role of South-East Queensland and Wide Bay in Export & Domestic, we report that Central Queensland will also account a notable share of CAPEX – particularly in the Export-led and Domestic-led scenarios – accounting for almost one-third of hydrogen-related CAPEX in both scenarios.

Ultimately, the hydrogen boom remains for the most part a regional boom, especially in the Export-led and Domestic-led futures. Yet surprisingly, there could be a critical energy supply and hydrogen production role for South-East Queensland and Wide Bay to meet the extreme levels of demand if both sides of the market (Export & Domestic) activate.

“For the most part, the hydrogen boom will be a regional boom. Although South-East Queensland and Wide Bay could also play a critical role if both sides of the market (export and domestic) activate.”

Figure 10b and 10c: Hydrogen-related annual CAPEX, Queensland, average 2021 to 2050



Note: South-West Queensland excluded as less than 1% of hydrogen investment per scenario. Source: CSIRO (2022) for CSQ.

Revealing the true scale of infrastructure needed: combining hydrogen-related and base renewables CAPEX

Bringing together hydrogen-related and base renewables CAPEX indicates that renewable energy infrastructure (generation and transmission) is likely to be the critical area of future investment – accounting for a stunning 65% to 80% of all renewables boom CAPEX through to 2050.

One of our major findings for hydrogen-related CAPEX was the outsized investment required for upstream supply of renewable power – accounting for more investment on average than the direct production and storage of the resource regardless of scenario.

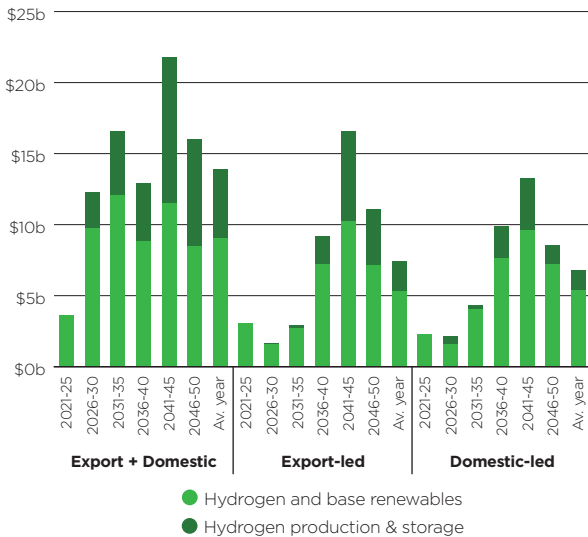
This alone is an extraordinary finding. Yet, sitting outside this is our ‘base renewables’ CAPEX forecast. That is, the additional renewable power required for our broader domestic decarbonisation agenda (ie renewable power used for non-hydrogen reasons like decarbonising electrification across Queensland). Our forecast in this domain is standard and doesn't change by scenario.

Here we combine our hydrogen-related and base renewable CAPEX projections – but split out and combine the renewables for hydrogen and for non-hydrogen purposes. This shows the true scale of the CAPEX for renewable infrastructure (both generation and transmission) required in Queensland through to 2050 to meet both our decarbonisation targets whilst developing a hydrogen industry (**Figure 11a**).

We report that the CAPEX required to achieve these goals ranges from \$5.3 billion to \$9.0 billion per year on average, depending highly on the type of hydrogen future that emerges (**Figure 11b**). In other words, a stunning 65% to 80% share of all renewables-related annual average CAPEX is likely absorbed by renewable energy infrastructure alone.

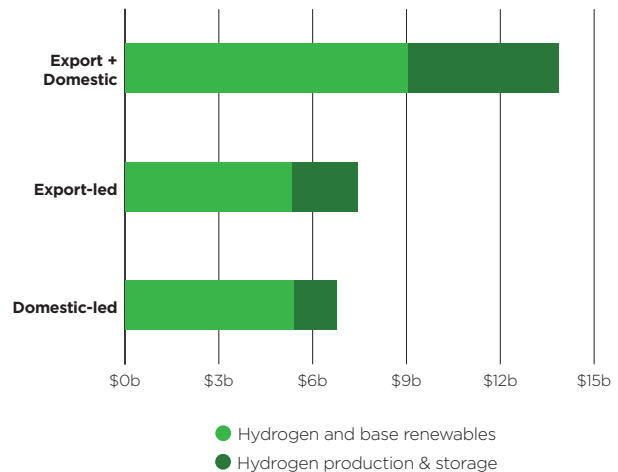
For the upper limit of this outlook (\$9.0 billion per annum in Export & Domestic), this would be the equivalent to almost half all civil construction CAPEX deployed each year in Queensland being redeployed into renewable energy generation and transmission infrastructure for decades. Even the lower bound estimates (\$5.3 billion) would be around 25% of all current civil CAPEX in the state each year to 2050 (the approximate yearly CAPEX for all of Queensland's civil construction work done from 2016 to 2021 was around \$20.5 billion).

Figure 11a: Renewable-related annual CAPEX, Queensland, 5 year intervals



Source: CSIRO (2022) for CSQ.

Figure 11b: Renewable-related annual CAPEX, Queensland, average 2021 to 2050



3.4 | Projected installed capacity and expected output volumes

This section focuses on the various physical capacity inputs and outputs that would be required or enabled across the three scenarios. Inputs are cumulative and include the installed capacity of renewable generation (in Gigawatts, GW) required to meet projected power demand (ie how much solar, wind and battery capacity would be required). For hydrogen inputs, we report on the cumulative electrolyser capacity installation required to produce modelled amounts of green hydrogen (also in GWs). Our main output measure is the amount of hydrogen produced in each scenario yearly through to 2050.

This section will therefore explain the total physical components and measures of Queensland's renewables boom over the longer-term, while outlining the primary drivers and likely construction location of these physical aspects of the industry. Across both inputs and outputs we break down our projected figures by region, technology, and export and domestic usage (where possible).

How much renewable energy will Queensland need to generate?

Cumulative renewable generation capacity required to meet Queensland's energy needs (hydrogen-related and base renewables) by 2050 could range from 105GW to 192GW (depending on scenario).

The renewable energy inputs stemming from a future hydrogen industry in Queensland would be substantial. Producing green hydrogen is an energy intensive process and by definition this power must be from solely renewable sources. In addition, we also need an unprecedented amount of renewable power for domestic decarbonisation. That is, the processes (like renewable electrification) which don't interact with the hydrogen market at all but are critical to a net zero economy.

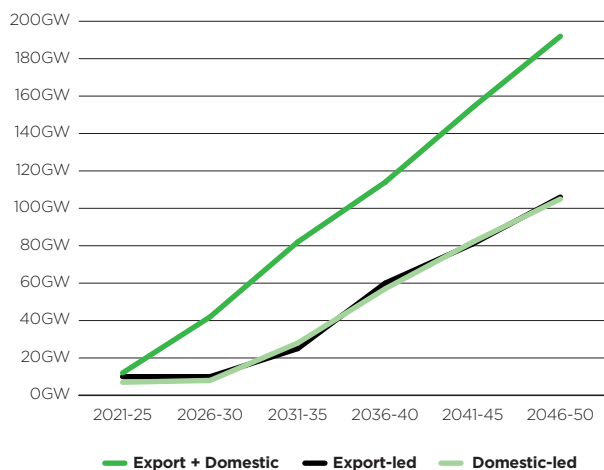
We estimate that the cumulative generation requirements for renewables required for Queensland's through to 2050 are extraordinary. Cumulative installed capacity by 2050 could range from 105GW to 192GW depending on scenario (Figure 12a). This would require a meteoric transformation of our energy network.

To put this into perspective, the current total installed capacity of all generation in Queensland is around 16.2GW if fossil fuels are included (Queensland Government, 2022). Renewables account for 3.8GW of this. This means Queensland would need an energy system 6.5 to 12 times larger than what we have now by 2050. For renewables only, this would be 27 to 50 times larger than current capacity.

Figure 12b shows this in annual average terms. To achieve Export & Domestic requirements we would need to install 6.4GW on average per year and every year to 2050. This would mean adding substantially more than all our current renewables capacity (3.8GW) in Queensland every year (on average). The Export-led and Domestic-led scenarios would require us to almost match this 3.8GW each year on average for the next thirty years (3.5GW per annum is required in Export-led and Domestic-led scenarios).

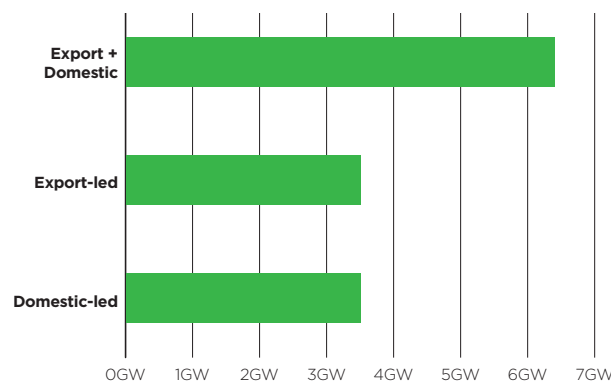
Like CAPEX, these estimates vary fundamentally by scenario - with the firing of both the export and domestic market for hydrogen stimulating capacity requirements 1.8 times higher (reaching 192GW) than a future in which only one side of the market materialises (around 105GW for either). This again shows how different sectors of market activation could have large impacts on the fundamentals of the future.

Figure 12a: Renewable power generation, cumulative installed capacity, all renewables-related activity, Queensland



Source: CSIRO (2022) for CSQ.

Figure 12b: Renewable power generation, average annual installed capacity (2021 to 2050), all renewables-related activity, Queensland



3.4 | Projected installed capacity and expected output volumes (continued)

Renewable generation: hydrogen and non-hydrogen types of demand

An extraordinary share of renewable generation would be utilised downstream for hydrogen production – ranging from 44% (46GW) to almost 70% (133GW) of all generation capacity added through to 2050. Base renewables would consume the remainder.

The second area of renewable capacity requirements we report on is the division between hydrogen and non-hydrogen types of demand. As mentioned, each hydrogen scenario includes both the hydrogen-specific component and the standard base renewables needed to support our non-hydrogen related domestic decarbonisation agenda.

Figure 13a overlays the cumulative capacity requirements for these base renewables on top of that which is hydrogen-related. This shows just how remarkably energy intensive the production of hydrogen is – accounting for from 44% to 70% of cumulative generation capacity requirements over the forecast period (**Figure 13a**). This means a hydrogen industry alone would require from 46GW (in Export-led or Domestic-led) up to 133GW (Export & Domestic) of installed generation capacity by 2050. On annual average terms this equates to 1.5GW per annum in Export-led and Domestic-led, and a mammoth 4.4GW in Export & Domestic (**Figure 13b**).

It is astounding that in Export & Domestic for example, the hydrogen industry alone by 2050 would require more than eight times all the current generation capacity installed in Queensland (16.2GW versus 133GW). By that time in Export & Domestic, the hydrogen industry would likely require more renewable power than the entire amount needed for non-hydrogen domestic decarbonisation (ie base renewables).

Yet, even if a hydrogen industry didn't materialise in Queensland in the future, we would still need to increase our installed capacity by 3.6 times by 2050 compared to now as base renewables require 59GW of power capacity added by 2050 (or around 2GW per year). This is a material consideration regardless of scenario, and base renewables actually accounts for more than half of installed capacity additions forecast for the Export-led and Domestic-led scenarios (around 56% in both).

Overall these capacity findings clarify and quantify just how power intensive the renewables boom could be in Queensland, and the game changing role hydrogen could play in renewable generation requirements. Such staggering capacity growth pathways also show why renewable generation is the major CAPEX cost base for the future hydrogen industry. This CAPEX is predicated on an incredibly large scale deployment of the vast amount of renewable power assets required.

Figure 13a: Renewable power generation, cumulative installed capacity, all renewables-related activity, Queensland

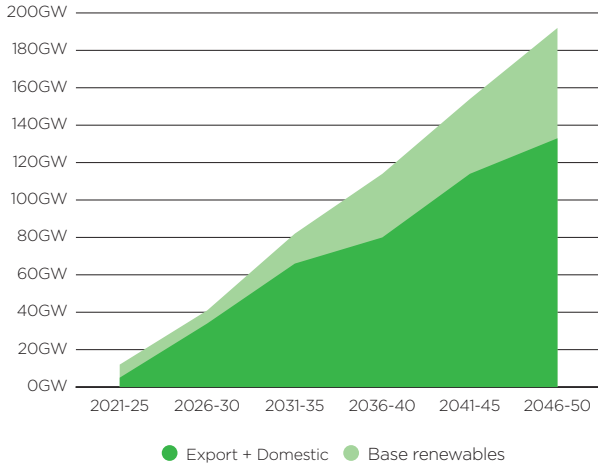
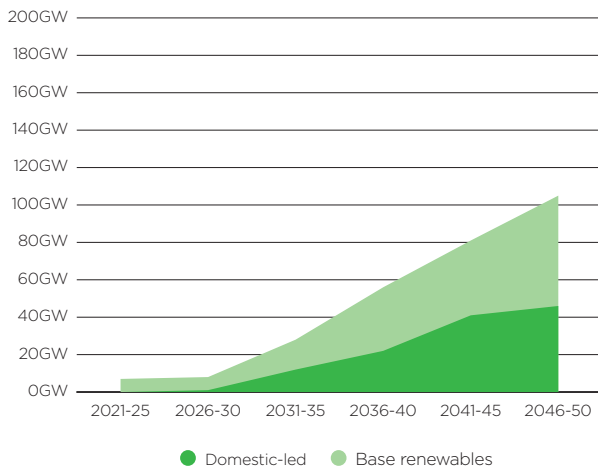
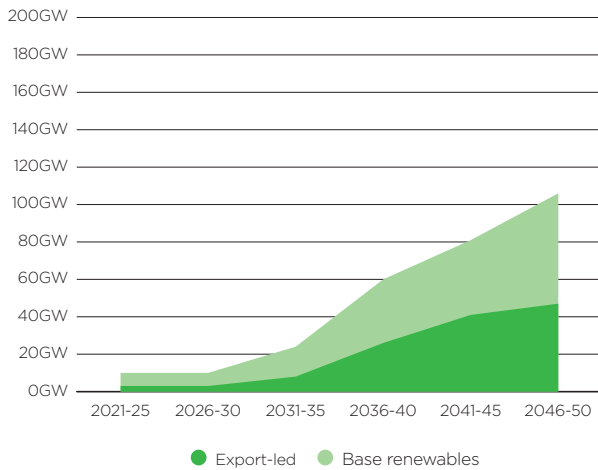
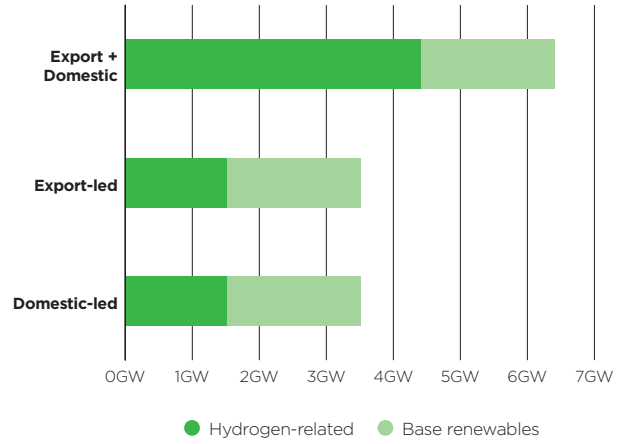


Figure 13b: Renewable power generation, average annual installed capacity (2021 to 2050), all renewables-related activity, Queensland



Source: CSIRO (2022) for CSQ.

3.4 | Projected installed capacity and expected output volumes (continued)

Balancing capacity across solar, wind and battery storage

A mix of renewable generation sources will be required to meet future demand regardless of scenario – but solar to dominate in an export and domestic market for hydrogen.

Critical to Queensland's competitive advantage in the hydrogen and renewables outlook is an abundance of both wind and solar resources. This mix, in combination with extensive battery storage options, is essential to achieving the type of ramp up in renewable generation outlined in the preceding section. Here we report on the most cost-effective portfolio of generation technologies our model identified to satisfy all renewables-related generation demand out to 2050 (ie for hydrogen and non-hydrogen uses by scenario).

Figure 14a shows that each future will draw upon the natural capital endemic to the state – and utilise a combination of solar, wind and battery storage technologies. However, it's clear that solar will likely dominate if both an export and domestic market for hydrogen materialises. More specifically, we found in Export & Domestic just over half (51%) of renewable power will be from solar PV, with a cumulative installed capacity of 99GW by 2050. This equates to installing a yearly average of around 3.3 GW of solar infrastructure over the next three decades (**Figure 14b**), close to all Queensland's current renewables put together (3.8GW). The amount of solar capacity required in this scenario is hard to overstate, equivalent to almost all the renewable capacity required for all technologies in the Export-led and Domestic-led scenarios. The remainder is divided between battery storage (52GW cumulative) and wind infrastructure (41GW cumulative).

A differently weighted portfolio emerged for the other two scenarios, which are very similar. In both cases, its wind infrastructure that dominates rather than solar. Wind accounts for around 40% of renewable generation capacity with 41GW in each scenario (the same amount of wind capacity also in Export & Domestic). More cumulative battery storage (36GW, 35%) is also needed than solar (28GW, 27%). These ratios are similarly reflected in the average yearly figures for Export-led and Domestic-led scenarios, with wind, battery storage and solar requiring around 1.2GW, 1.3GW and 0.9GW respectively on average each year from 2021 to 2050.

Across all scenarios then, the average installed capacity for wind and battery storage is similar. It's the ramp up in solar that's the key add-on in Export & Domestic that changes the aggregate trajectory of installed capacity over time. Almost 3.5 times more solar capacity is needed in this future, than the other two scenarios.

Figure 14a: Renewable power generation, cumulative installed capacity, all renewables-related activity, Queensland

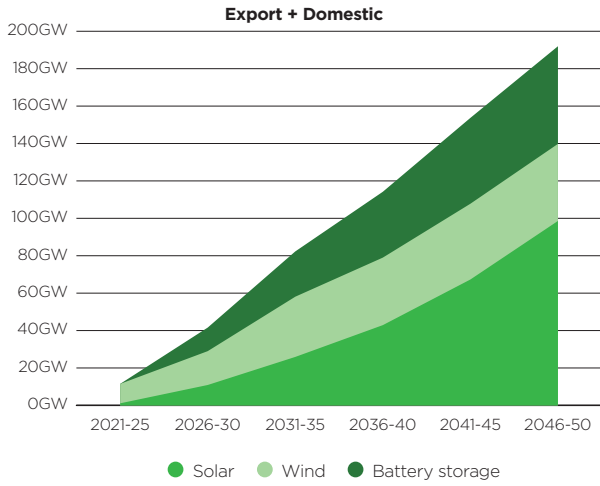
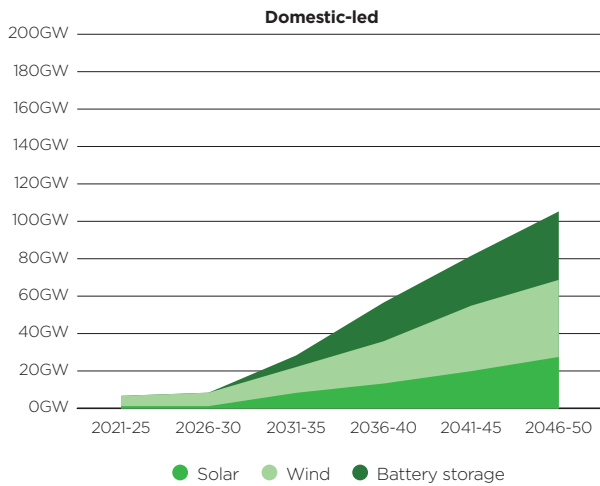
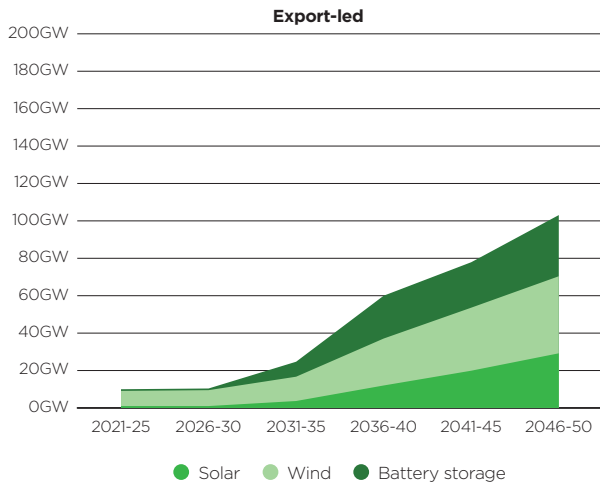
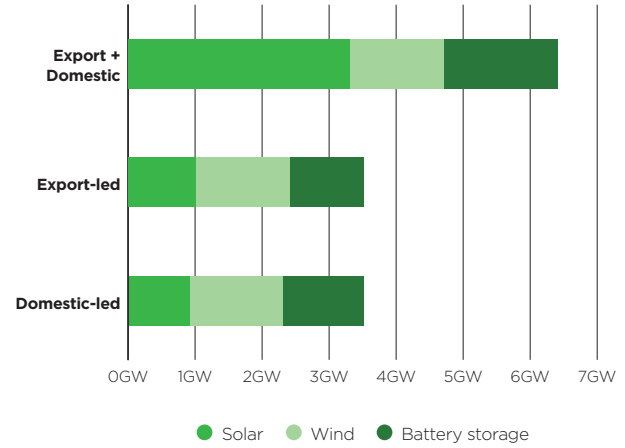


Figure 14b: Renewable power generation, average annual installed capacity (2021 to 2050), all renewables-related activity, Queensland



Source: CSIRO (2022) for CSQ.

3.4 | Projected installed capacity and expected output volumes (continued)

Estimating regional Queensland's renewable generation capacity

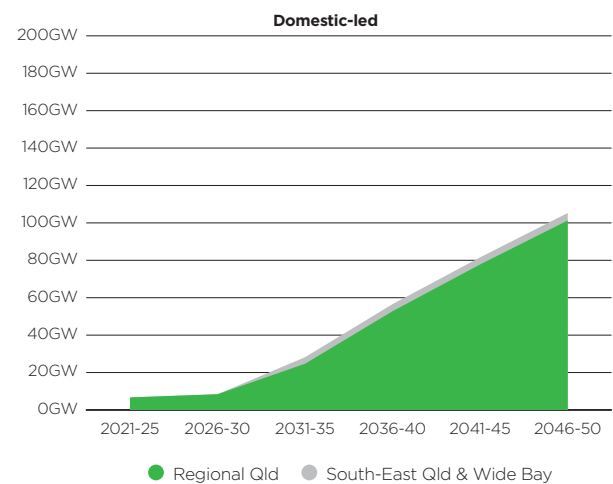
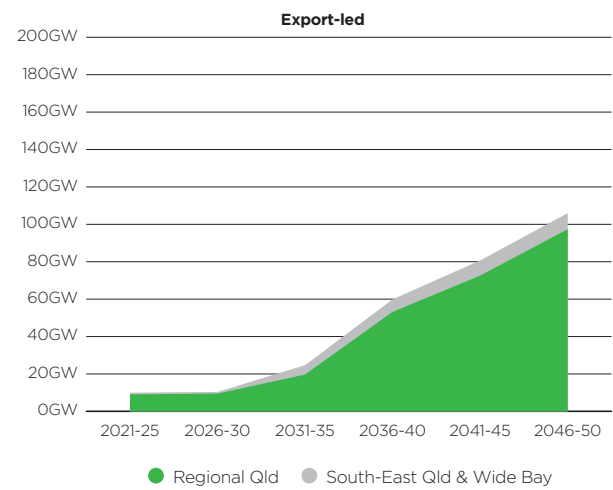
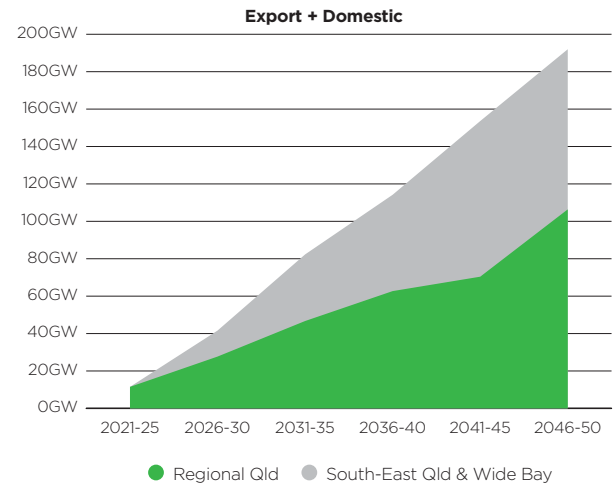
Most renewable generation capacity will be added in regional Queensland – ranging from 55% to 96% of total installation by GW (depending on scenario)

Queensland's abundance of wind and solar resources are not uniformly available across the state and are instead of higher quality in certain areas relative to others. This has significant impacts on the locality of our modelled renewables capacity results. **Figures 15a, b and c** provide comprehensive findings on the probable geography of this vast amount renewable capacity required across scenarios.

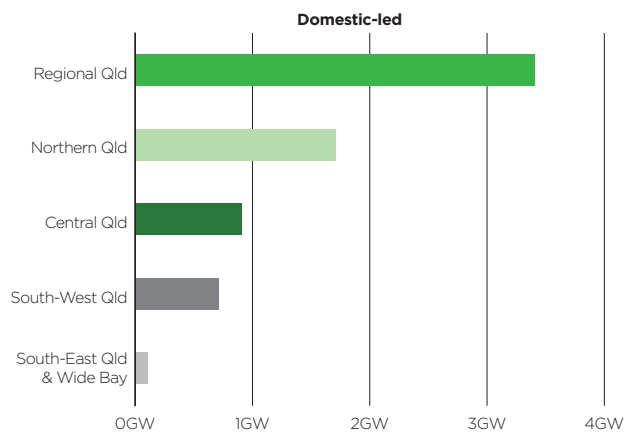
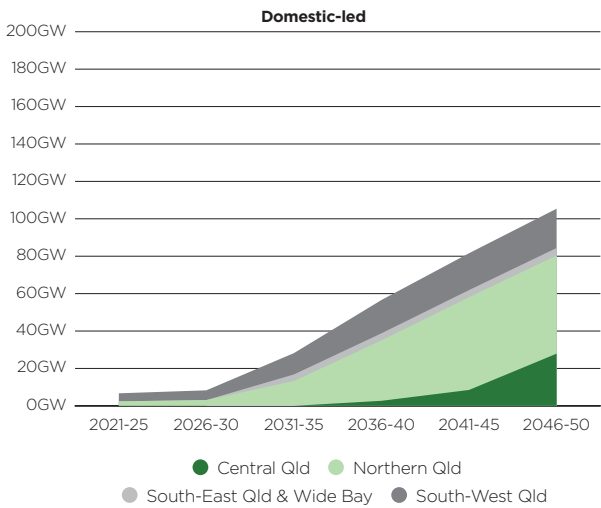
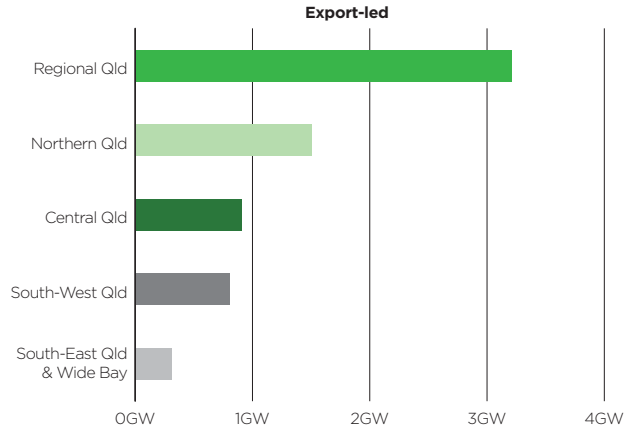
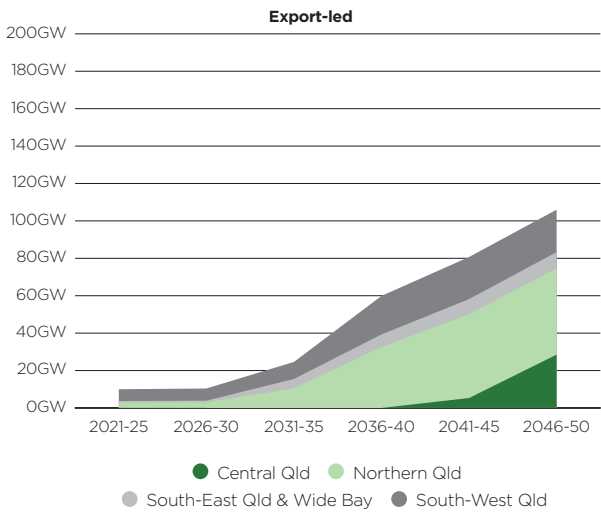
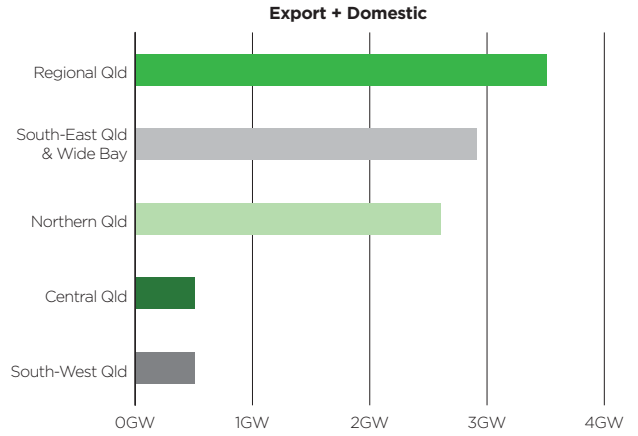
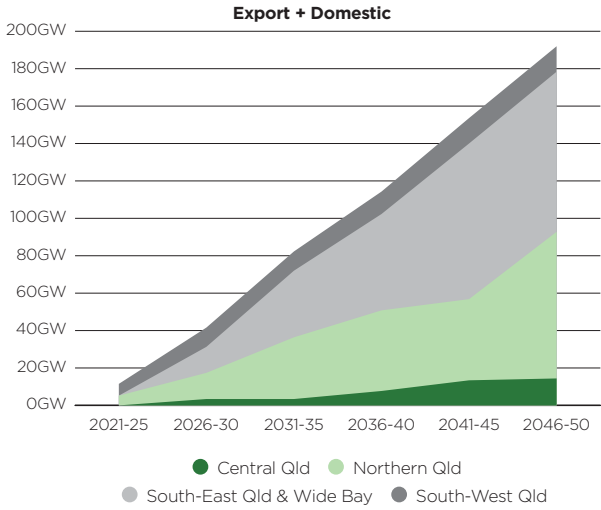
Our model suggests that, regardless of scenario, regional Queensland will host most renewable capacity through to 2050 ranging from 55% in Export & Domestic, to 92% and 96% in Export-led and Domestic-led respectively. The amount of installed capacity in regional Queensland is also similar across these futures – from 106GW, 97GW, 101GW. The major difference again is for Export & Domestic, which includes a vast amount of additional capacity in the South-East Queensland and Wide Bay area (86GW). Most of this capacity is in solar (not pictured).

The inclusion of South-East Queensland and Wide Bay also changes the results at the specific region level for Export & Domestic. As mentioned, South-East Queensland and Wide Bay is both a major and minor region in our analysis, which is most clearly discernible in the average annual figures. In Export & Domestic, South-East Queensland and Wide Bay accounts for the largest renewable capacity of any region (2.9GW per annum) followed closely by Northern Queensland (2.6GW). While for Export-led and Domestic-led Northern Queensland is the largest (1.5GW, 1.7GW per year respectively) and Central Queensland is second (1.0GW for each scenario). Across these scenarios, South-East Queensland and Wide Bay hardly features as part of the renewable generation network.

Figure 15a,b,c: Installed generation capacity, cumulative by major region; cumulative by minor region; average annual, top to bottom by scenario, Queensland



Source: CSIRO (2022) for CSQ.



3.4 | Projected installed capacity and expected output volumes (continued)

Estimating Queensland's installed electrolyser capacity

Cumulative installed electrolyser capacity could range from around 50GW to 269GW by 2050 – spanning a possible 6- to 36-fold growth from our 2025 pipeline estimates for Queensland (7.5GW).

A major measure of any future hydrogen industry is the overall size in GW of installed electrolyser capacity. Electrolysis is the process by which green hydrogen is produced. It uses an electrolyser powered in turn by renewable generation assets like those previously outlined to split hydrogen and oxygen from water molecules.

Importantly, electrolyser size doesn't quantify the energy created in this process, but the amount of energy used (it is the opposite of generation on this measure). For this reason, this section only concerns hydrogen-related measures and doesn't include base renewables, it also only refers to green hydrogen production, with blue discussed later.

Electrolyser capacity has also emerged as a rough but standardised proxy of the size of green hydrogen industries expected to emerge throughout the world as the race to net zero intensifies. As a benchmark for what follows, the global installed electrolyser capacity for green hydrogen production in 2020 was only 0.3GW.

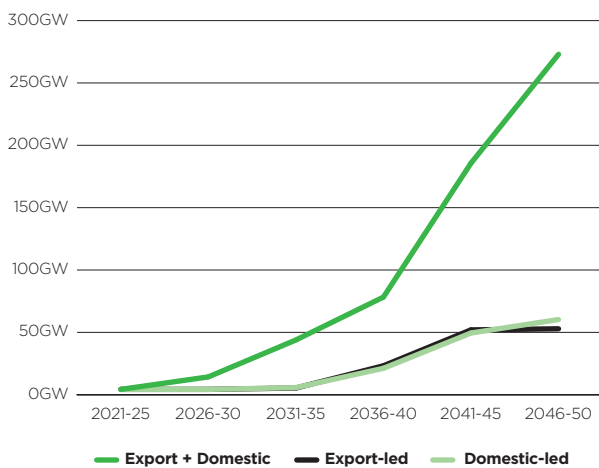
Global installed electrolysis capacity is estimated to reach around 80GW by 2030, and an estimated 500 to up to 3,200GW by 2050 (Clarke et al, 2022).

Our modelled figures of the cumulative installed electrolyser capacity required by scenario in Queensland are presented in **Figure 16a**. Again, by 2050 Export-led and Domestic-led scenarios are similar requiring from 49GW to 56GW. These are dwarfed by the requirements of Export & Domestic – an astounding five to six times larger stretching to 269GW. These capacity requirements are significant and represent a possible 6- to 36-fold growth from our 2025 pipeline estimates for Queensland (at 7.5GW).

In annual installation terms, an estimated 9GW of additional capacity would be needed each year to meet requisite volumes of green hydrogen required in Export & Domestic, compared to around 2GW in either other scenario (**Figure 16b**).

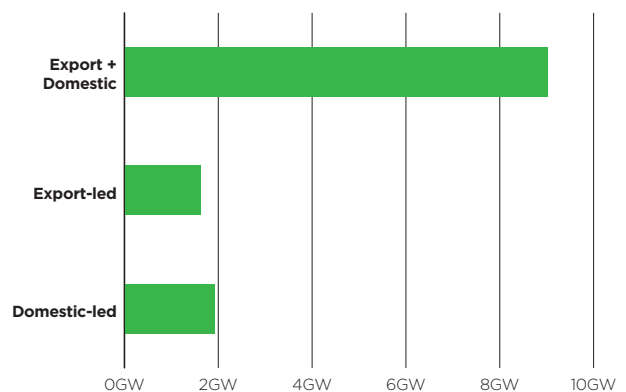
Two drivers account for the difference between scenarios. The first is the different volumes of hydrogen to be produced across scenarios, the second is that in Export-led a substantial proportion of hydrogen is produced via blue methods (SMR+CCS) which does not use electrolysers. Both of these drivers are discussed further later.

Figure 16a: Cumulative installed electrolyser capacity, hydrogen-related activity, Queensland



Source: CSIRO (2022) for CSQ.

Figure 16b: Average annual installed electrolyser capacity (2021 to 2050), hydrogen-related activity, Queensland





3.4 | Projected installed capacity and expected output volumes (continued)

Which regions will host Queensland's installed electrolyser capacity?

We estimate that most electrolyser capacity used for the production of hydrogen will be installed in regional Queensland – with Northern Queensland accounting for the largest share.

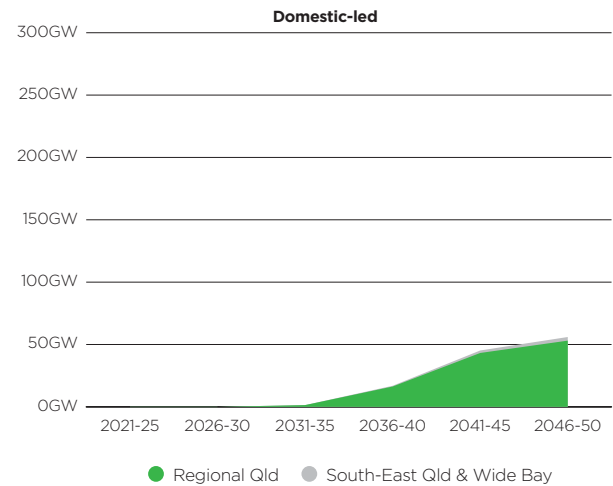
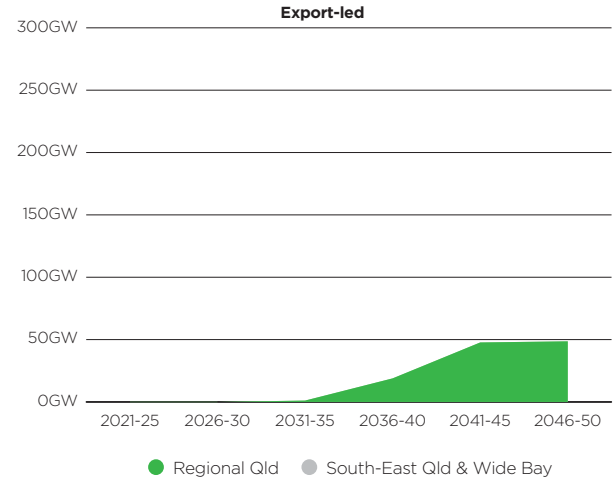
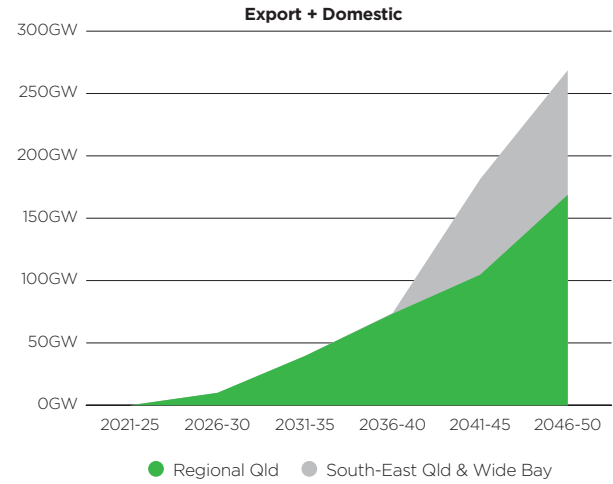
One critical question about the future hydrogen industry in Queensland is its location. Here we present electrolyser installation projections by major and specific regions of the state, in both cumulative and average annual terms.

Our modelled outputs suggest the most cost-effective location for the major share of electrolyser capacity will be regional Queensland, and that this share ramps up dramatically by scenario (**Figure 17a**). In Export & Domestic, around 169GW of electrolyser capacity could be installed by 2050 in regional Queensland, accounting for around 63% of all the state's electrolyser capacity. The remaining 100GW would be in South-East Queensland and Wide Bay. The share installed in regional Queensland moves up to 95% in Domestic-led (53GW) and 100% in Export-led (49GW).

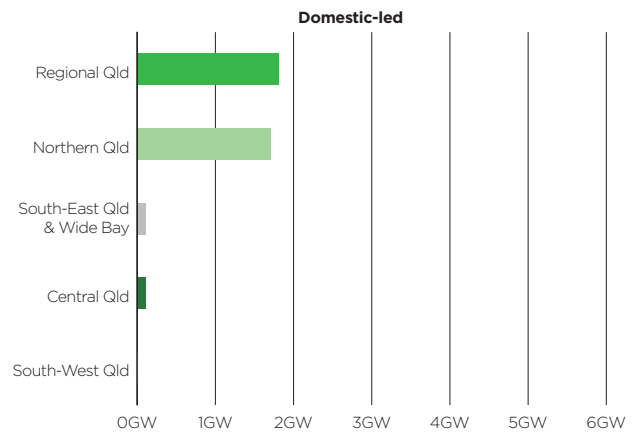
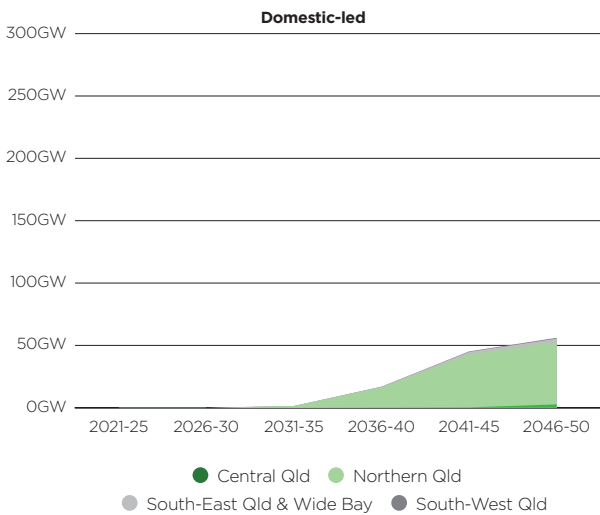
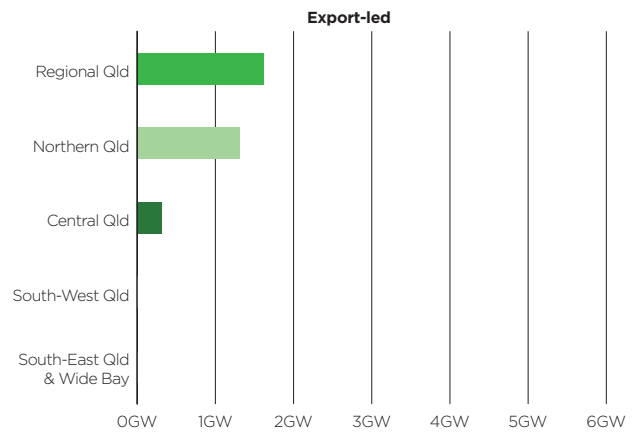
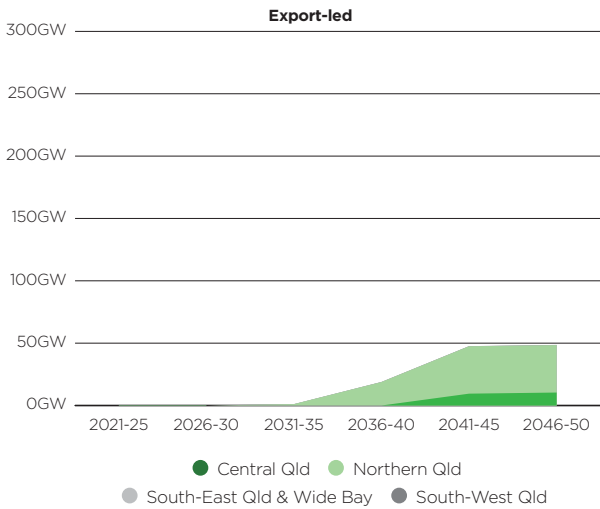
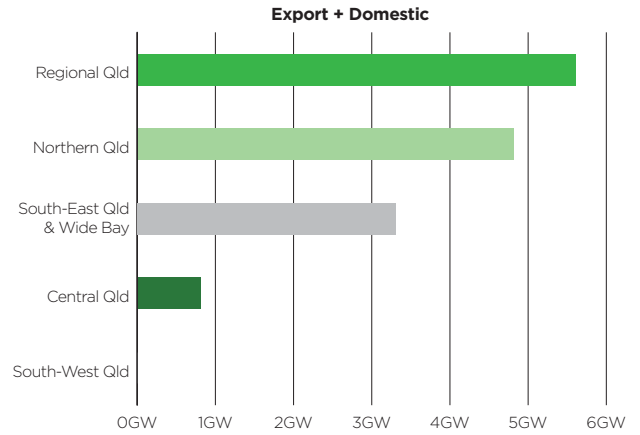
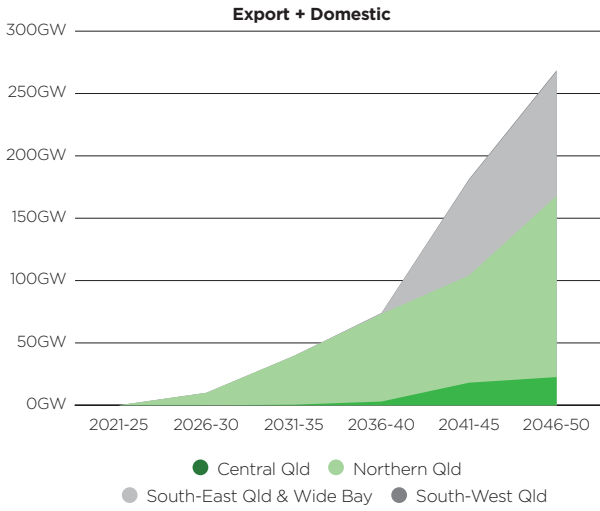
Northern Queensland is predicted to be the main location for electrolyser capacity regardless of scenario (**Figure 17b, 17c**). We estimate that 145GW of installed electrolyser capacity could exist in Northern Queensland by 2050, and account for more than half the state's electrolysis (54%) in Export & Domestic. This share is much higher in Export-led and Domestic-led (78% and 89%) but the overall electrolyser capacity is lower (38GW; 50GW).

Northern Queensland's prime position corroborates well with recent research suggesting it could become the most cost-effective location for hydrogen production in Australia by 2030 and 2040 (Percy, 2022). This is in addition to Northern Queensland containing the majority of ports for the likely export of larger volumes of hydrogen than the other parts of the state.

Figure 17a,b,c. Installed electrolyser capacity, cumulative by major region; cumulative by minor region; average annual, top to bottom by scenario, Queensland



Source: CSIRO (2022) for CSQ.



3.4 | Projected installed capacity and expected output volumes (continued)

Unlocking Queensland's hydrogen export potential

Scaling up the hydrogen industry in Queensland could see from 3,100 to 8,000kt/year produced by 2050 – with more than 70% bound for export regardless of scenario.

The amount of renewable energy and electrolyser capacity added will obviously enable a large output of hydrogen between the early 2020s and 2050. It's estimated that unlocking these inputs could see average yearly hydrogen production volumes more than doubling each decade from 2030 to 2050 across each scenario, all from a current baseline of zero (**Figure 18a**).

These hydrogen output volumes vary by scenario. We estimate that if both export and domestic demand materialises (Export & Domestic) then around 8,000kt of hydrogen could be produced in Queensland annually by 2050. This is around 30% higher than Export-led and around 2.5 times Domestic-led. Yet in both these latter scenarios, the 6,000 and 3,100kt/year produced annually by 2050 would still be non-trivial and draw upon substantial infrastructure and power assets, and require the development of a completely new industry in the state.

Figure 18b shows these same results by export and domestic use of hydrogen. As can be seen the majority of hydrogen produced in Queensland would be bound for export. This finding was consistent across all scenarios, even the scenario which had a low export but high domestic uptake assumption. Ultimately, our findings suggest the future hydrogen industry in Queensland is primarily as an export industry, and it's the export-orientated scale up that then drives any material uptake of hydrogen for domestic use in the state.

“Queensland's hydrogen industry will be mainly an export industry, and it's the export-orientated scale up that then drives any material uptake of hydrogen for domestic use in the state.”

Regarding export volumes, the highest amount is estimated for the Export & Domestic scenario. Our model suggests in this scenario around 6,000 of the 8,000kt/year of hydrogen produced by 2050 could be for export (an astounding 75% share). This would be equivalent to around one third of Australia's total hydrogen exports (18,000kt/year).

Even though the aggregate amount of exported hydrogen is less in Export-led and Domestic-led scenarios (4,400kt/year and 3,000kt/year), the share bound for export is close to equal (73%) or higher (93%) to Export & Domestic. It is surprising that a larger share of hydrogen production is exported under Domestic-led (given this is the Export Low, Domestic High). Clearly, having a strong hydrogen export industry has flow on effects for domestic use of hydrogen. Domestic use of hydrogen is not driving export.

These results are critical as they relate back to a primary goal of this paper. We set out to model variations in export and domestic market activation on the size of the hydrogen industry. We posited the main driver of industry size would be the relative demand in both export and domestic markets. And that a strong domestic sector may prove key to export success. These propositions can be clarified in light of our findings. The main driver of industry size will likely be variations in the export market, and it's the export sector that will prove key to domestic uptake.

Figure 18a: Hydrogen production volumes, per year for 5 year intervals, Queensland

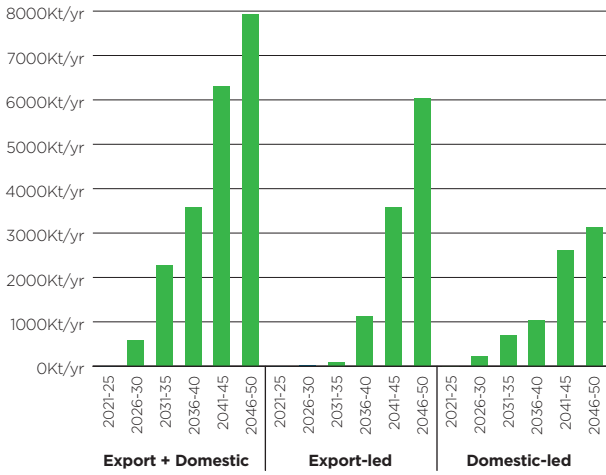
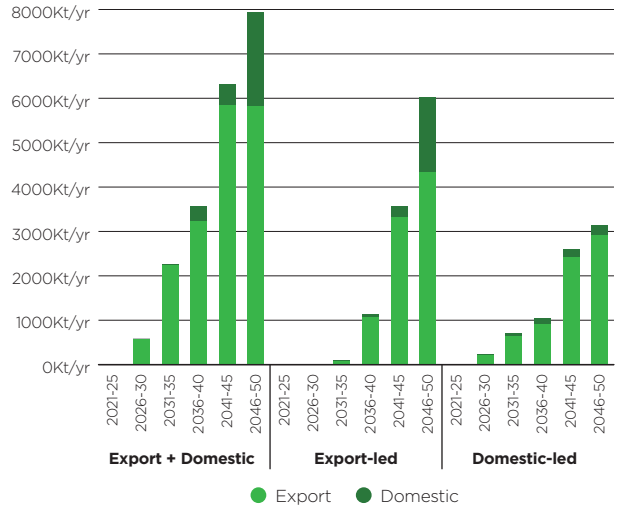


Figure 18b: Hydrogen production volumes, per year for 5 year intervals, Queensland



Note: These figures are presented in yearly average terms for each five year interval, and are not cumulative.
Source: CSIRO (2022) for CSQ

3.4 | Projected installed capacity and expected output volumes (continued)

Queensland's hydrogen industry: it is green or blue?

The predominance of green or blue hydrogen depends upon scenario - with both having the potential to play a critical role in Queensland's emerging hydrogen industry.

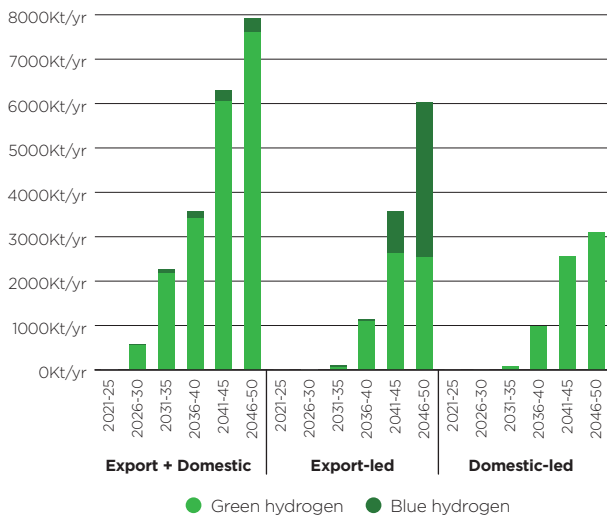
We primarily focus on the blue and green clean hydrogen production routes for the purpose of this report and paths to net zero. At present, these are the main commercialised routes of clean hydrogen production.

Figure 19 reports on the share of green and blue hydrogen produced under each scenario. It's evident that green hydrogen is critical to each future, and accounts for 96% of production in Export & Domestic (7,600 kt/year),

and all (100%) produced in Domestic-led (3,000 kt/year). However, in Export-led, a larger share of the hydrogen produced each year is from blue sources by 2050 (58%, 3,500 kt/year) than green sources (42%, 2,500 kt/year). This blue hydrogen is likely to be produced in equal parts Northern Queensland and South-East Queensland and Wide Bay (not pictured).

The significant share of blue hydrogen production reflects the scenario assumptions. The Export-led scenario has a lower global climate ambition target, thus renewable technology costs are higher. It also has a lower gas price. These two factors combined mean that blue hydrogen (using SMR+CCS) is a cost-effective hydrogen production technology in this scenario.

Figure 19: Hydrogen production volumes, per year for 5 year intervals, Queensland



Note: These figures are presented in yearly average terms for each five year interval, and are not cumulative.
Source: CSIRO (2022) for CSQ.

Hydrogen production: finding a home in Northern Queensland

By 2050, most of the state's hydrogen will be produced in regional Queensland - from 66% to 96% of total state output by volume - with most of this produced solely in Northern Queensland.

Across both green and blue methods our model has selected regional Queensland as the most cost-effective location for hydrogen production. This finding was consistent across all scenarios. This maps well with the capacity measures already reported, with the majority of renewable generation assets and electrolyser capacity co-located in the regional parts of the state.

This means, despite which future emerges by 2050, most of the state's hydrogen will likely be produced in regional Queensland. But both the share and volume will vary by scenario (**Figure 20a**). An estimated 5,200 kt/year of hydrogen is forecast to be produced in regional Queensland in Export & Domestic (66% of all hydrogen produced). From 4,500 kt/year (74%) to 3,000 kt/year (96%) are estimated for Export-led and Domestic-led respectively. A clear supporting role is likely to emerge for South-East Queensland and Wide Bay for Export & Domestic and Export-led futures, ramping up in the last decade of the forecast period to account for the remaining share of production in both cases.

Northern Queensland in particular accounts for the highest share of hydrogen production at the specific region level. This is consistent across all scenarios and is unsurprising given the forecast co-location of bulk renewable generation and electrolyser capacity inputs in the region (**Figure 20b**). As mentioned, the region has also been identified as one of the most cost-effective locations in Australia for hydrogen production each decade to 2050. We estimate that more than half of all Queensland's hydrogen is produced in Northern Queensland in Export & Domestic (56% or 4,500 kt/year). While the absolute volume is lower in Export-led (3,800 kt/year) and Domestic-led (2,800 kt/year), the share of total production is even higher (61% to an astounding 91%). Overall this further demonstrates that Northern Queensland is shaping up to be the home of hydrogen and renewables in Queensland through to 2050.

“Northern Queensland is shaping up to be the home of hydrogen and renewable energy in Queensland.”

Figure 20a: Hydrogen production volumes, per year for 5 year intervals, Queensland

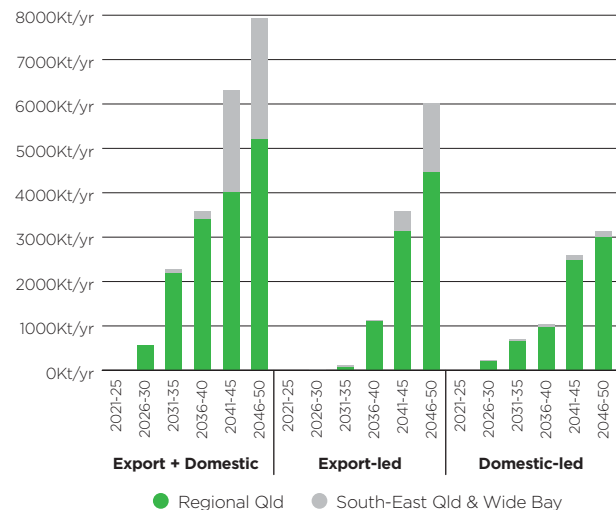
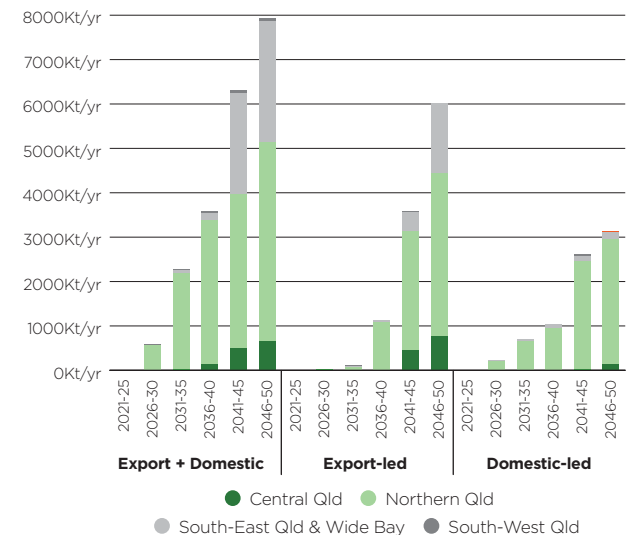


Figure 20b: Hydrogen production volumes, per year for 5 year intervals, Queensland



Note: These figures are presented in yearly average terms for each five year interval, and are not cumulative. Source: CSIRO (2022) for CSQ.

3.5 | Construction labour demand arising from the renewables outlook

This report's fundamental question is what will be required of Queensland's construction workforce to deliver the renewables boom?

In Chapter 2 we modelled the workforce implications of the near-term pipeline to 2025, suggesting that around 4,600 construction workers could be required from 2021 to 2025 to deliver confirmed projects. In this section we turn our attention to the longer-term construction labour demand implied in each scenario to 2050. We do not include operational or maintenance jobs which fall outside the scope of this paper – only the labour required to construct renewables infrastructure.

Our reporting framework is similar to CAPEX, in that we focus primarily on the average construction labour required across five-year intervals starting from 2021-25 through to 2046-50. We do this for each scenario, followed by an indication of the average construction jobs expected across this entire three decade period.

We start by reporting construction jobs at the highest level possible – covering the complete build-out of all renewables-related works (hydrogen industry and base renewables). We then break down the various labour demand profiles emerging for each major area of infrastructure deployment. This will illustrate the primary drivers of construction demand expected as the industry scales. We also focus on where in Queensland this workforce will likely be located.

It's clear from our CAPEX and installed GW capacity projections that the future energy transition – especially one predicated on the mass export of hydrogen – will lead to an unprecedented increase of renewable electricity generation and hydrogen production technologies. Building the next generation of Queensland's energy infrastructure will require a workforce consisting of thousands of construction-related employees.

Total number of construction jobs arising from the renewables boom in Queensland

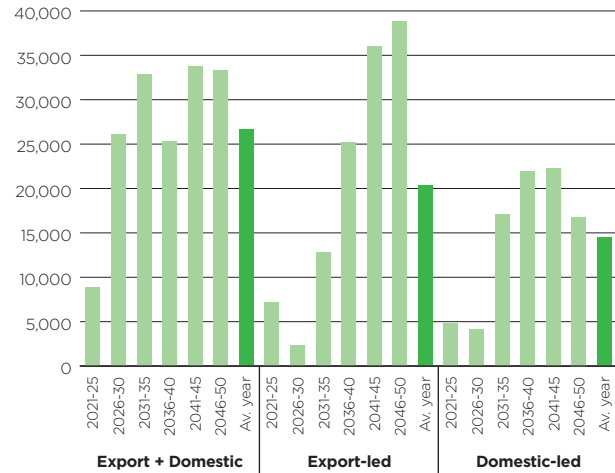
Construction jobs arising from the build out of all Queensland's renewable-related infrastructure to 2050 could range from 14,500 to 26,700 (depending on scenario).

Building the next generation of Queensland's energy infrastructure will drive sustained demand for thousands of construction workers from 2021 to 2050. And although the deployment profile and average yearly demand varies from scenario to scenario, it's clear that the long-term renewables outlook is a labour intensive prospect.

Figure 21a and 21b outline the aggregate construction labour required to deliver both hydrogen-related and base renewables infrastructure under each scenario. That is, the entire renewables boom in Queensland. Export & Domestic is the most labour intensive in average terms, requiring 26,700 workers from 2021 to 2050. Export-led and Domestic-led require 20,400 and 14,500 on average respectively.

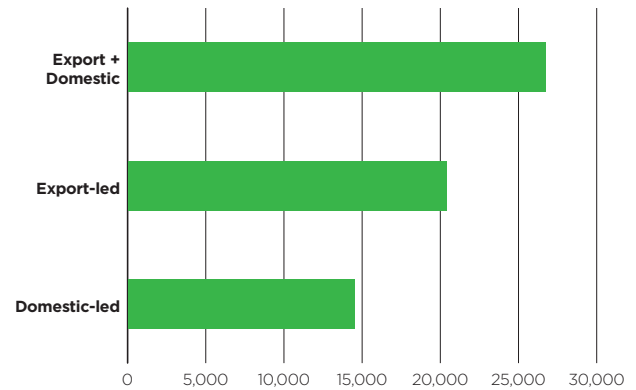
Figure 21a also shows the labour deployment profile per scenario can vary – the main feature being the dramatic spike in Export-led labour demand in 2041-45 and 2046-50 (reaching from 36,000 to 39,000 workers on average). This is driven by the higher share of blue hydrogen production (more than 50%) compared to the other scenarios. Blue facilities (SMR+CCS) are more bespoke in design (and hence labour intensive to build) than modular green electrolyser facilities.

Figure 21a: Renewables-related construction labour demand, five year intervals, Queensland



Source: CSIRO (2022) for CSQ.

Figure 21b: Renewables-related construction labour demand, average workers 2021 to 2050, Queensland



3.5 | Construction labour demand arising from the renewables outlook (continued)

Division of labour between hydrogen and non-hydrogen infrastructure

A large share of construction jobs would be required solely for hydrogen-related infrastructure – accounting for 43% to 69% of renewables-related labour demand. Yet this leaves a substantial number of workers to deliver base renewables.

The first major breakdown of construction labour we report on is the division between hydrogen and non-hydrogen types of labour. As mentioned, each hydrogen scenario also includes the base renewables required to support our non-hydrogen related domestic decarbonisation agenda (ie electrification). Its critical to understand the construction labour requirements of these two pathways in the renewables boom.

Figure 22a outlines the modelled construction demand for each scenario. It's clear that the labour required to deliver either hydrogen-related or base renewables infrastructure is substantial. In all scenarios, the dominant share of construction labour required in these domains can change from one time interval to the next. This demonstrates one reason why the labour intensity of the renewables boom is so significant. Construction labour is needed at the same time on both these fronts. To build a large scale hydrogen industry dedicated to export and, at the same time, build the assets required to decarbonise domestic electricity use.

Figure 22b shows how the average number of construction workers required to deliver hydrogen-related infrastructure varies by scenario. Export & Domestic suggests that around 18,500 workers on average could

be required to deliver just hydrogen-related assets, accounting for 69% of all renewables boom construction workers deployed. This scales down markedly for Export-led (12,200 on average or 60% of renewable construction labour needs) and Domestic-led (6,300, or 43%). In all scenarios the remaining construction workforce is the 8,200 required to deliver non-hydrogen base renewables infrastructure.

This means that even if a hydrogen industry didn't eventuate in Queensland, we would still need around 8,200 construction workers from 2021 to 2050 to deliver the generation and transmission infrastructure to aid domestic carbon abatement.

“Even if a hydrogen industry doesn't eventuate, we will still need around 8,200 construction workers between 2021 to 2050 to deliver the infrastructure needed to meet Queensland's net zero targets.”

Figure 22a: Renewables-related construction labour demand, five year intervals, Queensland

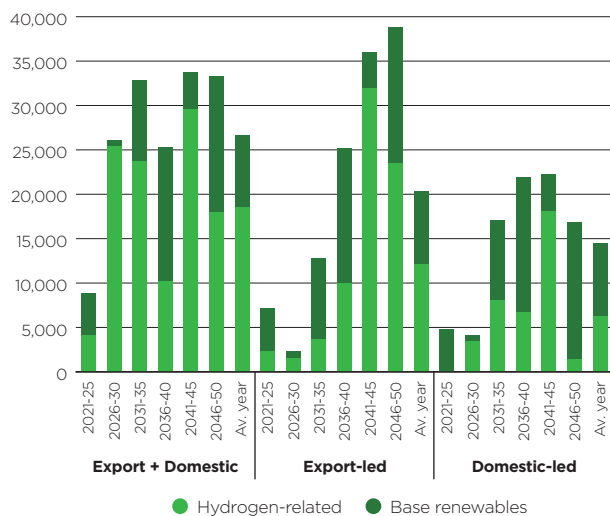
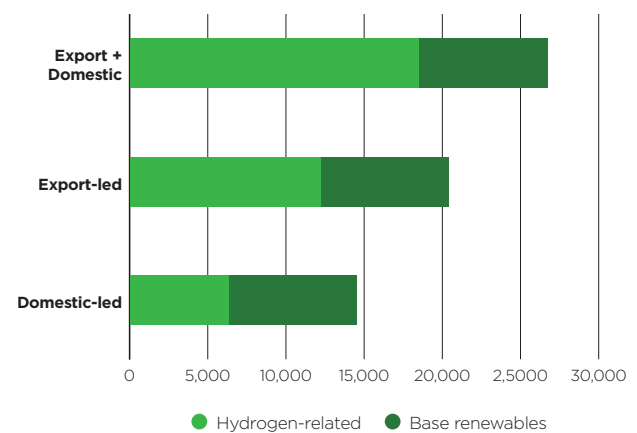


Figure 22b: Renewables-related construction labour demand, average 2021 to 2050, Queensland



Source: CSIRO (2022) for CSQ.



3.5 | Construction labour demand arising from the renewables outlook (continued)

Where and when will the renewables jobs be created?

Most construction jobs generated across renewables-related projects will be in regional Queensland, spanning from 13,600 (52%) up to 16,200 (94%) on average from 2021 to 2050 (depending on scenario).

Understanding the geographical composition of the construction labour demand arising from the total renewables boom is critical.

Regional Queensland has already been identified as the most cost-effective location for the vast majority of renewables-related industry infrastructure and CAPEX out to 2050. Construction labour demand maps closely onto this finding.

In average terms, most construction jobs emerging from all renewables-related infrastructure will be in regional Queensland (**Figure 23b**). Export & Domestic would demand 13,800 jobs in the region and account for 52% of renewables labour demand, Export-led 16,200 (79%), and Domestic-led 13,600 (94%). That said, there is a clear demand for labour in South-East Queensland and Wide Bay as well, particularly in Export & Domestic, where 12,900 workers could be required on average from 2021 to 2050.

Figure 23a shows the intensity of this regional demand over time. Peak periods could see 28,000 to 30,000 workers required (2046-50) for Export & Domestic and Export-led respectively in regional Queensland. South-East Queensland and Wide Bay also see dominant periods in Export & Domestic.

Figures 23c and 23d break down regional Queensland into a further three regions to show that demand for construction labour will be present in each region to varying degrees and at different time intervals. For Export & Domestic, Export-led and Domestic-led, the highest number of jobs in regional Queensland on average are located in Northern Queensland, ranging from 10,100 (38% of jobs), 8,300 (41% of jobs) and 7,400 (51% of jobs) respectively. Material amounts of labour will also be required in Central Queensland and South-West Queensland, requiring up to 4,800 and 3,100 construction workers on average respectively.

Figure 23a: Renewables-related construction labour demand, five year intervals, Queensland

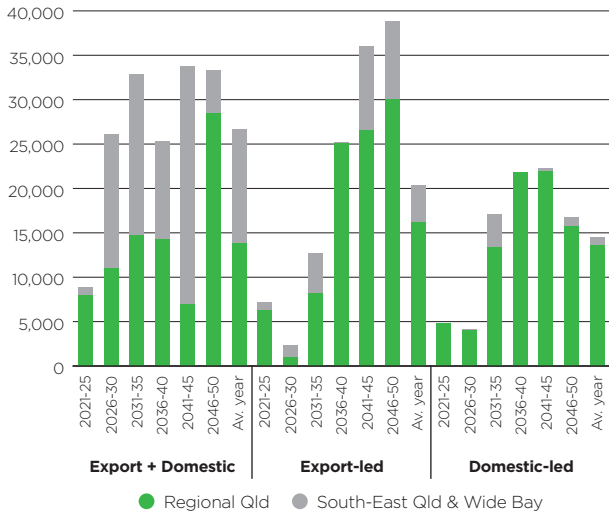


Figure 23b: Renewables-related construction labour demand, average 2021 to 2050, Queensland

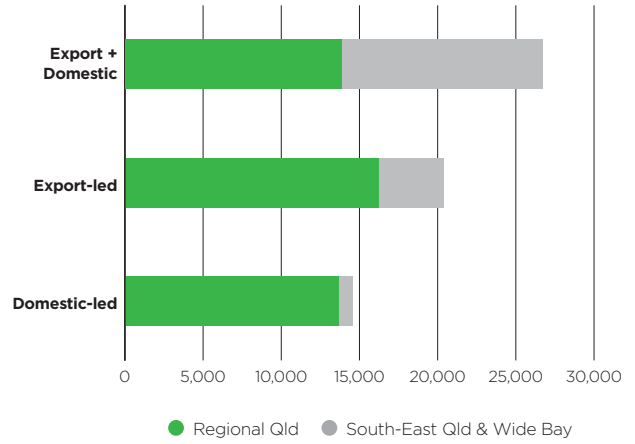


Figure 23c: Renewables-related construction labour demand, five year intervals, Queensland

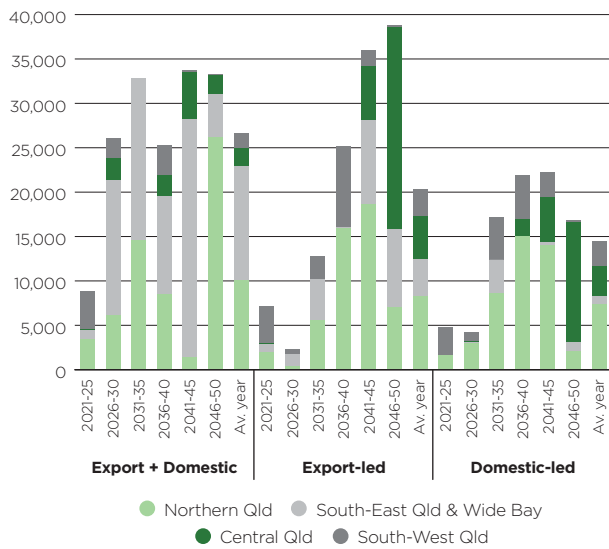
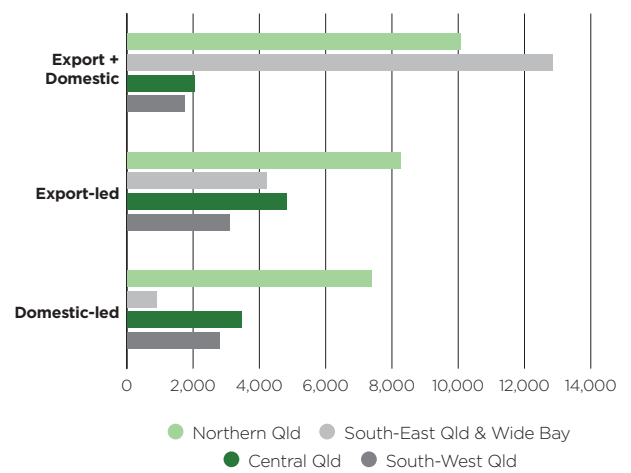


Figure 23d: Renewables-related construction labour demand, average 2021 to 2050, Queensland



Note: South-East Queensland and Wide Bay is not broken down further from prior graphs, while Regional Queensland is broken down into Northern, Central and South-West. Source: CSIRO (2022) for CSQ.

3.5 | Construction labour demand arising from the renewables outlook (continued)

Construction jobs needed to build hydrogen-related assets

Construction jobs generated by the build out of Queensland's hydrogen-related assets from 2021 to 2050 could range from 6,300 to 18,500.

We now dig deeper into the construction labour required to build out the hydrogen-related assets of the renewables boom from 2021 out to 2050. Given that an estimated 60% to 80% share of all renewables CAPEX will be absorbed by hydrogen-related infrastructure – averaging from \$4.0 billion to \$11.2 billion per year – the volume of construction labour to be deployed will be significant. We expect something on the scale of past export-orientated construction booms in Queensland, like the mining and LNG ramp up of recent years. But unlike the decade long construction phases of these past industries, the construction period of our hydrogen industry could be more sustained, spanning up to three decades.

Against this backdrop we present our construction workforce estimates for hydrogen-related infrastructure in Queensland by scenario (**Figure 24a and 24b**). These projections include jobs in the construction of both hydrogen production (both blue and green) and storage facilities, and upstream power supply and transmission assets.

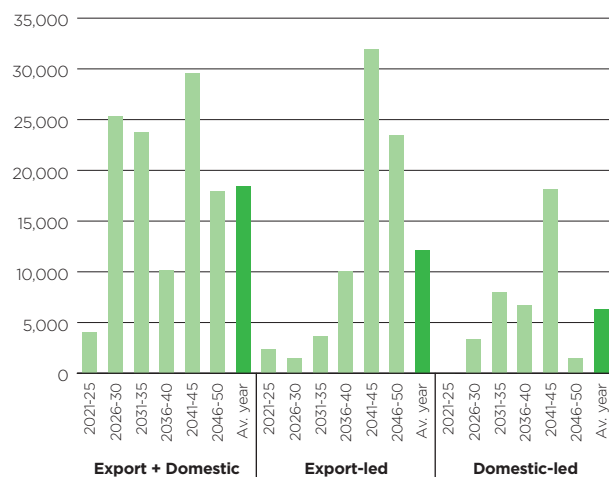
We found that construction jobs generated by the build out Queensland's hydrogen-related assets from 2021 to 2050 would be significant, but vary dramatically by scenario. Export & Domestic could require 18,500 workers on average, Export-led 12,200 workers, and Domestic-led 6,300.

The vast differences in labour demand reflect the scenario assumptions, and correlate closely with the amount of hydrogen to be produced, especially the quantities for export (see **Figure 18b** above in this chapter). This suggests that it's the size of Queensland's export market that will largely dictate the quantum of construction workers required in the hydrogen industry.

Across all scenarios the peak interval for construction labour is the 2041-45 period, where from a quarter to almost half of all hydrogen-related construction workers could be required. In Export & Domestic and Export-led around 30,000 workers or more could be required during this five year period. In most cases this is due to an intense build out of hydrogen production infrastructure.

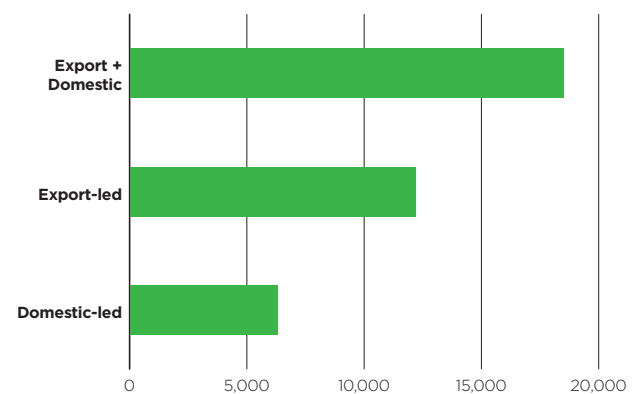
“The peak for Queensland construction jobs will come between 2041 and 2045 when an intense build out of hydrogen-related assets is forecast across all scenarios.”

Figure 24a: Hydrogen-related construction labour demand, five year intervals, Queensland



Source: CSIRO (2022) for CSQ

Figure 24b: Hydrogen-related construction labour demand, average 2021 to 2050, Queensland



Labour demand differences across green and blue hydrogen

In a future where green hydrogen dominates, a staggering 79% to 82% of construction labour would be required in the build out of upstream power supply assets (renewable generation and transmission). This scales down substantially for a future in which blue hydrogen dominates.

Hydrogen-related infrastructure can be split into two main categories. One is the onsite production and storage of hydrogen in processing facilities (what we've called 'hydrogen production and storage'), the second is the upstream renewable power supply and transmission assets required to provide the energy inputs used for that production process (what we've called 'hydrogen renewables').

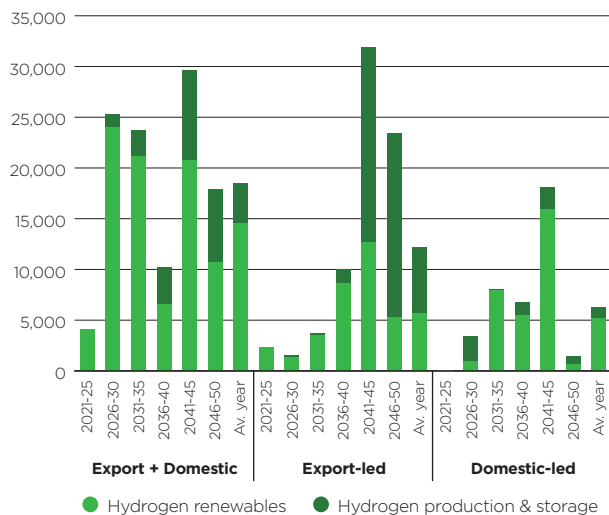
As mentioned, the amount of renewable energy required to power the production of green hydrogen is substantial. Whereas blue hydrogen doesn't require renewable power at all and uses natural gas with the carbon emissions captured downstream. Construction of a green hydrogen industry can therefore be conceived as the co-construction of two separate but interlinked sectors – an upstream supply chain of renewable power assets and hydrogen production facilities.

In this context we report our findings of the construction labour demand required for both hydrogen renewables and hydrogen production and storage sectors from 2021 to 2050 (see **Figure 25a and 26b**). Keeping in mind that most hydrogen produced in Export & Domestic and Domestic-led is green while in Export-led it is blue (see **Figure 19** in this chapter). The major finding is that in Export & Domestic and Domestic-led futures, the majority of hydrogen-related construction jobs (from 79% to 82% respectively) are in the build out of upstream power supply assets. This is a remarkable insight into the construction workforce requirements for a large scale green hydrogen industry in Queensland.

Yet given the different volumes of hydrogen produced in these scenarios, these proportions carry different labour needs. Close to three times the number of hydrogen renewables workers are needed in Export & Domestic (14,500) compared to a Domestic-led industry (5,100).

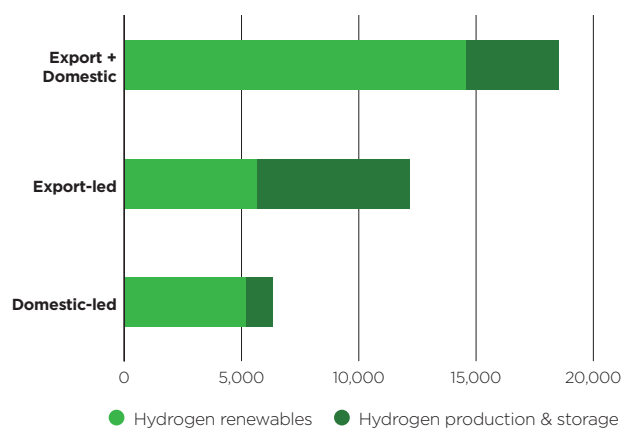
In either case, this extraordinarily high proportion of the hydrogen construction workforce required solely in the build out of upstream renewables was surprising. It re-emphasises the energy intensity of green hydrogen production and the flow on effects this has for infrastructure and, ultimately, on construction labour deployment.

Figure 25a: Hydrogen-related construction labour demand, five year intervals, Queensland



Source: CSIRO (2022) for CSQ

Figure 25b: Hydrogen-related construction labour demand, average 2021 to 2050, Queensland

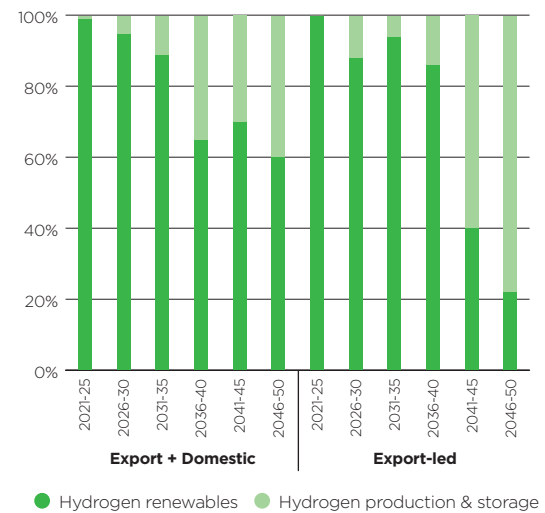


3.5 | Construction labour demand arising from the renewables outlook (continued)

This all changes for Export-led. The majority jobs required on average is instead in the construction of hydrogen production and storage infrastructure (54% or 6,500). This reflects the dominance of blue hydrogen production in this scenario, which doesn't require a renewable power supply chain.

One final result concerns the timing of labour deployment across these findings. Closely following CAPEX, we found that the proportion of labour required for these two sectors changes systematically over time for the Export & Domestic and Export-led scenarios (**Figure 25c**). More and more labour is dedicated to the construction of hydrogen production and storage facilities overtime. This provides another potential insight into the future build out sequence of Queensland's hydrogen industry. Labour flows are concentrated on upstream renewable power supply infrastructure first, then followed by a ramp up in the deployment of hydrogen production and storage facilities that utilise these inputs.

Figure 25c: Hydrogen-related construction labour demand (%), five year intervals, two scenarios only, Queensland



Source: CSIRO (2022) for CSQ

Labour demand: across generation, transmission, production and storage

The majority of upstream jobs would in turn be solely in renewable generation (rather than transmission), while the majority of facilities jobs would be in the build out of production infrastructure (rather than storage).

Even deeper labour profiling is possible by splitting 'hydrogen renewables' into generation or transmission asset construction labour needs, and 'hydrogen facilities' into production or storage labour needs.

This process revealed a set of standard findings across all scenarios. Firstly, a remarkable share of upstream construction jobs in the hydrogen industry would be more specifically in renewable generation (ie building wind, solar and battery assets) rather than transmission (Figure 26a and 26b). The share across scenarios is extremely high, with more than 90% of upstream jobs on average in generation – spanning from 13,200 (Export & Domestic), 5,200 (Export-led) or 4,700 (Domestic-led) across the scenarios respectively.

Taken together with our earlier finding that where a green hydrogen industry dominates, most construction jobs are in upstream power supply; by extension, this means that most construction jobs in a green hydrogen dominant future would be specifically in building renewable generation assets (eg solar, wind and battery storage). Specially, we estimate from 72% to 75% of all construction jobs for Export & Domestic and Domestic-led respectively could be in generation. That is, three in four construction workers in a green hydrogen industry would be required in the build out of renewable generation assets like wind farms, solar farms and industrial scale battery storage. This finding does not appear to hold in a blue hydrogen dominant future (eg Export-led) where more jobs are in hydrogen processing facility construction.

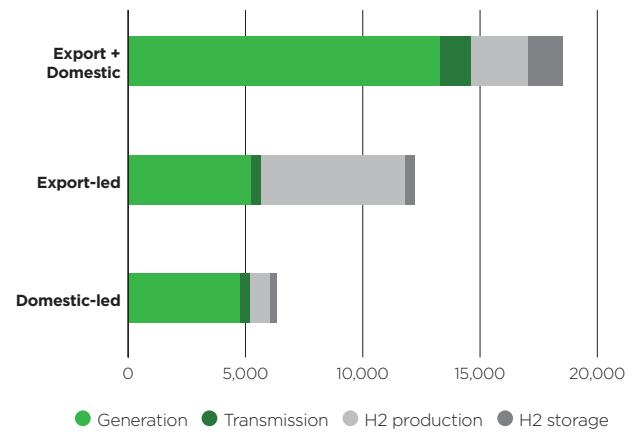
Our second major finding was in the hydrogen facilities domain. Here we found the majority of construction jobs were consistently in the deployment of hydrogen production rather than storage infrastructure. Specifically, from 62% of hydrogen facilities construction jobs in Export & Domestic, 74% in Domestic-led, and up to 94% in Export-led.

Figure 26a: Hydrogen-related construction labour demand, five year intervals, Queensland



Source: CSIRO (2022) for CSQ

Figure 26b: Hydrogen-related construction labour demand, average 2021 to 2050, Queensland



3.5 | Construction labour demand arising from the renewables outlook (continued)

Labour demand in a future where blue hydrogen dominates

For hydrogen production facilities, there is large variation in the construction labour demand given blue versus green hydrogen production methods, with blue carrying substantially more labour requirements.

As mentioned throughout this report there are two main commercial pathways for no or low emissions hydrogen production – green electrolysis and blue SMR+CCS. The model has selected blue hydrogen as the dominant production method in Export-led (accounting for 58% of hydrogen produced by 2050), while Export & Domestic and Domestic-led are green dominant (accounting for more than 95% in both scenarios).

The dominance of blue or green hydrogen carries substantial implications for construction labour requirements at the hydrogen production facility level. As highlighted already, hydrogen production is the second most labour intensive element in the four parts of the hydrogen-related infrastructure portfolio (after renewable generation), so variations in the drivers of labour in this domain could impact overall labour flows demanded by the industry.

In this context, **Figure 27a and 27b** outlines the construction labour required for green and blue hydrogen production facilities by scenario. As can be seen, the construction labour required to build blue hydrogen facilities dwarfs green to a remarkable degree. This is despite the volume of hydrogen produced and CAPEX requirements in Export-led being lower than Export & Domestic (see **Figure 19 and Figure 9b** in this chapter respectively).

At play here is the finding that for the same capital cost its substantially more labour intensive to build blue hydrogen facilities than green hydrogen facilities. For instance, \$1.0 billion of green hydrogen production CAPEX in 2036-40 requires the deployment of an estimated 570 construction workers, while the same CAPEX for blue production requires 5,300. This result makes sense given the deeper context that electrolyzers are modular and are purchased in a shipping container and require less civil work and construction than a SMR with CCS plant, which would be bespoke in design (CSIRO, 2022).

The Export-led scenario has a lower global climate ambition target, thus renewable technology costs are higher. It also has a lower gas price. These two factors combined mean that SMR+CCS is a cost-effective hydrogen production technology in this scenario.

Figure 27a: Hydrogen production, construction labour demand, five year intervals, Queensland

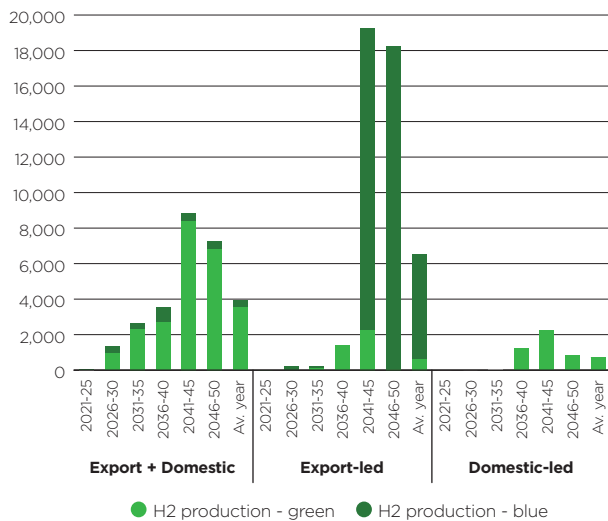
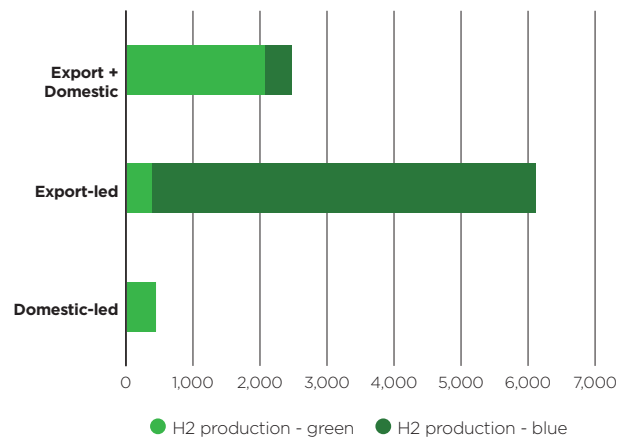


Figure 27b: Hydrogen production, construction labour demand, average 2021 to 2050, Queensland



Note: A marginal amount of fossil fuel derived hydrogen ('grey' hydrogen) was selected by the model but the associated labour demand has been excluded in the above due to the small amount
Source: CSIRO (2022) for CSQ

Estimating hydrogen construction jobs by Queensland region

Developing the state's hydrogen industry will generate substantial construction jobs in regional Queensland – from 6,400 to 9,000 from 2021 to 2050 depending on scenario. Jobs in South-East Queensland and Wide Bay will only scale up strongly given high domestic and export uptake.

The location of construction jobs in the future hydrogen industry is a key focus of this paper. Here we present these construction job estimates by both major and specific regions of Queensland.

One major finding concerns the higher number of hydrogen construction jobs required in South-East Queensland and Wide Bay in Export & Domestic (Figure 28a and 28b). In this scenario 64% of average construction labour from 2021 to 2050 are in that region (an estimated 11,800 jobs, compared to 6,700 in regional Queensland). This is counter to regional Queensland's dominance in all other geographic findings – for example regional Queensland accounts for the largest share of hydrogen CAPEX (Figure 10a), installed renewable and electrolyser capacity CAPEX (Figure 17b,c), hydrogen production volumes (Figure 20a) and all renewables-related jobs (Figure 23b).

This finding is driven by the extraordinary amount of additional upstream supply infrastructure required in Export & Domestic. A large share of this demand is met from solar and battery storage capacity sourced in South-East Queensland and Wide Bay, which the model optimised as the most cost-effective locality to meet this demand.

This results in the demand for thousands of local construction jobs (11,800 from 2021 to 2050) with around 85% of these in upstream asset deployment rather than hydrogen production and storage. In Export & Domestic, regional Queensland will still generate more construction jobs in the build out of hydrogen production and storage facilities at 2,300 jobs, compared to 1,600 in South-East Queensland and Wide Bay.

Such disproportionate workforce demand only appears in South-East Queensland and Wide Bay given certain conditions like those in Export & Domestic. In Export-led and Domestic-led, regional Queensland has predominance, accounting for three-quarters (9,000) to virtually all roles (6,400) in these scenarios respectively (Figure 28b).

At the specific region level, most jobs outside South-East Queensland and Wide Bay in Export & Domestic will be in Northern Queensland (6,200 on average). Northern Queensland also accounts for the most jobs in Export-led and Domestic-led respectively (4,400 and 4,200, on average) followed closely by Central Queensland (3,500 and 2,900, on average). See Figure 28c for these details.

Figure 28a: Hydrogen-related construction labour demand, five year intervals, Queensland

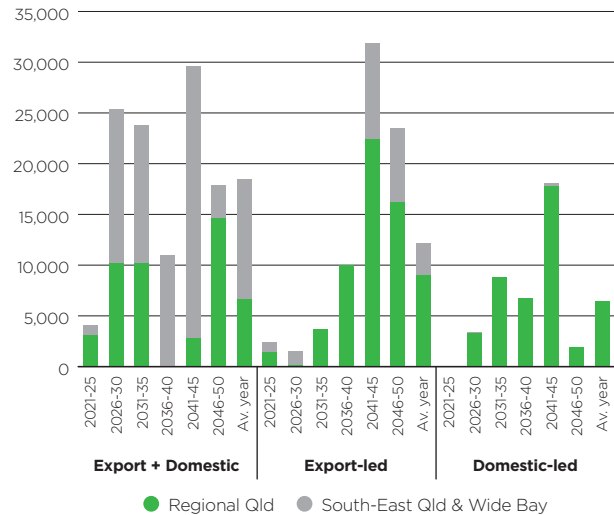
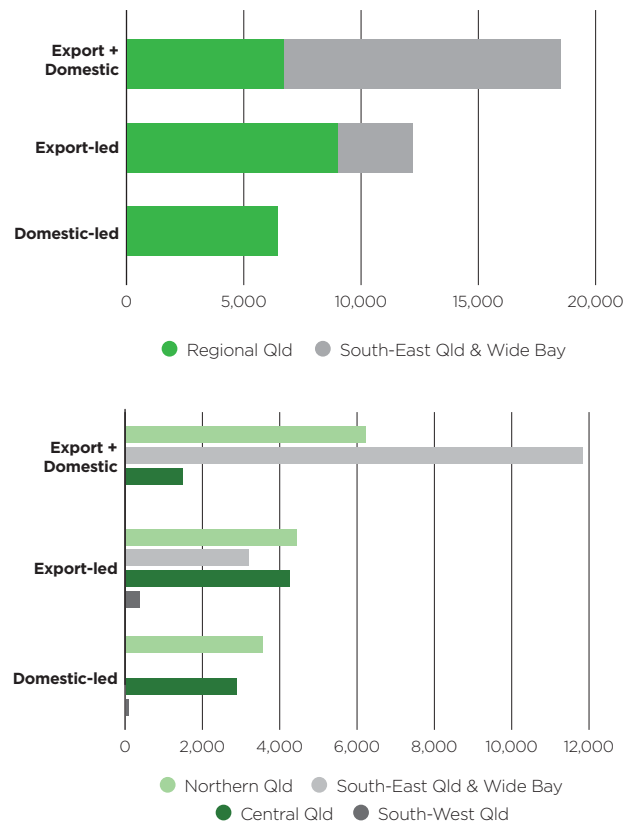


Figure 28b and 28c: Hydrogen-related construction labour demand, average 2021 to 2050



Source: CSIRO (2022) for CSQ

3.5 | Construction labour demand arising from the renewables outlook (continued)

Demand for upstream renewable power infrastructure: the double boom effect

Ultimately, bringing together hydrogen-related and base renewables job estimates indicates that building the requisite renewable energy infrastructure out to 2050 could become the main area of construction labour demand – accounting for 68% to 92% of all construction jobs.

A key finding for hydrogen-related construction jobs was the outsized number of workers required to build upstream renewable power infrastructure – accounting for around 80% of all construction jobs required where green hydrogen dominates (ie Export & Domestic, and Domestic-led).

This alone is an extraordinary finding. Yet, simultaneous to this would be the additional construction workers required to construct 'base renewables' assets. That is, those same types of renewable power infrastructure but used domestically to help meet Queensland's carbon reduction targets (ie renewable power used for non-hydrogen reasons like decarbonising electrification across the state). In most cases, the types of infrastructure needed will be the same across hydrogen-related and base renewables assets (solar, wind and battery storage).

This is one of the challenges for our renewables future. There are conceivably two booms occurring in tandem both of which leverage the same type of assets. The hydrogen export boom and the domestic decarbonisation drive – both of which are renewables intensive.

To quantify the workforce impact of these overlapping asset requirements we combine hydrogen and base renewables workforce projections – but split out renewables required for hydrogen and combine it with the renewables required for non-hydrogen purposes. This shows the true scale of the workforce required solely to build out our renewable infrastructure footprint (both generation and transmission) needed in Queensland through to 2050. This represents the labour required to meet both our decarbonisation targets whilst developing various sized hydrogen industries (**Figure 29a**).

The labour required to build out these renewable assets would account for an extraordinary share of the total employment footprint arising from our projections – 85% in Export & Domestic (22,700 workers) up to 92% in Domestic-led (13,300). The Export-led scenario has slightly less share due to the labour intensity of blue hydrogen technology installation (68%, 13,800).

In any case, building the requisite renewable energy infrastructure out to 2050 could become the main area of construction labour demand in future, as the race towards hydrogen and domestic decarbonisation both intensify.

Figure 29a: Renewables-related construction labour demand, five year intervals, Queensland

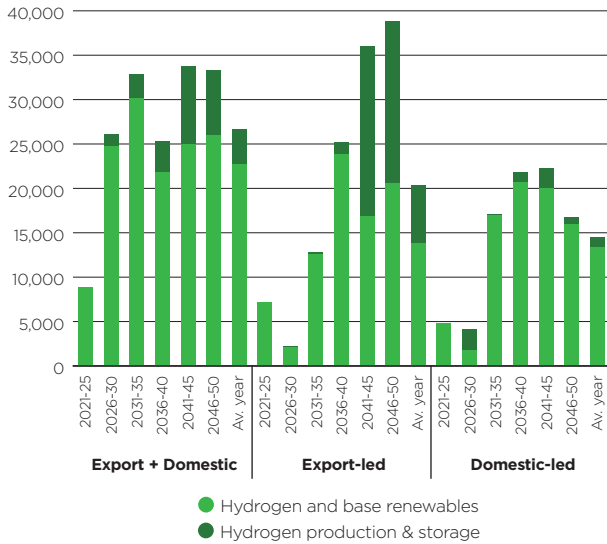
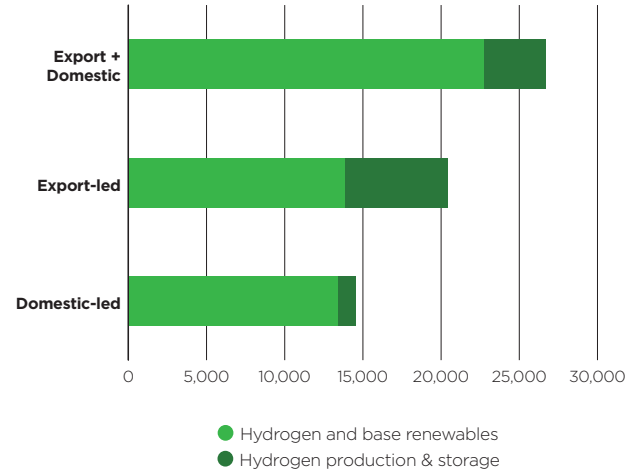


Figure 29b: Renewables-related construction labour demand, average 2021 to 2050, Queensland



Source: CSIRO (2022) for CSQ

“As the race towards hydrogen and domestic decarbonisation both intensify – both leveraging the same type of assets – we may effectively have two booms at once. In any case, building the renewable energy infrastructure Queensland needs out to 2050 is likely to be the main area of construction labour demand in future.”

3.5 | Construction labour demand arising from the renewables outlook (continued)

What type of construction jobs will be needed out to 2050?

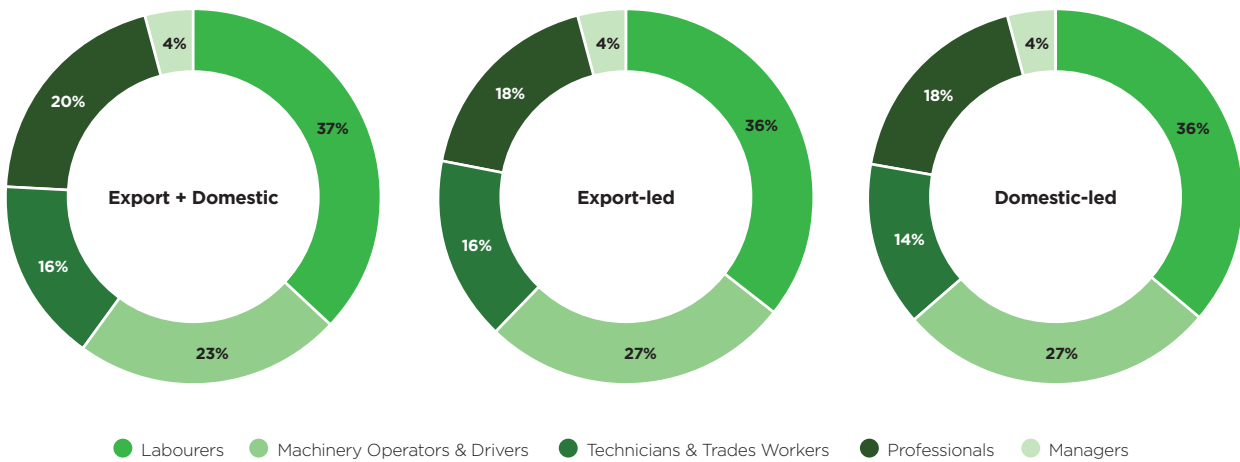
Regardless of scenario, middle- and low-skilled jobs will dominate the labour profile of the renewables construction workforce.

So far this chapter has discussed the amount of construction labour required over the long-term renewables outlook. Here we provide a breakdown of these aggregate figures into their broad occupational profile. **Figure 30** illustrates the average profile by main occupational group expected over the outlook period.

We found only minimal differences in this profile across scenarios. This suggests that while the number of workers will change dramatically given different futures, the underlying profile of construction workers required per unit of CAPEX will be reasonably consistent.

This consistency includes middle- and low-skilled jobs dominating the labour profile of the renewables construction workforce. Most workers will likely be Labourers, accounting for more than a third of the renewables construction workforce on site at any one time (36% to 37%). This would be followed by Machinery Operators and Drivers (23% to 27%). Collectively these two occupational groups could account for up to two-thirds of the total renewables workforce. Highly skilled Technicians and Trades Workers could constitute from 14% to 16% of roles of the renewables workforce.

Figure 30: Renewables-related construction labour profile, by main occupational group, Queensland, 2021 to 2050



Source: CSQ occupational analysis of CSIRO (2022) outputs.





Long-term impacts on the construction industry

4 | Long-term impacts on the construction industry

How large could the impact of renewables be?

The renewables transition will be a meteoric challenge. But in the context of the entire industry, it could be large enough to rebase some long-held fundamentals. Particularly about thresholds of activity and labour traditionally required in the industry.

We have the advantage of being in the early stages of this challenge. It's therefore prudent to estimate how large the transition's impact could be on the overall construction industry. Both activity and labour demand should be a part of this consideration.

To quantify this impact we firstly estimate the size of the construction industry in future (ie from 2021 to 2050) without the renewables transition in play. This is our 'baseline' construction outlook. It include the aggregate cost of all construction projects the industry could need given population growth forecasts to 2050 (see Chapter 5 for methodology).

We then add renewables-related CAPEX to this baseline to create a second dataset. This captures the overall size of the industry in future given both baseline and renewables-related activity. The difference between baseline only and renewables + baseline quantifies the potential impact of the transition. The impact of renewables on the labour demand uses a similar method, albeit with some additional steps.

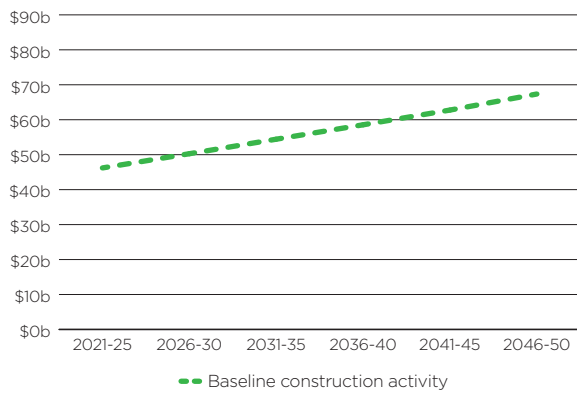
4.1 | Transition impacts on activity

A much busier period lies ahead for the industry as the transition unfolds

Our baseline estimate for future construction activity in Queensland is \$56.6 billion per annum. The renewables transition is expected to add up to a further \$13.9 billion to this figure. This is a 25% increase over our baseline projection.

Figure 1 illustrates the baseline amount of construction industry activity expected in Queensland over the transition period. Following a linear trend, we expect annual activity to grow from \$46.2 billion up to \$67.4 billion over this timeframe. An average of \$56.6 billion per annum across the whole period is predicted.

Figure 1: Forecast baseline construction activity, Queensland, annual average for 5 year intervals



Source: CSQ analysis of CSIRO (2022); QGSO (2018); ABS (2021); ABS (2021c); ABS (2021d).

Figure 2 adds our renewables-related activity to this baseline. Regardless of scenario, the renewables transition expands the amount of activity required by the industry over the next 30 years. This is not a short-term shock to activity, and could represent a rebasing of long-term demand.

Figures 3a and 3b illustrate these results in average yearly terms. In our baseline outlook we predict around \$56.6 billion of construction activity per annum. In the Export & Domestic scenario, the transition adds \$13.9 billion a year to this baseline. This puts total yearly activity up to \$70.5 billion and makes the industry 25% larger as a result of the renewables outlook. Even the remaining scenarios would still require from 12-13% more activity than our baseline projection.

Figure 2: Impact of renewables transition on baseline construction activity, Queensland, annual average for 5 year intervals

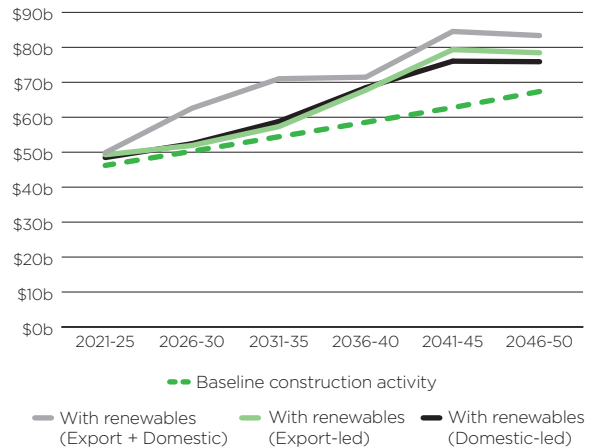
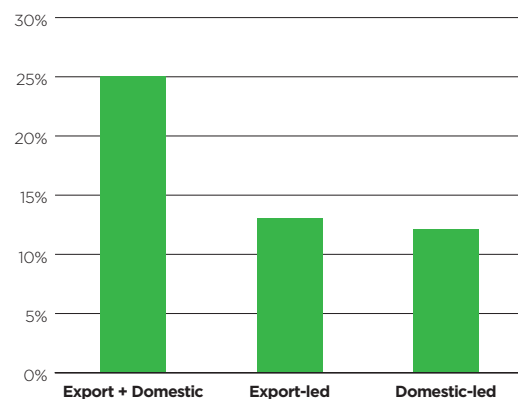
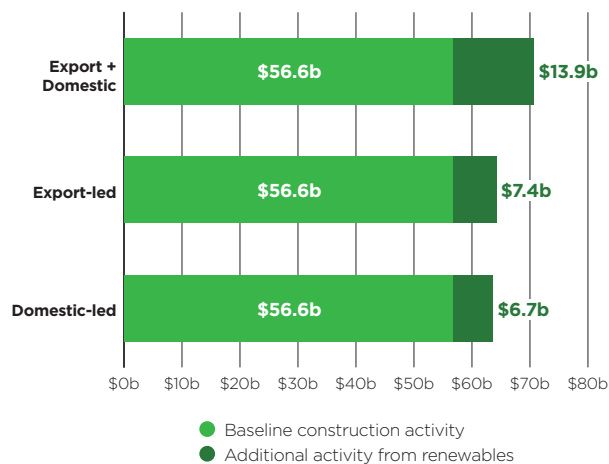


Figure 3a and 3b: Impact of renewables transition on baseline construction activity, Queensland, 2021-2050 (a) annual activity (b) % additional annual activity from renewables compared to baseline



Source: CSQ analysis of CSIRO (2022); QGSO (2018); ABS (2021); ABS (2021c); ABS (2021d).

4.1 | Transition impacts on activity (continued)

The transition's impact will be much larger in regional Queensland than the South-East

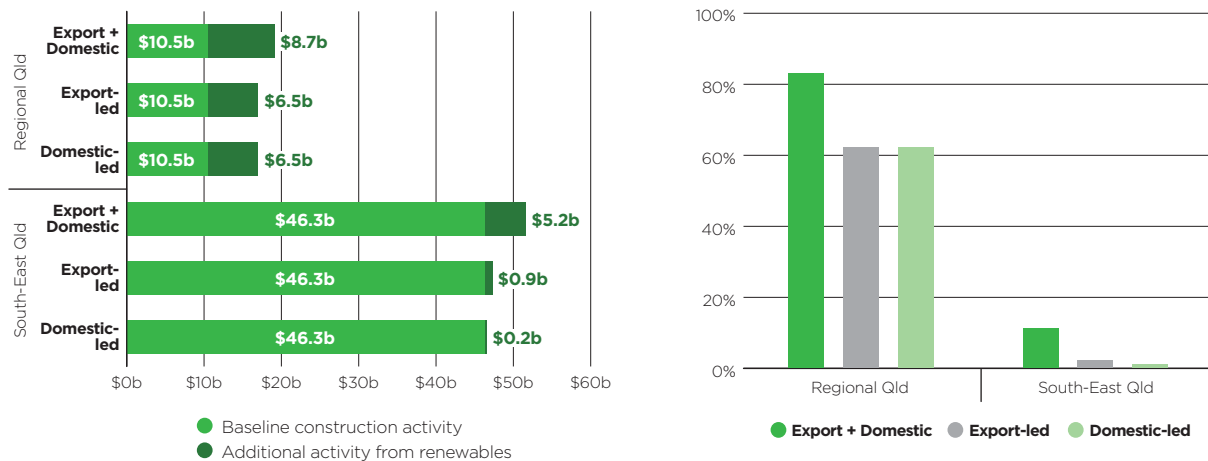
The renewables transition could add 80% additional activity to our baseline outlook for regional Queensland, compared to less than 15% in South-East Queensland.

Construction activity arising from the renewables transition will not be evenly distributed across the state. As we've outlined, the renewables boom is concentrated in regional Queensland rather than the South-East. Regional Queensland also has much less construction activity in general compared to South-East Queensland (ABS, 2021c).

This context maximises the geographic differences of the transition's impact (**Figure 4a and 4b**). Baseline activity in regional Queensland is forecast to be around four times smaller than the South-East (\$10.5 billion per annum and \$46.3 billion, respectively). Simultaneously, renewables CAPEX is consistently higher in regional Queensland. The regional impact of the transition is profoundly larger as a result.

In our Export & Domestic scenario, the transition in regional Queensland could add up to 83% of additional activity to our baseline outlook. Yearly activity goes from \$10.5 billion (baseline) to \$19.2 billion (baseline + renewables). South-East Queensland sees only a 11% increase in this scenario (although from a much higher base). This pattern is similar across the remaining scenarios.

Figure 4a and 4b: Impact of renewables transition on baseline construction activity, 2021-2050 (a) annual activity (b) % additional annual activity of renewables compared to baseline



Note: South-East Queensland includes Wide Bay.
Source: CSQ analysis of CSIRO (2022); QGSO (2018); ABS (2021); ABS (2021c); ABS (2021d).

The engineering sector will have to expand drastically to absorb the renewables pipeline

Our baseline outlook for the engineering sector is \$24.2 billion per annum. The renewables transition could add another 60% to this projection.

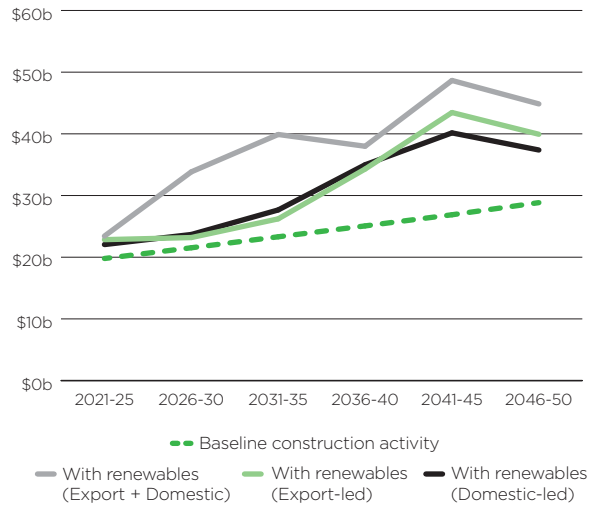
Two major sectors deliver all the construction industry activity in Queensland – the engineering sector and the building sector. Each sector accounts for around half of total industry activity (ABS, 2021c). The engineering sector delivers major projects like roads, dams and ports; while the building sector delivers residential and commercial structures.

Almost all renewables-related infrastructure will be deployed by the engineering sector. It's therefore important to measure the full impact of the transition on this sector in isolation from the whole industry.

Figure 5 presents both our baseline and baseline + renewables forecasts for engineering sector activity in Queensland. Regardless of scenario, the renewables transition profoundly extends the amount of activity required by this sector over the next 30 years. For the most part, the impact of the transition on the engineering sector is twice as large as the impact on the construction industry overall.

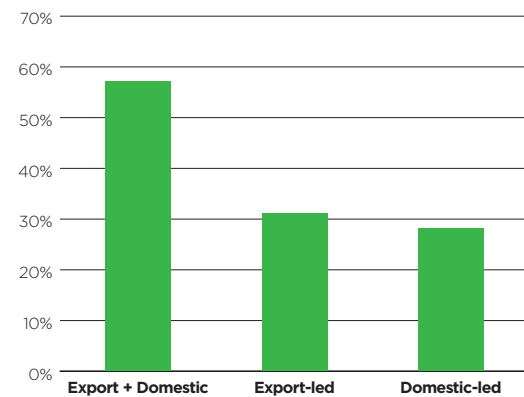
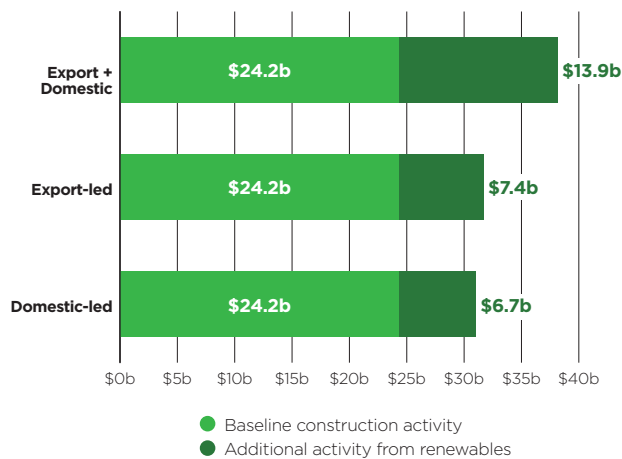
Figures 6a and 6b illustrate this impact in annual average terms. In our baseline outlook we predict around \$24.2 billion of engineering activity per annum from 2021 and 2050. This increases from 28% to 57% when renewables are added on top (depending on scenario). In the Export & Domestic scenario this rebases yearly activity from \$24.2 billion up to \$38.1 billion. Absorbing and adjusting to this level of activity could be a major challenge for the engineering sector.

Figure 5: Impact of renewables transition on baseline engineering construction activity, Queensland, annual average for 5 year intervals



Source: CSQ analysis of CSIRO (2022); QGSO (2018); ABS (2021); ABS (2021c); ABS (2021d).

Figure 6a and 6b: Impact of renewables transition on baseline engineering construction activity 2021-2050 (a) annual activity (b) % additional annual activity of renewables compared to baseline



Source: CSQ analysis of CSIRO (2022); QGSO (2018); ABS (2021); ABS (2021c); ABS (2021d).

4.1 | Transition impacts on activity (continued)

The transition will put Northern Queensland on a profoundly steeper trajectory

The renewables transition could more than double construction activity in Northern Queensland compared to baseline. Activity in Northern Queensland's engineering sector could triple under these conditions.

We now estimate the impact of the renewables transition within regional Queensland. This will further demonstrate how concentrated these impacts could be for different locations of the industry.

Figure 7a and 7b show the transition's impact will be largest in Northern Queensland. In an Export & Domestic future, the renewables outlook could take annual construction activity from a baseline of \$5.3 billion per annum up to \$11.8 billion. This represents more than double the amount of activity (a 120% increase) as a result of the transition compared to baseline. Given the three decade time horizon, this could fundamentally reshape the construction industry in Northern Queensland, putting it on a profoundly steeper trajectory.

Other parts of regional Queensland will still experience a material impact from the transition simultaneously with Northern Queensland. Central Queensland can still expect total activity of around 50% higher over baseline levels, while South-West Queensland could be 30% higher.

Figure 8a and 8b shows these regional impacts are much higher for their respective engineering sectors. Northern Queensland's pipeline of engineering construction activity could increase from a baseline of \$3.0 billion per annum up to \$9.5 billion when renewables is also included. This translates to more than a tripling (a 215% increase) in the total volume of work delivered on average each year compared to baseline estimates. Simultaneously, engineering activity in Central and South-West Queensland could both rise more than 50% above baseline as a result of the renewables boom.

Figure 7a and 7b: Impact of renewables transition on baseline construction activity, 2021-2050 (a) annual activity (b) % additional annual activity of renewables compared to baseline

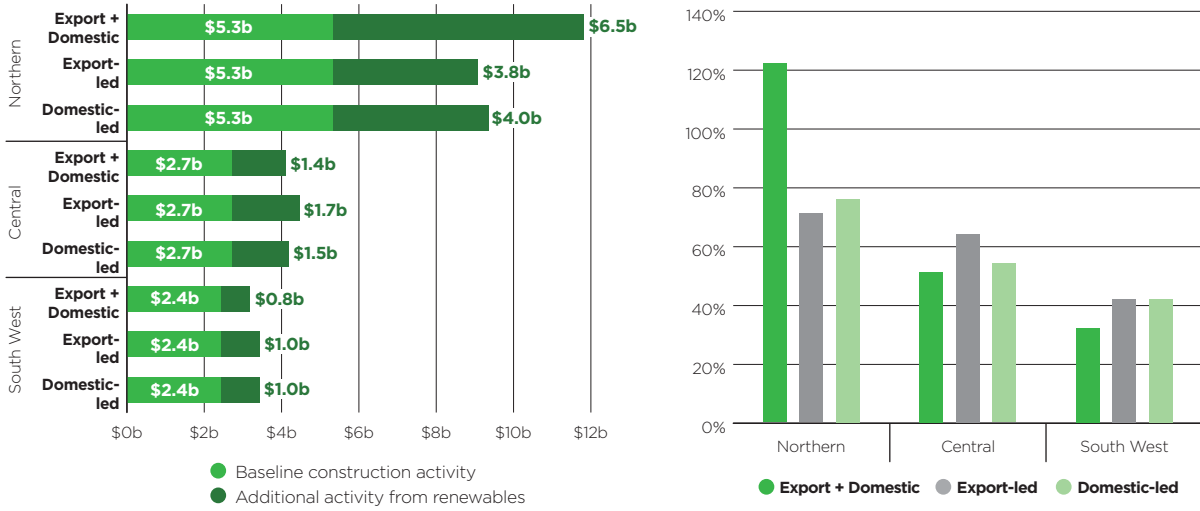
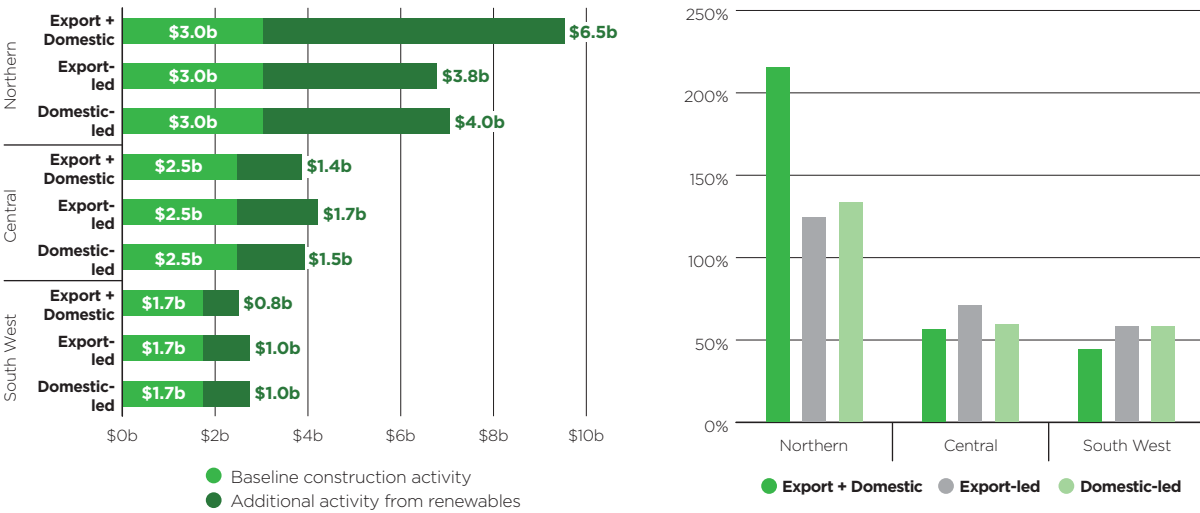


Figure 8a and 8b: Impact of renewables transition on baseline engineering construction, activity 2021-2050 (a) annual activity (b) % additional annual activity of renewables compared to baseline



Source: CSQ analysis of CSIRO (2022); QGSO (2018); ABS (2021); ABS (2021c); ABS (2021d).

4.2 | Transition impacts on labour demand

How much bigger will the workforce need to be?

There are currently around 230,000 workers in the Queensland construction industry (ABS, 2021). These workers fall into more than 340 different occupations (ABS, 2016). However, not all of these will be directly required for the build out of renewables infrastructure in future. We estimate that only 19 of these occupations are specifically renewables-relevant. Workers in this subset account for around a third (34%) of the existing construction workforce in the state, approximately 80,000 employees (ABS, 2016).

It's important to measure the transition's impact on the baseline demand for workers in these renewables-relevant occupations in future, rather than just the construction workforce as a whole. This isolates the impact of the transition on the pool of workers with the skills most essential to that transition against their baseline demand across the rest of the industry. It also avoids wrongly assuming that any worker in the industry, regardless of their qualifications and skills, could be deployed on renewables projects. Hence, it avoids underestimating the impact.

It also means we assume the renewables construction workforce required in future will consist of workers in existing occupations (eg electricians and plumbers), rather than in new roles emerging specifically for the transition. This may change as things progress. But at present, we've seen several solar, wind, and hydrogen projects delivered successfully using the existing construction workforce. And it was via the occupation profile of these projects that the 19 unique roles were identified³. Chapter 5 describes the methodology involved.

The transition will have a material and long-lasting impact on labour demand

Our baseline estimate of future labour demand across renewables-relevant occupations is around 105,000. The renewables transition could require up to 26,700 more on top of this figure. This is a 25% increase over our baseline projection.

Figure 9 provides our baseline estimate of workers required in future across these 19 occupations. We expect the industry to drive demand from around 85,000 workers to up to 124,000 across the forecast horizon.

Figure 10 adds our renewables job estimates to baseline. Regardless of scenario, the renewables prospect is predicted to drive a sustained and material increase in demand over the forecast period. In an Export & Domestic hydrogen future, 94,000 construction workers could be required in 2021-25 (rather than the 85,000 under baseline) rising to 158,000 in 2046-50 (rather than the 124,000).

Figures 11a and 11b present impacts in average terms. Under baseline conditions around 104,600 construction workers in these critical occupations would be required in Queensland. Adding renewables to this outlook boosts this total requirement up to 131,300 for the Export & Domestic scenario.

In percentage terms this means that the pool of workers in occupations most essential to the renewables transition would need to grow by up to 25% to meet aggregate demand carried by the transition. The labour demand impact of the remaining scenarios are still substantial at 19% (Export-led) and 14% (Domestic-led).

³ These occupations accounted for 90% of the total renewables construction workforce required onsite across completed solar, wind and hydrogen projects in CSQ holdings

Figure 9: Baseline construction labour demand*, Queensland, average for 5 year intervals



Figure 10: Impact of renewables transition on baseline construction labour demand*, Queensland, average for 5 year intervals

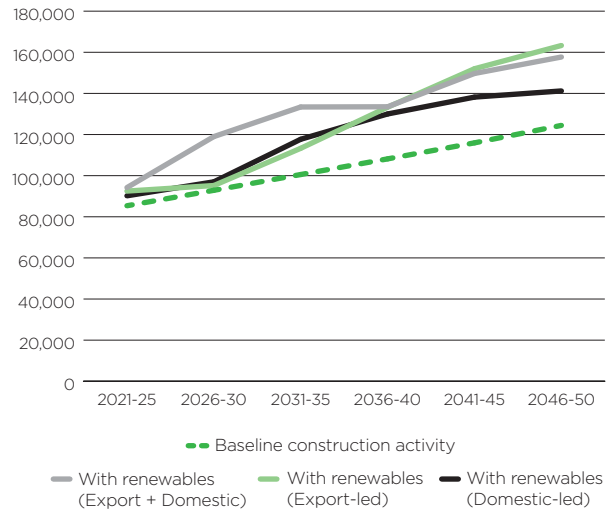
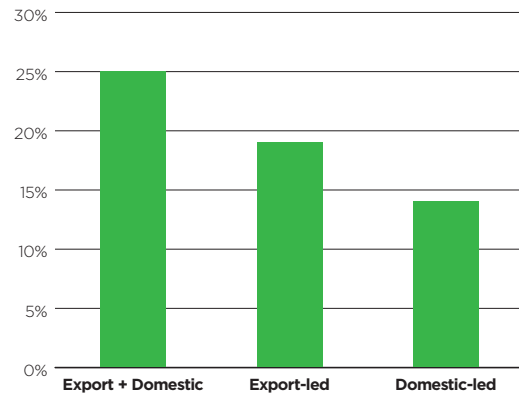
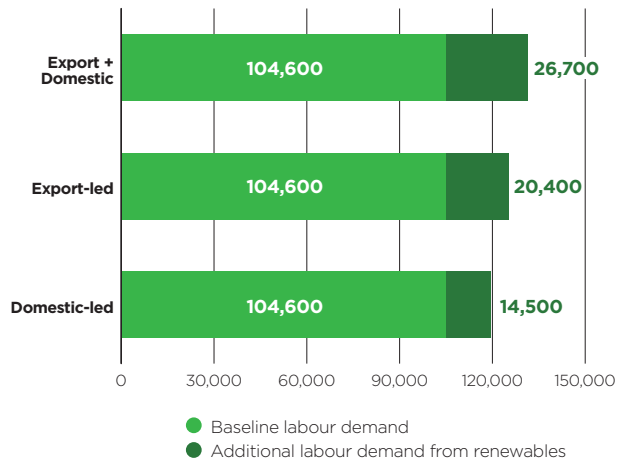


Figure 11a and 11b: Impact of renewables transition on baseline construction labour demand*, Queensland, 2021-2050 (a) additional workers (b) % additional renewables workers on baseline



Note: *for 19 existing occupations critical to renewables but also in demand by the entire industry (eg electricians and plumbers).
 Source: CSQ analysis of CSIRO (2022); QGSO (2018); ABS (2021); ABS (2021c); ABS (2021d).

4.2 | Transition impacts on labour demand (continued)

Larger workforce impacts are expected in regional Queensland vs South-East

We predict construction labour demand in the regions could increase by more than 60% above baseline levels – compared to 16% in South-East Queensland.

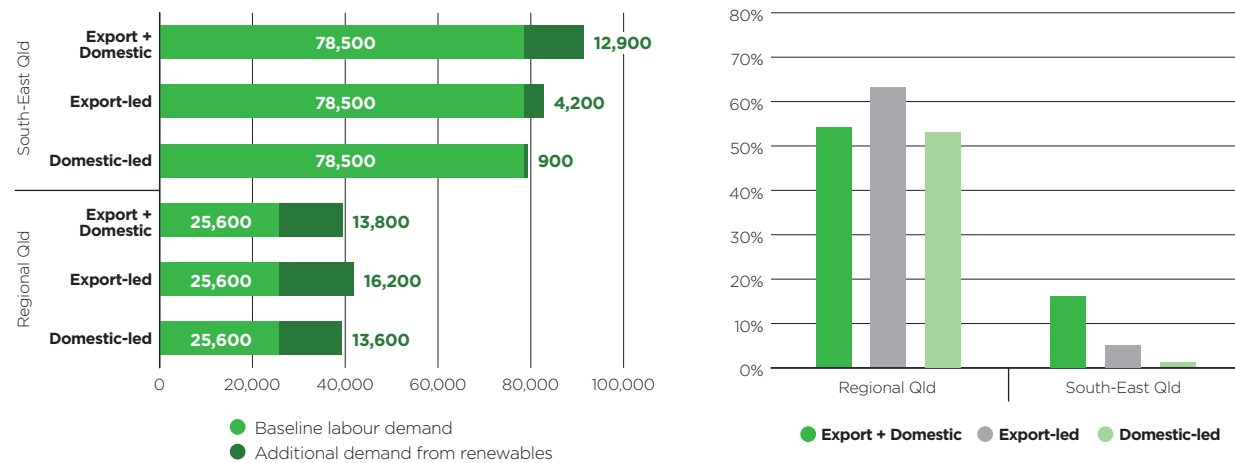
More construction workers will be required to deliver the renewables transition in regional Queensland than the South-East. Yet the underlying construction labour market is much thinner in the regions – typically three times smaller than South-East Queensland. This carries extraordinary implications for the workforce impact of the transition.

Figures 12a and 12b quantify this impact. In regional Queensland, we expect demand for around 25,600 workers at baseline. For South-East Queensland, this is higher at 78,500. Renewables jobs demand trends in the opposite direction regardless of scenario – with more jobs in the regions than the South-East.

Against this backdrop, the geographic impact of the transition is maximised. The transition could add more than 50% labour demand to baseline in regional Queensland across scenarios. In Export & Domestic this moves up more than 50%, reflecting a shift from 25,600 to 39,400. For South-East Queensland, the transition could add up to a maximum 16% (Export & Domestic), from a higher baseline than the regions of 78,500 up to a new point of 91,400.

It's clear that the prospect of labour demand increasing from 50-60% above baseline is vastly different to around 16%. Arguably the first is a shock (albeit a long-term one) the second an adjustment. This helps to show the pinch points for renewables labour could be in regional Queensland in future rather than South-East Queensland.

Figure 12a and 12b: Impact of renewables transition on baseline construction labour demand*, Queensland, 2021-2050
(a) additional workers (b) % additional renewables workers on baseline



Note: *for 19 existing occupations critical to renewables but also in demand by the entire industry (eg electricians and plumbers).
 Source: CSQ analysis of CSIRO (2022); QGSO (2018); ABS (2021); ABS (2021c); ABS (2021d).

Northern Queensland leads the regions with sharpest increase in labour demand

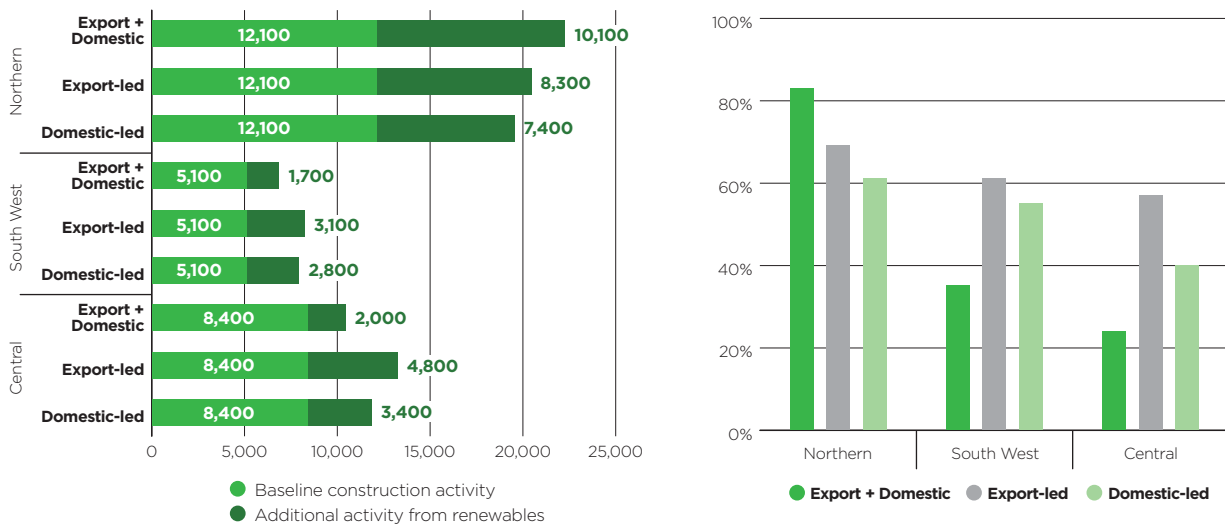
In Northern Queensland, our baseline estimate for future construction needs is 12,000 workers. The renewables transition could add another 10,000 on top to this figure. This is an 80% increase over our baseline projection for construction labour demand in Northern Queensland.

Figures 13a and 13b compare our findings for the three jurisdictions within regional Queensland. The renewables transition will clearly have a material impact on labour demand in all these jurisdictions. An Export & Domestic future would carry at least 50% higher labour demand over baseline in Northern, South-West and Central Queensland simultaneously.

Yet, it's the Northern region that could see the most acute 'shock' to future labour demand as a result of the renewables transition. This directly reflects one of the primary findings of this research - that most renewables-related CAPEX and jobs will be concentrated in this part of Queensland. This catalyses a steep demand impact in future when overlaid with a relatively thin baseline workforce outlook.

In Export & Domestic, demand for renewables labour drives workforce requirements 80% higher compared to baseline in this region. The labour required alone to service this renewables demand (10,100 workers) is almost as high as the number of workers required to satisfy all baseline construction needs (12,100) in future. By this logic, the demand for renewable construction labour could fundamentally resize the industry in Northern Queensland from 12,100 to around 22,200 workers.

Figure 13a and 13b: Impact of renewables transition on baseline construction labour demand*, within regional Queensland, 2021-2050 (a) additional workers (b) % additional renewables workers on baseline



Note: *for 19 existing occupations critical to renewables but also in demand by the entire industry (eg. electricians and plumbers). Source: CSQ analysis of CSIRO (2022); QGSO (2018); ABS (2021); ABS (2021c); ABS (2021d).



Methodology and references

5 | Methodology and references

Chapter 2: Current pipeline methodology

About CSQ's Queensland Renewable Energy Projects database (QREP)

QREP is a census of renewable energy projects in Queensland, including hydrogen projects, developed by CSQ. To create the database, we screened and integrated three separate green energy databases to form a comprehensive unit record account of the aggregate investment pipeline for major renewable energy projects in Queensland.

Each line item in this database is a distinct renewable energy project. Core descriptors of each project (where available) include:

- capital investment/construction cost
- geographic coordinates
- statistical region
- installed capacity (GW)
- project type/renewables class
- expected commencement and/or completion dates for construction
- major project proponents

The database was last systematically updated and time-stamped on 15 December 2021. Revisions and updates are planned to follow the release of this report and will form part of CSQ's broader major projects intelligence platform.

Developing QREP

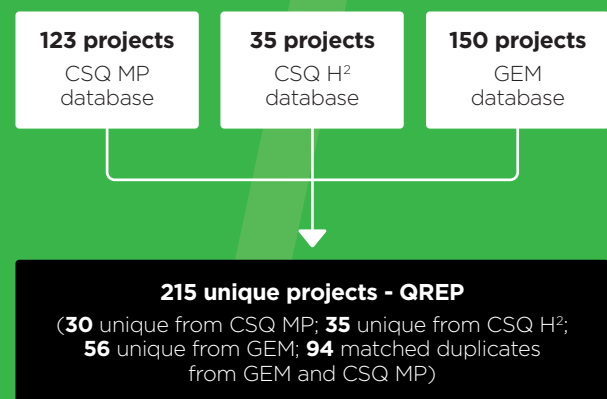
CSQ already tracks major infrastructure projects across Queensland in our Major Projects (MP) database, which includes renewable energy projects. However, given the accelerating wave of renewable energy project announcements over the last 12 to 18 months, particularly around hydrogen infrastructure, we combined this database with two other primary sources to complete a full census of projects. One primary source was internally developed by CSQ, the other externally provided. Integration and reconciliation of these assets ensures the full population of known projects in the pipeline across the state are included.

The first primary source database was CSQ's internally developed Hydrogen Projects (H²) database. We started tracking project announcements in Queensland systematically from June 2021 across several dimensions like cost, electrolyser size, location, and construction start and end date. We also located other hydrogen project lists in the public domain in various levels of completeness and included these where appropriate (for example CSIRO's HyResource project holdings).

For the second primary source database we purchased the renewable project holdings of Green Energy Markets (GEM) – a consulting firm that provides trusted green energy project lists to government organisations and other firms across Australia. This source did not include hydrogen projects.

Chart 1 outlines how these assets were integrated with our MP database to create QREP. For matched projects, CSQ's MP information was prioritised over GEM (mainly for fields like start and end dates, values and project status). This was to ensure a valid comparison of the renewable project pipeline with the broader civil projects in CSQ's MP database. Any completed or abandoned projects were removed from the primary databases to ensure QREP projects were all active parts of the pipeline.

Chart 1: Simplified flow chart of database development



Construction project status definitions

Table 1 below outlines how renewable energy projects are assigned one of four status indicators. This is based on satisfying one or more of the below criteria. This is the same classification methodology used for CSQ’s larger MP database.

Forecasting project end date

Having a construction end date for each renewable energy project was a key input variable required for the workforce demand modelling. Yet, the majority of QREP projects (66%) did not have a known construction end date. A methodology to forecast project end date was therefore developed.

Forecasting a construction end date for a project can be achieved by many means. The most common methods include the use of known cost and time variables from already completed projects as predictors for unknown projects (see Mensah et al 2017 for a full review). These predictors are usually drawn and applied to projects within a single sector of the construction industry (eg roads, bridges, dams and railways) rather than using time and cost parameters drawn from one sector in another (eg applying known time and cost from completed road projects to estimate construction time for a dam).

Drawing upon this framework, we developed a simple time-cost estimation method of completion date. That method was independently developed for each major sector of renewable energy infrastructure in QREP (solar, wind and hydrogen).

To do this, we accessed completed project lists for each renewable area in CSQ’s MP database and supplemented these with publicly available sources. We determined the average cost per month for each class of project. The total cost of the project could then be divided by the average cost per month for past projects to forecast the target duration in months. The number of months could then be added to the known start date to estimate end date.

We found that monthly project costs for completed projects scaled in a non-linear manner based on project size. For instance, the completion of a smaller scale solar farm (costing \$100 million and 13 months duration) had a monthly cost of \$7.8 million. This does not mean it takes 130 months (10 years) to build a \$1 billion solar farm. The known project duration for a solar farm valued at over \$1 billion ranged from 12 to 24 months. To better account for this feature in our estimations, average project cost per month was stratified by project scale (basically three tiers – small, medium and large). This enabled us to estimate project duration based on four parameters – cost, time, sector and size.

Table 1: Criteria used to assign QREP projects a status

Project	Underway	Committed	Planned	Possible
Description	Projects are under construction	Projects include those that have not yet begun but have firm prospects for commencing	Projects have been announced but prospects for commencing are less certain	Projects have been announced but have only limited details (eg no value or start / end date)
Criteria	<ul style="list-style-type: none"> principal contractor on site calling of subcontracts site works commenced (including earthworks) construction commenced 	<ul style="list-style-type: none"> expression of interest called or closed registrations for tender called or closed principal contractor awarded / builder appointed 	<ul style="list-style-type: none"> development application submitted or approved construction certificate submitted or granted called for design or documentation commencement or completion date known rezoning applications or approvals sketch plans in progress/completed site acquisitions or feasibility studies tenders for development/design environmental impact studies publicly announced 	<ul style="list-style-type: none"> any 'planned' criteria however if there is no start or end date, project is assigned to possible

5 | Methodology and references (continued)

The estimation factor (construction cost per month) resulting from this process is listed in **Table 2** below. The number in brackets represents the total number of projects in the renewable energy database that had their end date estimated. Comparing actual end dates with what the model would predict found decent predictive reliability, with predictions within 2 and 3 months of real completion dates for solar and wind respectively.

Table 2: Construction cost per month used to estimate construction duration

Size*	Solar (91)	Wind (22)	Hydrogen (17)	Other**
Small scale	\$9,521,620	\$13,775,900	\$3,279,600	\$2,770,800
Medium scale	\$25,000,000	\$34,507,100	\$35,163,400	\$19,266,600
Large scale	\$151,710,600	\$82,475,900	\$46,482,800	\$71,769,700

*Size definitions changed slightly by sector, but generally small = <\$500 million total cost; medium = \$500-\$900 million; large = >\$900 million **Other includes battery storage, manufacturing, transmission lines, hydroelectric and biogas projects

Modelling construction workforce demand

Forecasting construction labour demand from QREP was a key goal of the near-term part of this project. For this section we deployed CSQ's Occupational Demand Profile (ODP) modelling methodology, which we already use across our suite of workforce planning solutions to service Queensland's construction industry.

There are basically four main forecasting approaches used to determine occupational labour demand in the construction industry (for a full review, see Wong et al 2012). Our ODP model is broadly representative of the 'bottom-up' coefficient approach. This approach is based on the premise that each type of construction project (eg solar farm or wind farm) will require a near universal profile of trades to deliver each share of labour per unit of project expenditure over time (Chan et al, 2002 in Wong et al, 2012). And hence each project, regardless of its cost or build timeframe, follows a standard linear demand pattern for construction labour.

Based on this standard relationship between project expenditure, time and labour deployment on past projects, the labour required for each trade occupation (eg in the form of jobs per month per \$million) can be derived. We use third-order polynomial regression to estimate these coefficients (which best captures the negative skewness typically seen in labour requirements). These coefficients, in turn, can then be used to forecast occupational demand on a novel project if the cost and duration (start and end date) of that project are known. This was why it was critical to estimate end dates.

Aggregating occupational trade demand across a project can then be used to determine the quantity of construction jobs required per project, either at peak or on average across the construction lifecycle. And in turn, aggregating across all future projects provides a prospective estimate of the overall construction labour demand footprint for industries (eg renewable energy) or sectors (eg hydrogen). Hence the name 'bottom-up' approach.

Deriving these coefficients obviously relies on having rich timeseries data on the monthly labour deployed (by construction trade) and expenditure patterns of real-world completed construction projects. Moreover, these 'base project' inputs need to be specific to the sector we are trying to forecast. That is, detailed and comprehensive data on completed solar, wind or hydrogen projects for this report.

CSQ has long collaborated with Turner and Townsend, a professional services company with a specialisation in occupational demand modelling, to commission these inputs. To date, Turner and Townsend has provided CSQ with base project inputs across more than 10 project categories including a solar farm, a wind farm and more recently, a hydrogen processing facility.

The construction occupation breakdown for these base projects (more than -95%) map directly to the official 4-digit ANZSCO occupational role classification - enabling standardised outputs for trade demand in units commonly understood across the economy. Some headline parameters from these base projects used to estimate construction labour demand in this project are showcased in **Table 3** below.

Table 3: Base project input parameters

Project Parameter	Solar Farm	Wind Farm	Hydrogen Processing Facility
Cost	\$500M	\$300M	\$1B
Duration (months)	20	30	39
Number of unique construction occupations	32	27	43
Project brief	720MW & 300W-hr of battery storage	A wind farm consisting of 69 wind turbines	Solar power source & produces ammonia



5 | Methodology and references (continued)

Chapter 3: Renewable outlook to 2050 methodology

Aus-TIMES: Modelling the future in the Australian Energy System

As nations and regions throughout the world progress towards a net zero emissions future, sophisticated energy system models are required to address the challenges of the energy transition.

The Integrated MARKAL-EFOM System (TIMES) is perhaps the most well-known and widely used energy system model globally, with over 100 country versions and abundant related studies (Calvillo et al, 2017). TIMES has been used successfully by state and federal governments, national and international communities and researchers (US EPA, 2022). The advantage of TIMES over other models is coverage of the entire energy system, rather than only certain parts or sectors (Balyk et al 2019). TIMES has been developed as part of the longest running technology-related co-operation programme of the International Energy Agency.

TIMES has a number of distinct features. Using customised scenarios and constraints (eg net zero emissions by 2050), it transforms inputs covering an entire existing energy system – most commonly a country (eg Australia in 2022) – into a plausible future energy system. The model generates the least cost future energy system required in that future – while determining the optimal mix of technologies and fuel choices. Essentially, TIMES configures the most cost-effective energy system (and the road map to get there) while satisfying scenario requirements. Outputs include installed capacity of various technologies, and the associated costs, including capital investment and construction costs (Calvillo et al, 2017). Outputs are generated in five-year intervals (eg 2025, 2030) or at the end of the time horizon (eg 2050).

Many types of scenarios can be modelled and analysed in TIMES, mainly by configuring the underlying assumptions for the particular area we are interested in (eg variations in the demand for hydrogen exports vs domestic usage, variations in hydrogen production costs) and leaving the remaining dimensions constant. This feature is one of the main strengths of TIMES, as it allows certain technology pathways or ‘futures’ to be investigated, facilitating the development of different potential energy roadmaps. Importantly, hydrogen-centric scenarios have been successfully modelled in TIMES in Australia and internationally, but not yet in Queensland (Butler et al, 2020; Dodds, 2020).

National energy systems are highly idiosyncratic, driving a need to prioritise and contrast optimal pathways to a low-emissions society across a highly endemic set of economic and environmental conditions. For this reason it’s common that each country develops its own national TIMES model to investigate such energy-related roadmaps.

The Australian version of the TIMES model (Aus-TIMES) has been developed by CSIRO in collaboration with ClimateWorks Australia. Aus-TIMES uses a set of model-specific subsectors to represent the Australian economy, like the Australian and New Zealand Standard Industrial Classification (ANZSIC). It also includes all states and territories as separate units of analysis (including Queensland), which in-turn include sub-state transmission zones as additional units modelled (Queensland has four of these zones) (Butler et al, 2020).

Given the above, Aus-TIMES was highly suited to determining the long-term capacity and CAPEX required for a hydrogen industry in Queensland, along with the non-hydrogen renewables required to meet domestic net zero by 2050. To conduct the modelling, a base year of 2019 was used. This includes the inputs of energy balance, CO₂ emissions, vehicle estimates, current power generation assets and installed capacity of distributed generation (DISER 2020b; DISER, 2020a; ABS, 2020b, c; AEMO, 2020; Graham, 2021). Additional details of Aus-TIMES are outlined in Reedman et al (2021).

Estimating construction job numbers

CSIRO (2022) also undertook extensive work to calculate construction job numbers arising across scenarios and Aus-TIMES outputs. This included identifying the methods and assumptions used in prior work to estimate jobs emerging from hydrogen and renewables-related infrastructure. Construction jobs coefficients were calculated from these precedent studies and became the labour demand estimation framework used in this project. Operations and maintenance jobs were not part of this study.

CSIRO (2022) identified construction job numbers across the following four areas:

- Hydrogen production technologies – proton exchange membrane (PEM) electrolysis, alkaline electrolysis (AE), steam methane reforming (SMR) and steam methane reforming with carbon capture and storage (CCS)
- Hydrogen energy storage – hydrogen tanks
- Electricity generation technologies – specifically renewable energy such as wind and solar photovoltaics (PV), battery energy storage systems (BESS) and grid infrastructure
- Electricity transmission technologies – specifically those transmission lines and associated works associated with the expansion and connection of large-scale renewables

A summary table of CSIRO’s (2022) job estimation framework and outcomes is provided (**Table 4**).

Simply put, the Jobs and Unit metrics identified were applied to the capacity estimates generated by Aus-TIMES to estimate long-term construction labour demand.

Importantly, all possible hydrogen technologies were not explored (CSIRO, 2022). More speculative technologies, like solid oxide electrolysis, were not included due to a lack of robust research. However, these types of new technologies may become available at scale before 2050, reflecting the federal government’s Low Emissions Technology Statement that technology breakthroughs are part of the carbon neutral pathway for Australia by 2050 (Australian Government Department of Industry, Science, Energy and Resources, 2020).

Several additional demand drivers of construction labour that could arise from the scenarios (and Queensland’s renewables boom) were not included in these long-term projections or have not been included from CSIRO (2022). These areas include:

- water desalination plants (associated with hydrogen production)
- hydrogen pipelines
- upgrades to existing gas pipelines

- infrastructure upgrades to support renewable projects (roads/bridges/port expansions)
- the emergence of a green steel industry
- ammonia production plants (as a hydrogen carrier)
- renewable manufacturing facilities (eg electrolyser factories/battery storage factories)
- new mining infrastructure associated with sourcing renewable components (eg copper for solar panels)
- housing and other regional investment associated with population/income increases

This means the capacity, CAPEX and construction job estimates in this report may be underestimates.

Table 4: Methodology for estimating the number of future construction jobs

Sector	Sub-sector	Method	Source	Jobs	Unit	Notes
Renewable generation infrastructure	Wind	Employment multipliers	Briggs et al (2020)	1.4	Jobs/MW	No reduction in employment multiplier over time
	Solar			2.3		
	Battery storage			4.7		
Transmission infrastructure	n/a	Completed project job estimates	GHD (2020); BEZ (2020)	0.29	Jobs/MW	BEZ (2020) 26,400 jobs over 5 yrs to connect 90GW
Hydrogen production and storage infrastructure	Hydrogen production (Electrolysis)	Input-output modelling	Navigant consulting (2019)	2.3	Jobs/MW	Corroborates another study by CE Delft (2021)
	Hydrogen production (SMR)	Completed project job estimates	IEAGHG (2017)	125	Jobs/PJ	Build estimated 170,000 EUR in total for production of 110 GJ/hour
	Hydrogen production (SMR+CCS)			211		Adding CCS with a 90% CO2 capture onto the above SMR plant
	Hydrogen storage tanks (Electrolysis)		Peters et al (2003); HBR (2015)	51-161*	Jobs/ per tank	At least one day of hydrogen storage is assumed. Jobs figure scales overtime with tank capacity
	Hydrogen storage tanks (SMR+CCS)			106-163*		

Note: *Lower bound from 2021-2035, Upper bound from 2035-2050. Source: CSIRO (2022) for CSQ.

5 | Methodology and references (continued)

Chapter 4: Transition impacts methodology

Baseline construction activity outlook

To quantify the transition's impact we need to firstly estimate the size of the construction industry in future without the renewables transition in play. This is our 'baseline' construction outlook. We then add the renewables-related activity on top to assess the impact. Our baseline outlook includes the aggregate cost of all non-renewables construction projects the industry could be called to deliver through to 2050.

The long-term drivers of construction activity demand need to be modelled in order to estimate this outlook. There are a variety of known factors that contribute to this demand – including population growth, wage growth, household size, employment stability, new industry developments and interest rates.

Of these, population growth is considered a fundamental driver over the long run, and has been widely used to forecast construction demand (Shoory, 2016; Alias et al, 2016; Coleman et al, 2018; Sunde et al, 2017; Miller, 1998). While most of this work estimates residential construction demand only, there is conceivably a link between population forecasts and all construction industry demand, including non-residential construction (eg schools) and engineering construction (eg roads). For these reasons we used long-term population growth rates as the foundational input to estimate our baseline construction outlook.

We then followed a number of steps to leverage this technique. Firstly, we calculated the proportion of Queensland's population currently working in the construction industry (eg 5%) (ABS, 2021; 2021d). At the same time we estimated the dollar value of construction activity per construction worker in Queensland (eg \$180,000 per worker) (ABS, 2021; 2021c). We applied the workforce proportion to population forecasts through to 2050 (QGSO, 2018). These figures were then multiplied by activity per worker. We then did this for each transmission zone, and also for engineering activity only (ABS, 2011; 2016; 2021b).

The outcomes of this process was a baseline outlook for construction industry activity in Queensland each year from the early 2020s to 2050 given long-term population growth rates but no renewables-related activity.

Baseline construction labour demand for renewables-relevant occupations

Two streams of work were required to isolate the impact of the transition on the pool of construction workers with the skills most essential to that transition.

The first requirement was to determine which existing construction occupations are most renewables relevant. To achieve this, we extracted the known construction occupations required to deliver completed renewables

projects in CSQ projects database. One project in each of these sectors was available – solar, wind and hydrogen. The list constitutes 90% of the construction workforce required, is listed in the **Table 5** below.

The second requirement was to estimate the baseline demand for workers in these occupations across the whole industry throughout the transition period (without the demand for renewables infrastructure included). For this we again found that long-term population projections were fit for this purpose.

Forecasts of the size of the labour force expected in an economy are often based on population projections, which provide a useful proxy (Toossi, 2015; Stats NZ, 2021; ILO, 2017; ABS, 1999). Common here is the application of the current labour force participation rate to long-term population forecasts to estimate the future size of the workforce. While most existing work focuses on the labour force as a whole, some research has been applied to sectoral workforces which includes the construction workforce (Byrne et al, 2016).

Against this background, we calculated the proportion of Queensland's population currently working in renewables related occupations in the construction industry (eg 1.6%) (ABS, 2021d; 2021e). We applied that proportion to population forecasts through to 2050 (QGSO, 2018). We then did this for each transmission zone.

The outcomes of this process was a baseline outlook for renewables-relevant labour demand in the Queensland construction industry each year from the early 2020s to 2050 given long-term population growth rates (but without any demand specifically for renewable energy infrastructure).

Table 5: Renewables-relevant occupations

Occupation	
Electricians	Crane, Hoist & Lift Operators
Construction Managers	Electronics Trade Workers
Plumbers	Other Construction & Mining Labourers
Concreters	Industrial, Mechanical & Production Engineers
Earthmoving Plant Operators	Surveyors & Spatial Scientists
Structural Steel Construction Workers	Electrical Distribution Trades Workers
Truck Drivers	Electrical Engineers
Civil Engineering Professionals	Mechanical Engineering Draftspersons & Technicians
Other Miscellaneous Labourers	Other Engineering Professionals
Metal Fitters & Machinists	



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