Long-term demand forecast

Jemena Gas Networks

Final Report

March 2023

enea CONSULTING joins blunomy®

Contents

01 Executive summary

02 General approach and scope

03 Gas demand forecast

04 Gas blending forecast

05 Willingness-to-pay forecast

06 Possible model improvements

Glossary of terms

Term/phrase	Description
Customer segment	The set of Residential, Commercial or Industrial customers
Customer sub-segment	Sub-set of Residential, Commercial or Industrial customers
Scenario descriptions/narratives	Four scenarios developed by the expert panel which qualitatively describes four alternate set of futures up to 2050
Drivers	Factors used to generate customer demand trends over time (e.g. population growth, economic outlook, energy efficiency improvements, survival of gas appliances
Assumptions	Customer proportions, quantification of policy factors (e.g. how fast the state driven electrification would be), stability of relationships (e.g. between population growth and new connection) of variables that were assumed to quantify the gas demands
Outcomes	The versions of eventual reality that are described by the scenario narratives
Outputs	The results from the modelling or quantification exercises undertaken as part of this project

Abbreviation	Description
C&I	Commercial and industrial
WtP	Willingness-to-pay
TCO	Total cost of ownership

01

Executive summary

Executive summary (1/2)

Context and objectives

- The present report describes the methodology and key outcomes of a long-term gas demand forecasting project led by Blunomy for Jemena Gas Network (JGN).
- This project is part of a broader workstream that JGN is undertaking to inform future regulatory plans. It follows from a set of four scenarios developed by an expert panel.
- While the scenario narratives from the expert panel were already described qualitatively, this long-term gas demand forecasting project sought to quantify the outcomes described in the expert panel scenarios in terms of:
  - Customer numbers
  - Annual throughput
  - Gas mix
  - Gas wholesale price
  - Willingness-to-pay for gas from a customer perspective

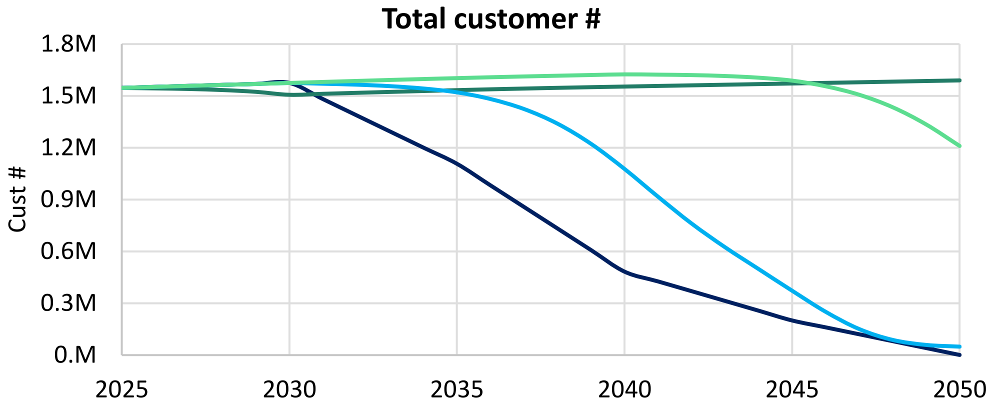
Approach used

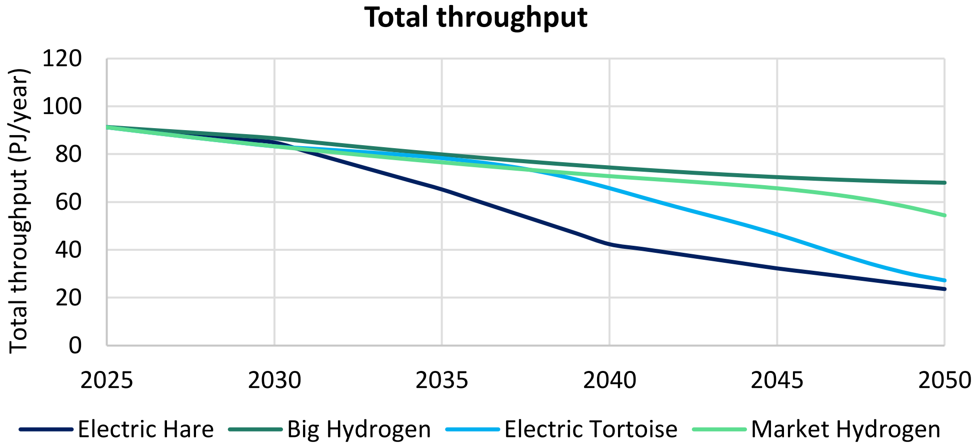
- The project drew primarily on the scenario narratives developed and leveraged on further consultations with Blunomy experts internally and within our network.
- Blunomy quantified the demand for network gas in terms of customer numbers and total throughput by:
  - breaking down the overall customer segments into relevant sub-segments,
  - determining the impact of the scenarios on these individual sub-segments,
  - and finally applying further drivers such as population growth, economic outlook and appliance lifespan to derive the final results.
- Blunomy also developed Willingness-to-Pay (WtP) forecast for the customer segments by:
  - adapting AEMO electricity price forecasts for scenario narratives
  - calculating the total cost of ownership to replace gas appliance based on capital expenditure estimates on the appliances and electricity price forecasts
- Further, Blunomy forecasted gas blending of the overall network to calculate the blended wholesale prices across the network consistent with the scenario narratives
- While the scenario narratives and model drivers[1] are quite prescriptive, there are aspects where Blunomy have made assumptions to pin down the quantities in the demand forecast. These assumptions are taken based on our interpretation of the 'version of future' that is in the spirit of each scenario. Along with JGN modelling and commercial teams, Blunomy progressively refined these assumptions[2], in order to develop more robust forecasts while constantly validating against the scenario narratives to ensure consistency with the descriptions.

Notes: [1] Besides the scenario narratives, the expert panel provided a series of qualitative assessment of various modelling parameters such as natural gas price, biomethane price, electricity prices in the form of 'High', 'Medium', 'Low'; [2] Related to proportions of various different sub-segments of customers, and application of drivers

Executive summary (2/2)

Key project results





From an overall perspective:

- Across the results, total customer numbers are primarily driven by residential customer numbers while total throughput trends are primarily driven by industrial throughput.
- In terms of customer numbers, by 2050, the results of the scenarios clusters around 1.2-1.6M in the case of the Big Hydrogen or Market Hydrogen scenarios or close to zero for the Electric Hare and Electric Tortoise scenarios
- In terms of total throughput, the range of outcomes in 2050 is tighter, with throughput ranging 54-68 PJ for Big Hydrogen or Market Hydrogen scenarios, and 23-27 PJ for Electric Hare and Electric Tortoise

Looking at each scenario individually:

- In the Electric Hare scenario where the state directs network-trimming and drives electrification, by 2050, customer numbers fall by >99% while throughput falls by 74%, compared to 2026
- In the Big Hydrogen scenario where state policies support renewable gas and enable mass market hydrogen, by 2050, customer numbers rise by 3% while throughput falls 26% due in part to improving efficiency, compared to 2026
- In Electric Tortoise scenario where market leads decarbonisation, by 2050, customer numbers fall by 97% while throughput falls by 70%, compared to 2026
- In Market Hydrogen scenario where the market-led decarbonisation leads to growth in green fuels, by 2050, customer numbers fall by 22% while throughput falls by 40%, compared to 2026

Notes: The results from this project are meant for the specific use-case of providing a quantitative view of the possible future envisioned by the scenario narratives developed by the expert panel. Blunomy did not challenge the scenarios provided, nor give any views on the likelihood of each scenario.

Assumptions were made as part of the modelling work done by Blunomy. The key criteria for these assumptions was to ensure alignment with the scenario narratives.

02

General approach and scope

Blunomy developed the demand forecast model iteratively, prioritising the key points of granularity, and in consultation with SMEs

The demand forecast modelling is based on the scenarios developed by the expert panel. This work entails:

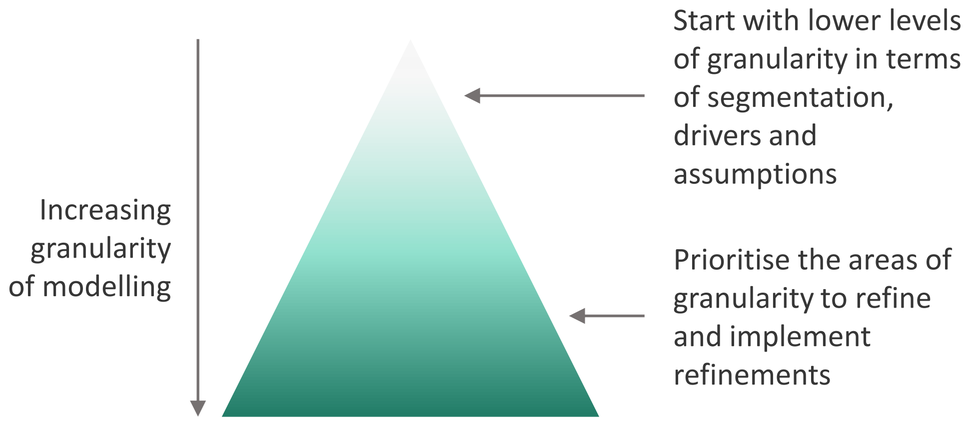
- Quantifying the outcomes described in the expert panel scenarios in terms of customer numbers and annual throughput
- Identifying the key drivers (e.g. population growth, economic growth, gas appliance lifespan, etc) applicable for the narrative in each scenario for each customer segment
- Developing and detailing assumptions regarding gas blending in the network
- Constructing an upper and lower bound for the willingness-to-pay (WtP) for each of the main customer segments

Throughout the modelling process, Blunomy does not:

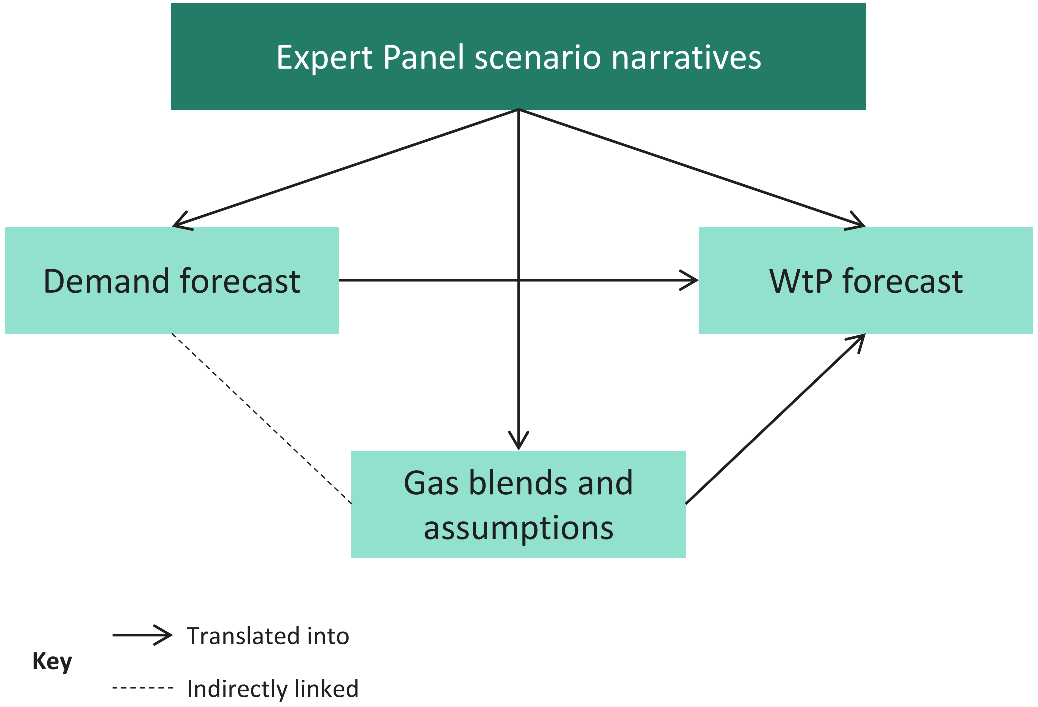
- Consider or give indication of the likelihood of the scenarios being realised
- Influence any assumptions, trends or outcomes described in the scenario narratives

The demand forecast model was developed iteratively, focusing on the key drivers and assumptions, and refining these in each iteration. This approach allowed for prioritised delivery of the model given the short project timeline.

Throughout the modelling process, Blunomy consulted with internal and external subject matter experts (SMEs), incorporating lessons from Australia and global experience of biomethane injection, gas decarbonisation, etc.



The expert panel scenario narratives and drivers are the foundation of the modelling and the primary input to the model



Linking the main outputs and scenarios

The scenario narratives and drivers defined by the expert panel are the foundations of the main outputs of the modelling:

- demand forecast
- gas blends and associated wholesale blended gas price forecast
- WtP forecast

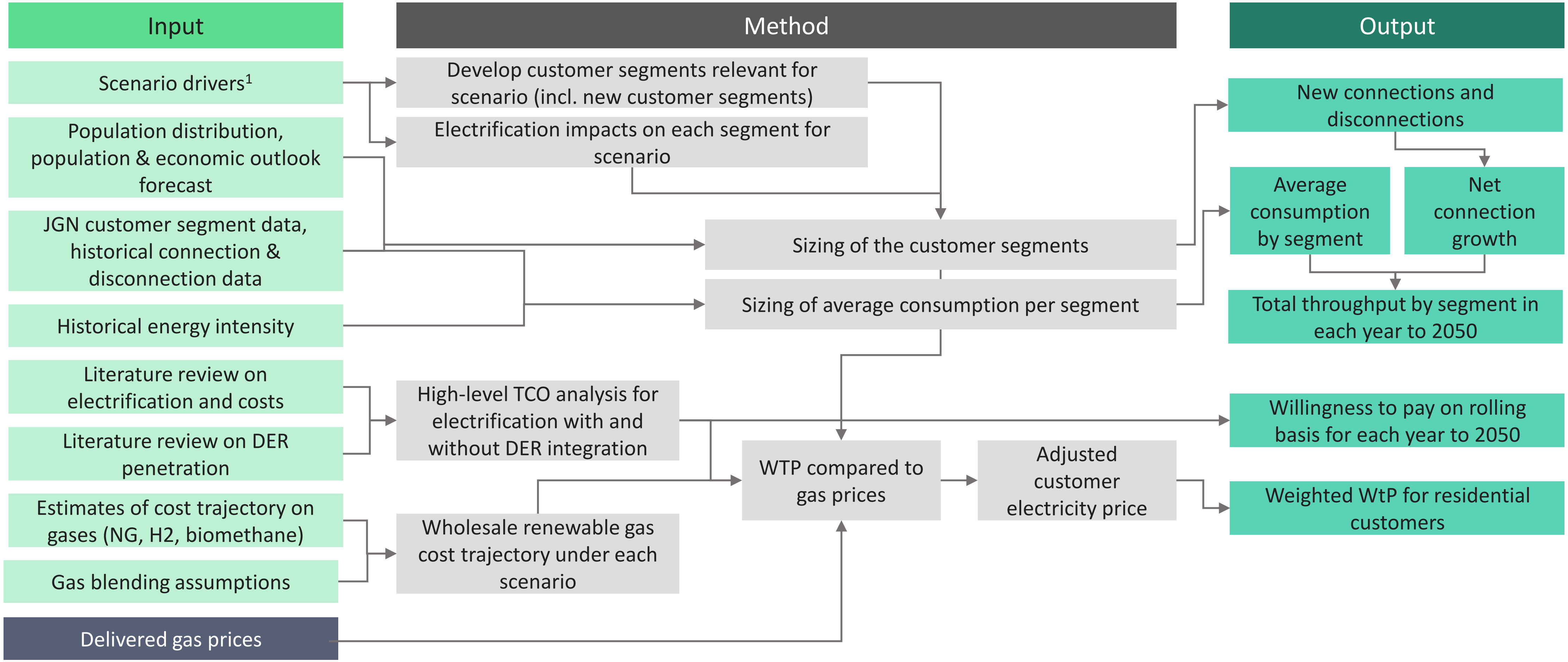
Each of the outputs have been designed and quantified to align with the outcomes described in the scenarios. This includes aligning with key drivers (and their Low, Medium, High rating), such as:

- expected demand from residential, commercial and industrial customers
- wholesale natural, hydrogen and biomethane gas prices
- delivered electricity price

The relationship between the demand forecast, WtP and gas blending and prices ensure overall consistency with the scenario narratives defined by the Expert Panel.

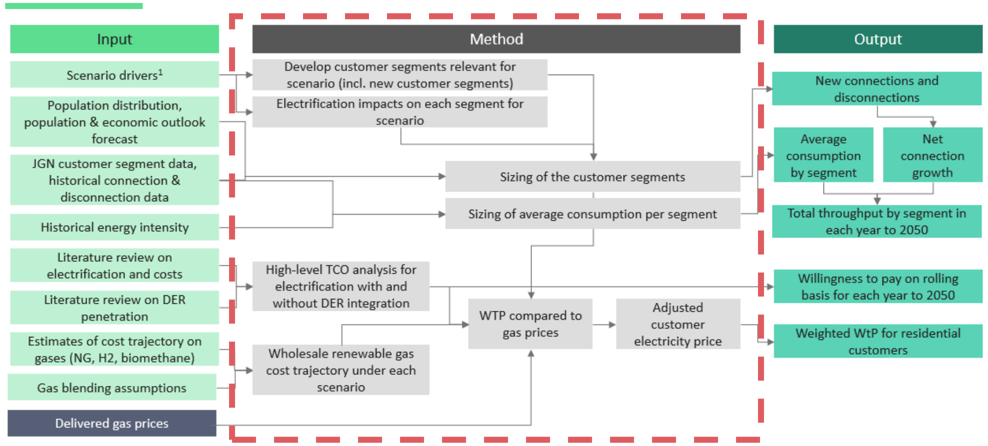
Other inputs, such as population growth rate, are used in conjunction with scenarios to model the required outputs

Key
- Input data or assumptions
- Inputs from JGN modelling
- Blunomy approaches
- Model outputs



Note: [1] Scenarios are provided by the expert panel engaged by JGN; Blunomy did not provide any inputs into the scenarios nor challenge the narratives of these scenarios as part of this forecasting exercise.

The method focuses on sizing the customer segments and quantifying scenario impacts and trends, and developing the WtP in parallel



Develop customer segments relevant for scenario

- Determining the relevant customer segments to be considered (e.g., households in Hunter Valley & Illawarra when that is mentioned etc.)

Electrification impacts on each segment for scenario

- Determining how which customer segments are electrifying (e.g., electrify when appliance reach end-of-life; or stay on gas)
- Assess if there is customer growth in each segment

New customer segments

- Defining new types of customers that are expected to connect to the network (e.g., H2 mobility refuelling)

Sizing of customer segments

- Obtaining # of customers based on population statistics, JGN customer profile, geographical locations, apportioning customers into smaller groups

Sizing of average consumption

- Based on existing Jemena gas consumption statistics; we allow it to decline for C&I customers based on historical reduction in energy intensity

High-level TCO analysis for electrification – with/without DER integration

- Total cost of ownership (TCO) analysis for electrification including CAPEX and OPEX of electric appliances then levelized to 'displacement costs' of gas
- DER integration trends and the impact on the LCOE[1] for residential customers
- This sets the **WtP thresholds** for each customer group

Wholesale renewable gas cost trajectory under each scenario

- Based on gas blending assumptions and price trajectories for NG, H2 and biomethane, calculate the wholesale gas prices for each scenario

WTP compared to gas prices

- Validation of WtP with delivered gas price for renewable blends with to ensure appropriate intersection with each other and alignment with the scenario narratives

Adjusted customer electricity price

- (Only for residential customers) Where necessary, solving for the delivered electricity price faced by customers when WtP and delivered gas price intersect

Notes: [1 Levelized cost of electricity

03

Gas demand forecast

03a - Detailed modelling approach

03b – Demand forecast results

Scenario narratives were interpreted and translated into impacts and trends on the customer connections and throughput

The scenarios were developed along 2 axes:

- Market-led vs government-led decarbonisation
- Renewable gas penetration

The approach taken by Blunomy examines the impact on customer connections and demand and willingness-to-pay according to different customer segments. In each scenario,

- the relevant customer segments and sub-segments were identified
- the time horizon of various impacts were flagged based on the dominant trend leading to 2030, and then between 2030 and 2050 described in the scenario narratives
- appropriate treatment of the customer sub-segments were derived based on the scenario narratives. Relevant drivers[1] were identified to provide sizing of customer segments and quantify the trends described in the scenario narratives

Government-led

1. Electric Hare

"Strong commitment to achieving net zero, government take proactive steps to reduce emissions through highly coordinated measures supporting electrification"

2. Big Hydrogen

"Strong government policy support… drives down the cost of hydrogen production…"

Biomethane focus limited to hard-to-abate / gas-dependent users and hydrogen is a niche product

Renewable gas penetration

Biomethane as stepping stone to hydrogen mass market

3. Electric Tortoise

"Traditional market-led pressures to transition"

4. Market Hydrogen

"path to decarbonisation is forged by market forces, and while not well-coordinated, achieves a diverse energy mix…"

Market-led

Notes: [1] Examples of drivers include population growth, economic growth, historical disconnection rate (based on historical Jemena data), etc.

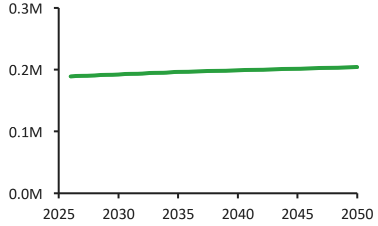
Customer segments were decomposed into sub-segments, treated based on scenario descriptions and combined for the overall trend

Scenario narrative | Relevant segments | Define scenario effects | Sizing of segment | Demand forecast

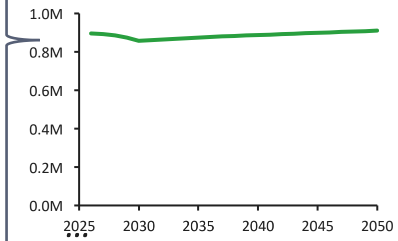
Coastal
Hunter/Illawarra Region
Non-highrise
Owned
Rented
Highrise
Owned
Rented
Outside Hunter/Illawarra
Non-highrise
Owned
Gas Loyalist
Electrification-driven
Rented
Highrise
Owned
Rented
Country
Non-highrise
Owned
Rented
Highrise
Owned
Rented

Customer sub-segments are derived for each scenario, as detailed above

Initial segment sizing is based on JGN data and where residential segments are expected to grow, new connections are determined by a **population growth index or economic growth index**

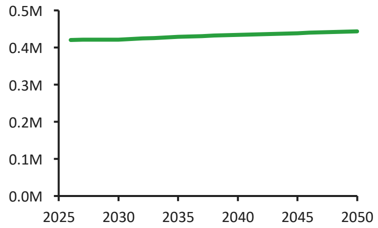


Net connections of non-highrise residential customers in the Hunter/Illawarra regions – in Big Hydrogen this sub-segment is expected to maintain connection to the network throughout 2026 – 2050.

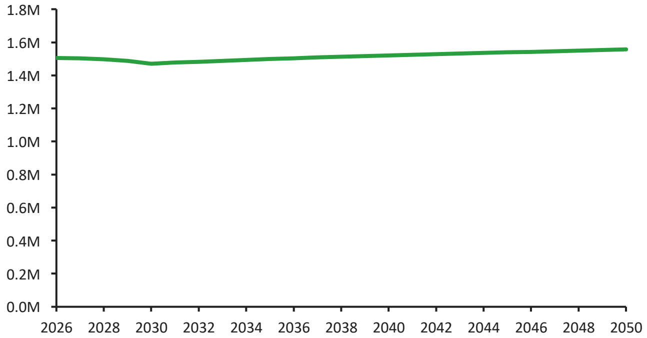


Net connections of non-highrise residential customers in other coastal regions – in Big Hydrogen this sub-segment is expected to disconnect between 2026 – 2030 due to electrification, then resume growth beyond 2030 as renewable gases become viable

…



All other residential subsegments



Each sub-segments of residential customers are treated individually, reflective of the expected behaviour from each group based on the scenario narratives

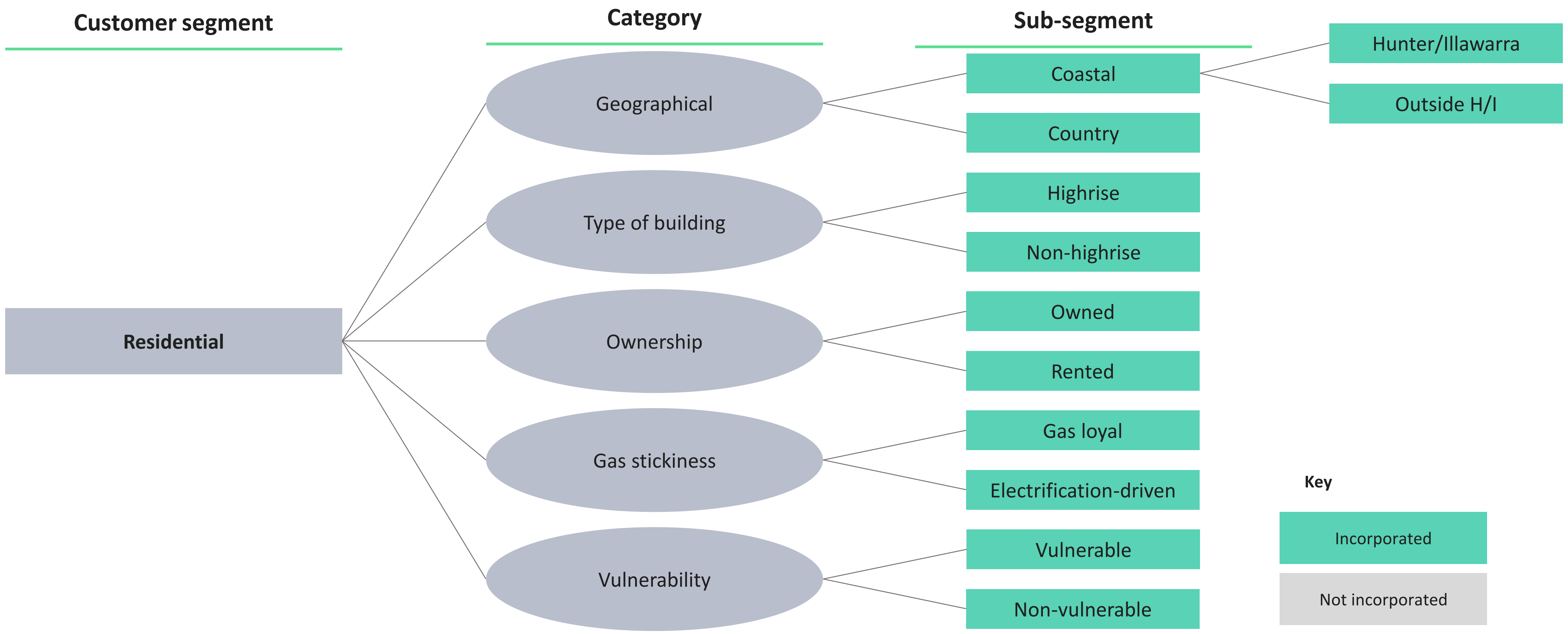
Total residential customer connections are obtained by totalling the sub-segment net connections at each year

The general trend of total residential customers will most closely resemble the largest sub-segment of customers

The same approach is taken for calculating the total throughput of residential customers

This process is repeated across all customer segments and their sub-segments to aggregate the total customer connections and throughput in each year

Residential customers were sub-segmented based on five different cross-sections for more granular characterisation



Residential customer sub-segments were quantified using population census or some assumptions taken based on public survey data

Category	Sub-segment	Definition of sub-segment	Basis of quantification
Geographical	Coastal – within Hunter/Illawarra regions	Total population of the suburbs within the Hunter and Illawarra LGAs	Customer # calculated based on mapping of suburbs to LGAs and LGA categorisation of coastal vs country[1]
	Coastal – outside Hunter/Illawarra regions	Total population of suburbs within the coastal LGAs, except for the Hunter and Illawarra LGAs	
	Country	Total population of suburbs within the country LGAs	
Type of building	Non-highrise	# of residential customers not in high-rise dwellings[2]	Customer # calculated based on historical data from Jemena which includes separation of high-rise vs non-highrise connection #
	Highrise	# of residential customers in high-rise dwellings[2]	
Ownership	Owned	Proportion of customers who own their residence	Using owned vs rented split of residences in NSW data for each dwelling type
	Rented	Proportion of customers renting their residence	
Gas stickiness	Gas loyal	Proportion of customers that are unlikely to electrify, and instead continue with gas appliances. Only applicable to non-highrise customers who own their residence.	Assumed to be a % of all non-highrise where the residence is owned by the customer
	Electrification-driven	Proportion of customers that are likely to electrify. Only applicable to non-highrise customers who own their residence.	
Vulnerability	Vulnerable	Proportion of customers who are unable to electrify/disconnect from the gas network predominantly due to financial hardship/stress and are therefore gas-loyal by circumstance	Assumed to be a % of all gas loyal customers, based on the Energy Consumer Sentiment Survey[3]
	Non-vulnerable	Proportion of customers who are able to electrify but choose to be gas loyal	

Notes: [1] Coastal and country LGAs as defined by Jemena; [2] Segmented based on historical Jemena data for residential customers [3] ECSS Results in June 2022 had 14% of households indicating they are under financial pressure; we have used a subset of this to represent those who are on the extreme end of the spectrum.

enea consulting joins blunomy®

Residential customers were sub-segmented in each scenario to align with the narratives, allowing for the most appropriate level of granularity

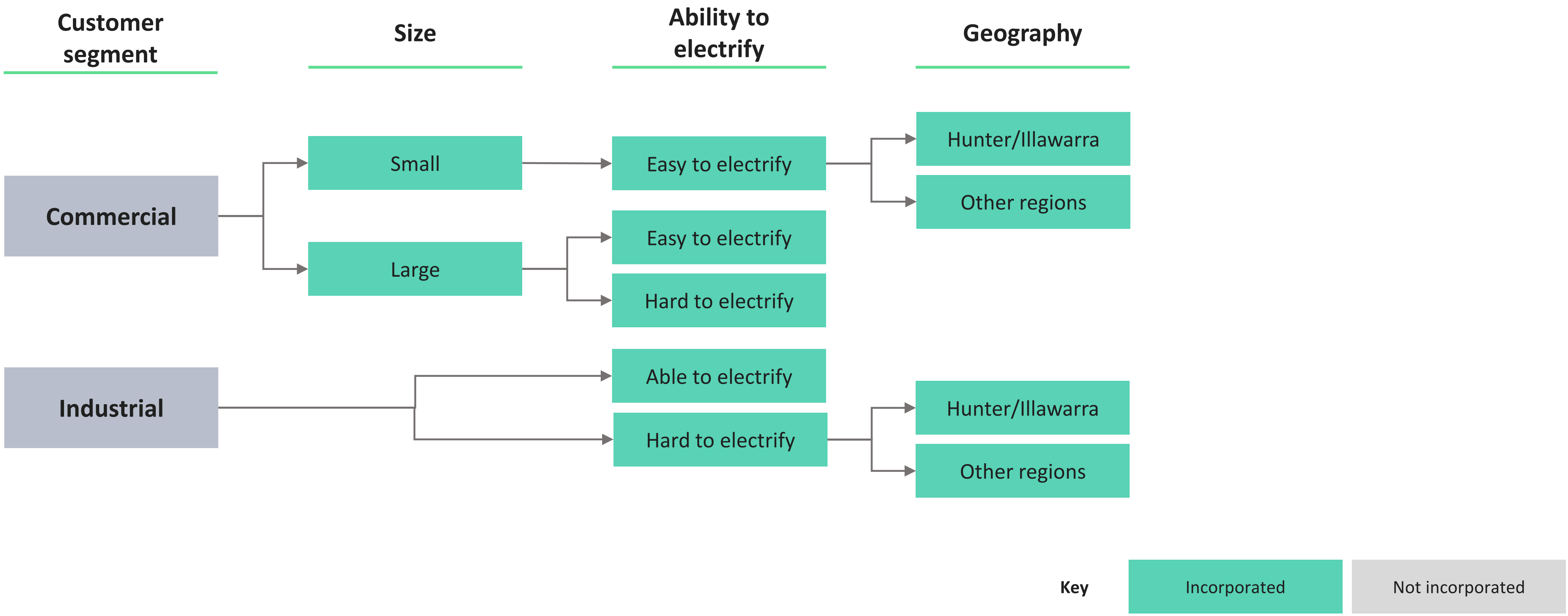
Electric Hare
Coastal
Non-highrise
Highrise
Country
Non-highrise
Highrise

Big Hydrogen
Coastal
Hunter/Illawarra Region
Non-highrise
Owned
Rented
Highrise
Owned
Rented
Outside Hunter/Illawarra
Non-highrise
Owned
Gas Loyalist
Electrification-driven
Rented
Highrise
Owned
Rented
Country
Non-highrise
Owned
Rented
Highrise
Owned
Rented

Electric Tortoise
Coastal
Non-highrise
Owned
Gas Loyalist
Vulnerable Household
Non-vulnerable Households
Electrification-driven
Rented
Highrise
Owned
Rented
Country
Non-highrise
Owned
Rented
Highrise
Owned
Rented

Market Hydrogen
Coastal
Hunter/Illawarra Region
Non-highrise
Owned
Rented
Highrise
Owned
Rented
Outside Hunter/Illawarra
Non-highrise
Owned
Gas Loyalist
Electrification-driven
Rented
Highrise
Owned
Rented
Country
Non-highrise
Owned
Rented
Highrise
Owned
Rented

Commercial and industrial (C&I) customers were broken down by size, ease of electrification and geography



Note: Size, Ability to electrify and geography are categories used to further segment

C&I customer sub-segments were quantified primarily based on data provided by Jemena and some high-level assumptions made by Blunomy

Customer type	Category	Sub-segment	Definition of sub-segment	Basis of quantification
Commercial	Size	Small	Residential-like commercial customers, as defined by Jemena, typically with consumption < 160 JG/year	Split of commercial customers provided by Jemena, segregated by typical annual consumption
		Large	All other commercial customers, typically consuming > 160 GJ/year	
	Geography	Coastal – within Hunter/Illawarra regions	Customers within the suburbs within Hunter and Illawarra LGAs	Using % of residential population within each geographical segment, assuming it is representative of small commercial customer spread
		Coastal – outside Hunter/Illawarra regions	Customers within the coastal LGAs, except for the Hunter and Illawarra LGAs	
		Country	Customers within the country LGAs, as defined by Jemena	
Commercial & Industrial	Ability to electrify	Easy-to-abate/electrify	Current gas use of these customers can be electrified (assuming all gas use can be electrified)	Commercial customers – assumed 90% Industrial customers – all customers using gas for low heat
		Hard-to-abate/electrify	Current gas use of these customers cannot be electrified (e.g. high heat processes)	Commercial customers – assumed 10% Industrial customers – all customers using gas for high heat, feedstock, GPG and gas storage

C&I customers were sub-segmented in each scenario to align with the narratives, allowing for the most appropriate level of granularity

Electric Hare
Commercial
Small Commercial
Coastal
Country
Large Commercial
Easy-to-Electrify
Hard-to-Electrify

Electric Hare
Industrial
Able-to-Electrify
Hard-to-Electrify

Big Hydrogen
Commercial
Small Commercial
Coastal
Hunter/Illawarra Region
Outside Hunter/Illawarra
Country
Large Commercial
Coastal
Hunter/Illawarra Region
Easy-to-Electrify
Hard-to-Electrify
Outside Hunter/Illawarra
Easy-to-Electrify
Hard-to-Electrify
Country
Easy-to-Electrify
Hard-to-Electrify

Big Hydrogen
Industrial
Able-to-Electrify
Hard-to-Electrify

Electric Tortoise
Commercial
Small Commercial
Coastal
Country
Large Commercial
Coastal
Easy-to-Electrify
Hard-to-Electrify
Country
Easy-to-Electrify
Hard-to-Electrify

Electric Tortoise
Industrial
Able-to-Electrify
Hard-to-Electrify

Market Hydrogen
Commercial
Small Commercial
Coastal
Hunter/Illawarra Region
Outside Hunter/Illawarra
Country
Large Commercial
Coastal
Hunter/Illawarra Region
Easy-to-Electrify
Hard-to-Electrify
Outside Hunter/Illawarra
Easy-to-Electrify
Hard-to-Electrify
Country
Easy-to-Electrify
Hard-to-Electrify

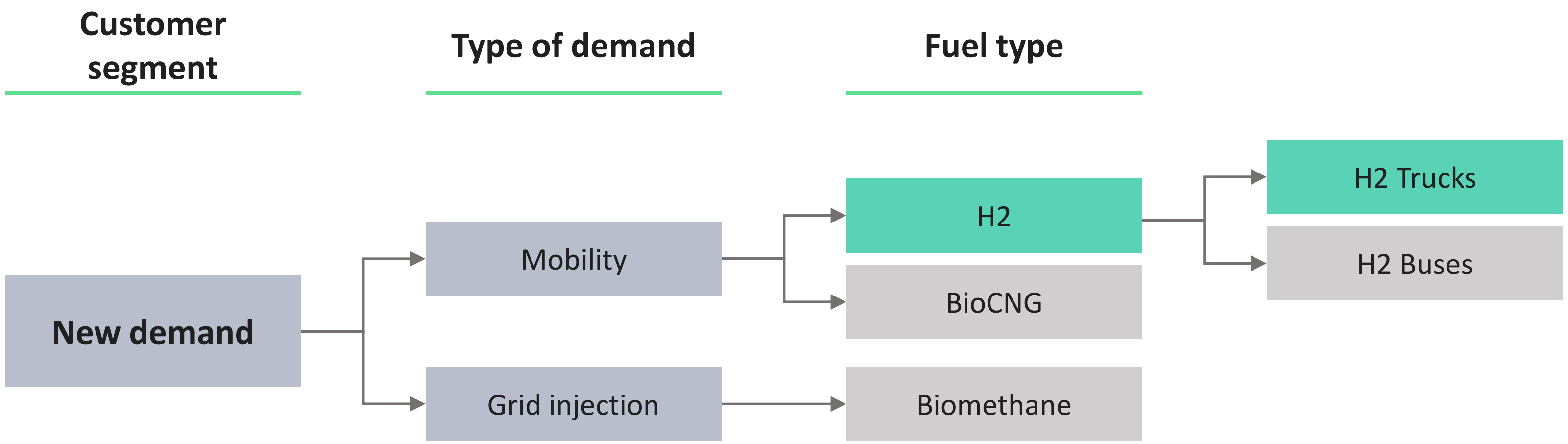
Market Hydrogen
Industrial
Able-to-Electrify
Hard-to-Electrify

Potential new sources of demand for gas network were considered, with hydrogen mobility prioritised for inclusion in the model

Some potential new sources of demand for the gas network were identified and evaluated to be included in the modelling

New demand	Reason for demand	Consideration for modelling	Status
Hydrogen vehicles	Hydrogen vehicles will require hydrogen refuelling and refuelling stations will need to be connected to the distribution networks (pure H2)	Hydrogen trucks are likely first to be deployed as part of Hume Highway initiative and because they are less substitutable with electric vehicles	Incorporated
Green steel manufacturing	Green steel manufacturing will use green hydrogen for reduction of iron in the process	Such processes requires large quantities of pure hydrogen, and the facilities will likely be connected through transmission pipelines rather than the distribution network	Not incorporated
BioCNG vehicles	Biomethane or BioCNG might be required for decarbonisation of these fleets which may substitute heavy duty transport (currently fuelled by diesel)	Will need to assess plans and demand for such vehicles and potential for fleet conversions in Australia	Not incorporated
E-fuel production	Green hydrogen will be required for the production of synthetic fuels (power-to-liquid) that will be used for aviation (e.g. e-kerozene) or maritime fuels (e.g. e-methanol)	Such processes requires large quantities of pure hydrogen, and the facilities will likely be more connected through transmission pipelines rather than the distribution network. The resulting fuels are liquids and will not be transported through gas pipelines	Not incorporated
Biomethane production	Biomethane production plans will need to inject into the gas grid as a means of supplying their customers	Will need to assess demand based on likely number of projects to connect to JGN	Not incorporated

New customers were defined based on the type of demand (grid injection, mobility) and fuel type required (hydrogen, biomethane, etc.)



For simplicity, these new demand customers are classified as industrial customers in the tally of customer numbers.

Note: *BioCNG and Biomethane production plants are potential sources of new demand for gas network to consider in the modelling; owing to the tight timeline and limited resourcing, we did not go deeper to model the demand from these sources*

Key Incorporated | Not incorporated

Note: Type of demand and fuel types are categories used to further segment the new demand; we have considered the demand for green hydrogen by the industry producing Sustainable Aviation Fuels (SAF) but owing to the demand capacities, they are likely connected to gas pipelines rather than distribution networks.

Blunomy identified drivers for new connections, disconnections and average throughput; from the scenario narratives and beyond

Output	Driver category	Drivers
Number of customers	Disconnection of existing customers	Historical disconnection rate
		Electrification driven by equipment lifespan[1] (by customer group)
		Electrification driven by policy (scenario driven)
		Shut-downs due to inability to afford capital facility upgrades (scenario-driven)
	Connection of new "traditional" customers	Population growth
		Economic growth
	Connection of new customer types	Hydrogen refuelling stations
Average throughput per customer	Average throughput per 'traditional' customer	Energy intensity trends
		Historical average throughput per type of customer
	Average throughput of new types of customer	Hydrogen vehicle growth

Notes: [1] Equipment lifespan and average age of appliances within a given customer cohort are defined using a survival curve function (explained in the next slide)

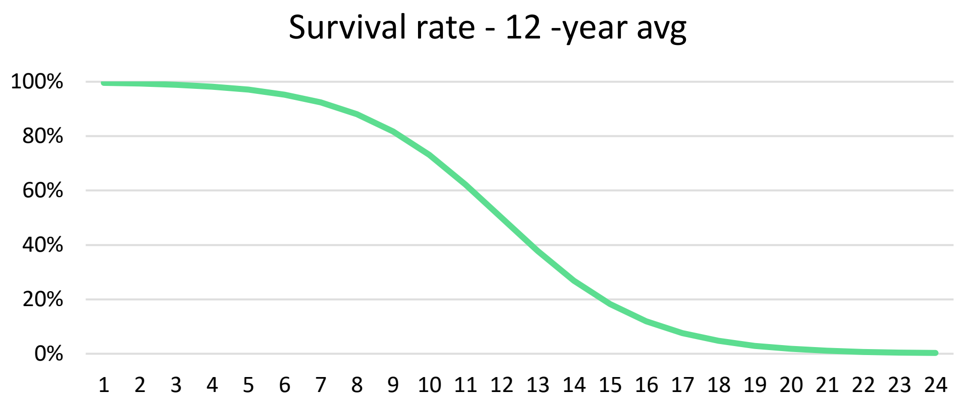
Two survival curves of 12-year and 20-year average lifespans are used to model gas appliance lifetimes

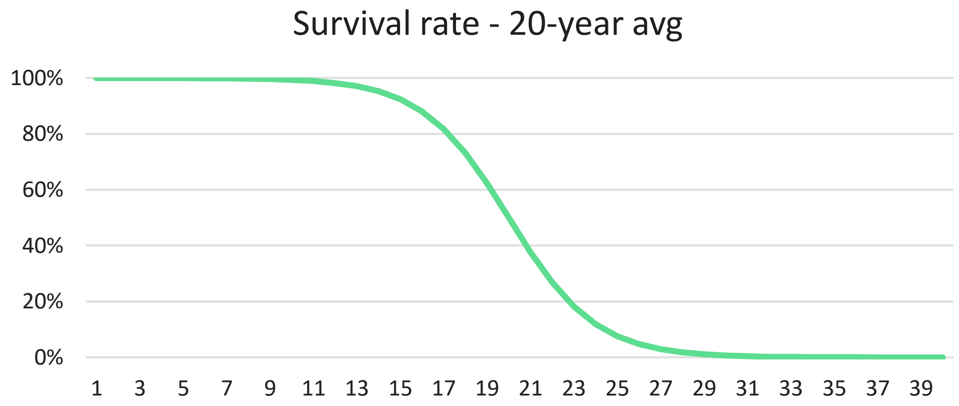
Use of survival curves as drivers

A survival curve is developed using the survival function, which models the cohort of uniformly distributed gas appliances gradually declining due to equipment failure. This is applied over the period when energy users discontinue their use of gas after their appliances reach the end of their lifespan.

The lifespan of residential and small commercial gas appliances are modelled with the 12-year survival curve (top graph) whereas the gas appliance survival for large commercial and industrial customers who are able to electrify are modelled using the 20-year survival curve (bottom graph).

Franco et al (2018) have used similar functions as a means to estimate the average lifespan of equipment. Like the function used in our modelling, the definition adopted for 'average lifespan' of the equipment is exactly when the proportion of equipment still surviving is at 50%.





Source: Franco et al (2018) Estimating Residential Appliance Lifetime for Energy Efficient Policy Analysis

03

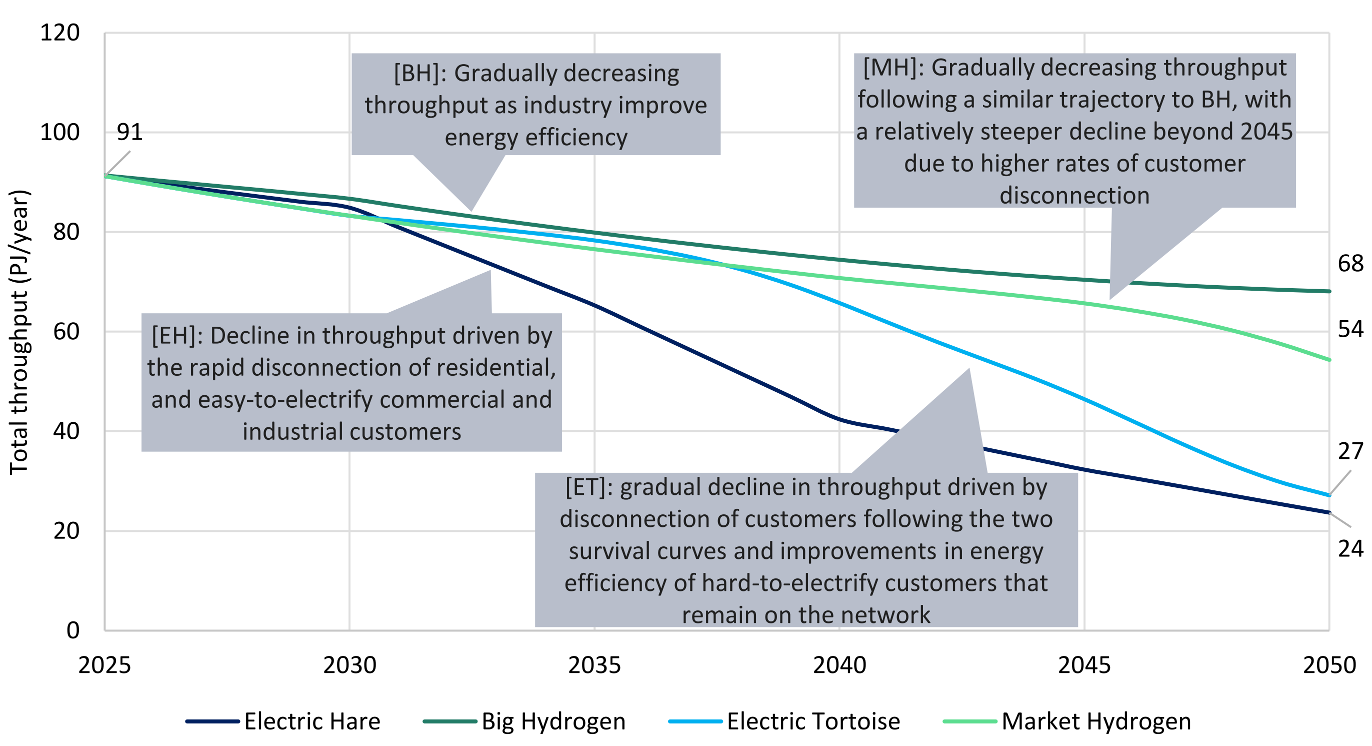
Detailed modelling approach

03a - Detailed modelling approach

03b – Demand forecast results

Total throughput declines in all scenarios, due to reducing customer numbers or improved energy efficiency

Total throughput for all customer segments

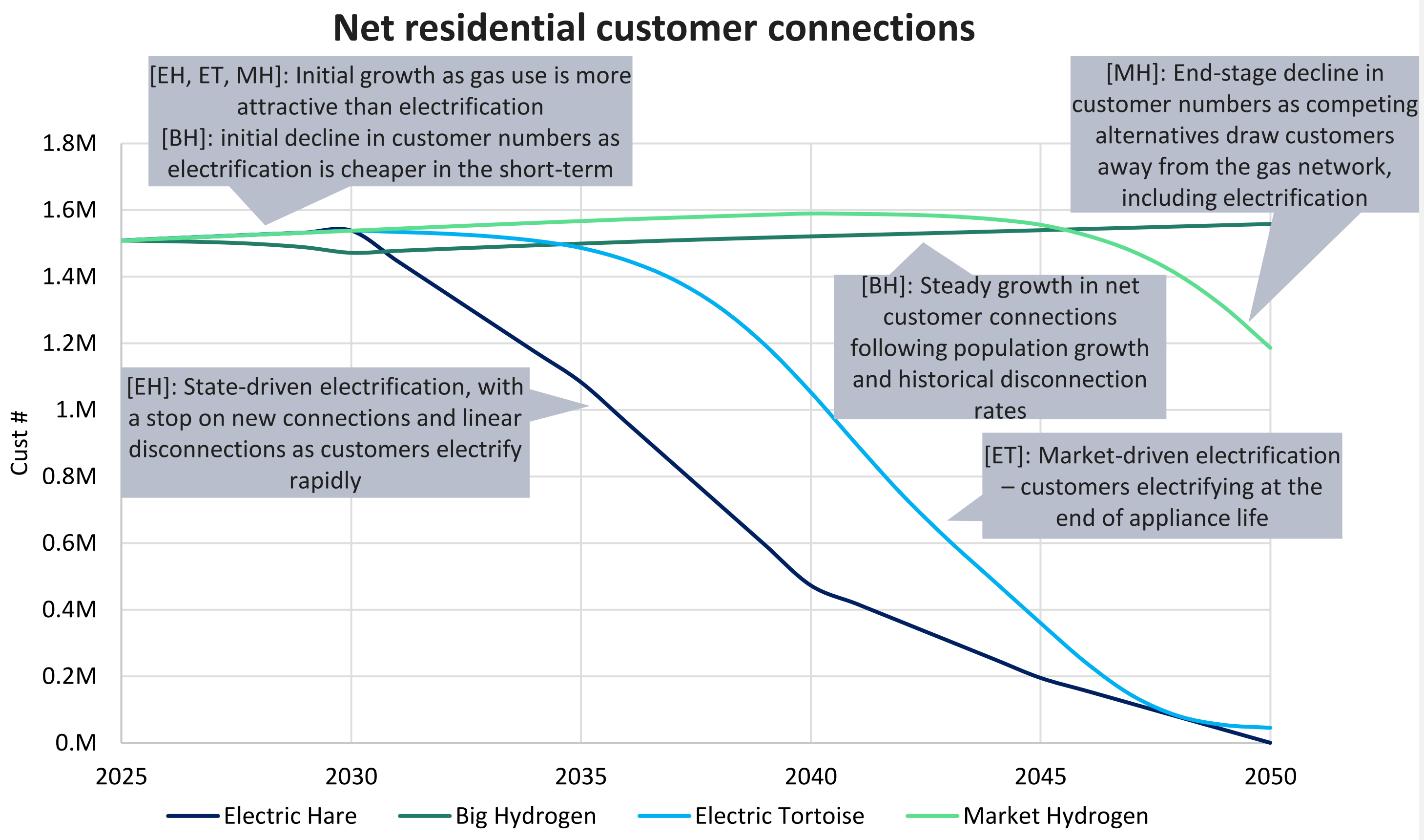


Discussion of results

- Total throughput across the scenarios are primarily driven by the industrial customer usage as they have the highest average throughput per customer
- Overall downward trend during 2025-2030 reflects historical reductions in average throughput and also decline amongst the industrial users as historical disconnections have surpassed the growth of users.
- Reduction in average throughput, especially for industrial customers, reflects a trend in improving energy efficiency and to some extent, partial electrification.
  - This project does not account for these efficiency gains or partial electrification amongst small commercial or residential customers as they are likely non-systematic and less significant
- Across the scenarios, total throughput (by energy) declines by 25-75%
- Evolution of customer numbers for each customer segment across the scenarios is discussed in the next slides.

Notes: EH = Electric Hare, BH = Big Hydrogen, ET = Electric Tortoise, MH = Market Hydrogen

Residential net connections decline rapidly in electric scenarios but remain relatively high in hydrogen scenarios

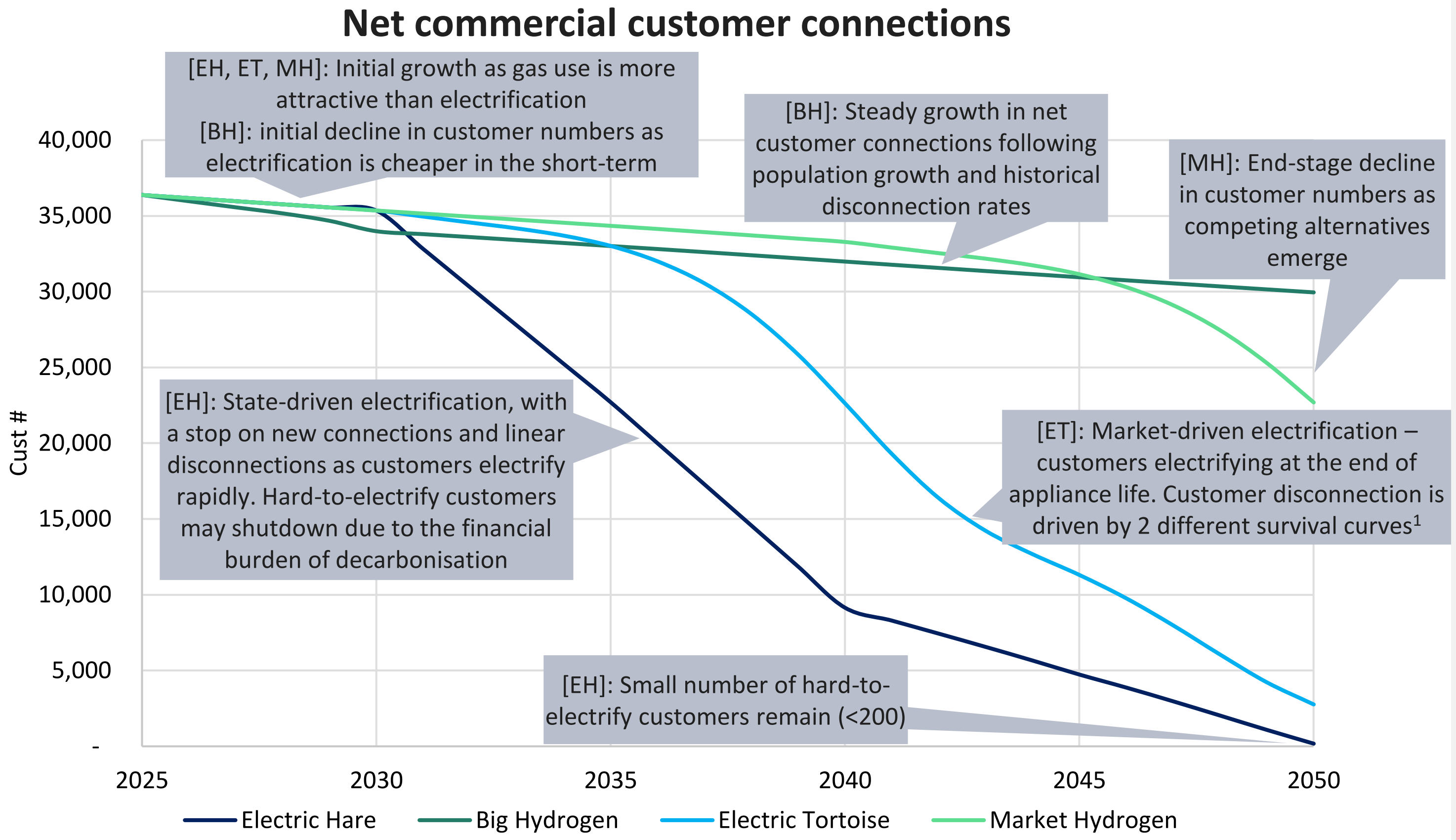


Discussion of results

- The outcome of each scenario is represented through an overall trend net customer connections
- Some general principles were following in quantifying customer connection trends, however there are some differences across sub-segments For example,
  - Coastal residential customers are the least gas sticky, beginning to electrify and disconnect very easily.
  - Of this group, those in non-highrise dwellings are comparatively faster than those in highrise dwellings given the fewer physical barriers to electrification
  - On the other hand, country customers are gas-stickier and lag behind coastal customers when customers are expected to begin electrifying and therefore begin disconnecting from the gas network ~5 – 10 years after coastal customers
- In Big Hydrogen and Market Hydrogen scenarios where renewable gas hubs[1] play a prominent role, residential customers within the Hunter and Illawarra regions are expected to maintain their connections throughout the period from 2026 – 2050 regardless of the attractiveness of electrification

Notes: EH = Electric Hare, BH = Big Hydrogen, ET = Electric Tortoise, MH = Market Hydrogen [1] according to the scenario narratives, renewable gas hubs are expected to be in the Hunter and Illawarra regions

Commercial net connections decline across all scenarios, with a more rapid decline in the electric scenarios

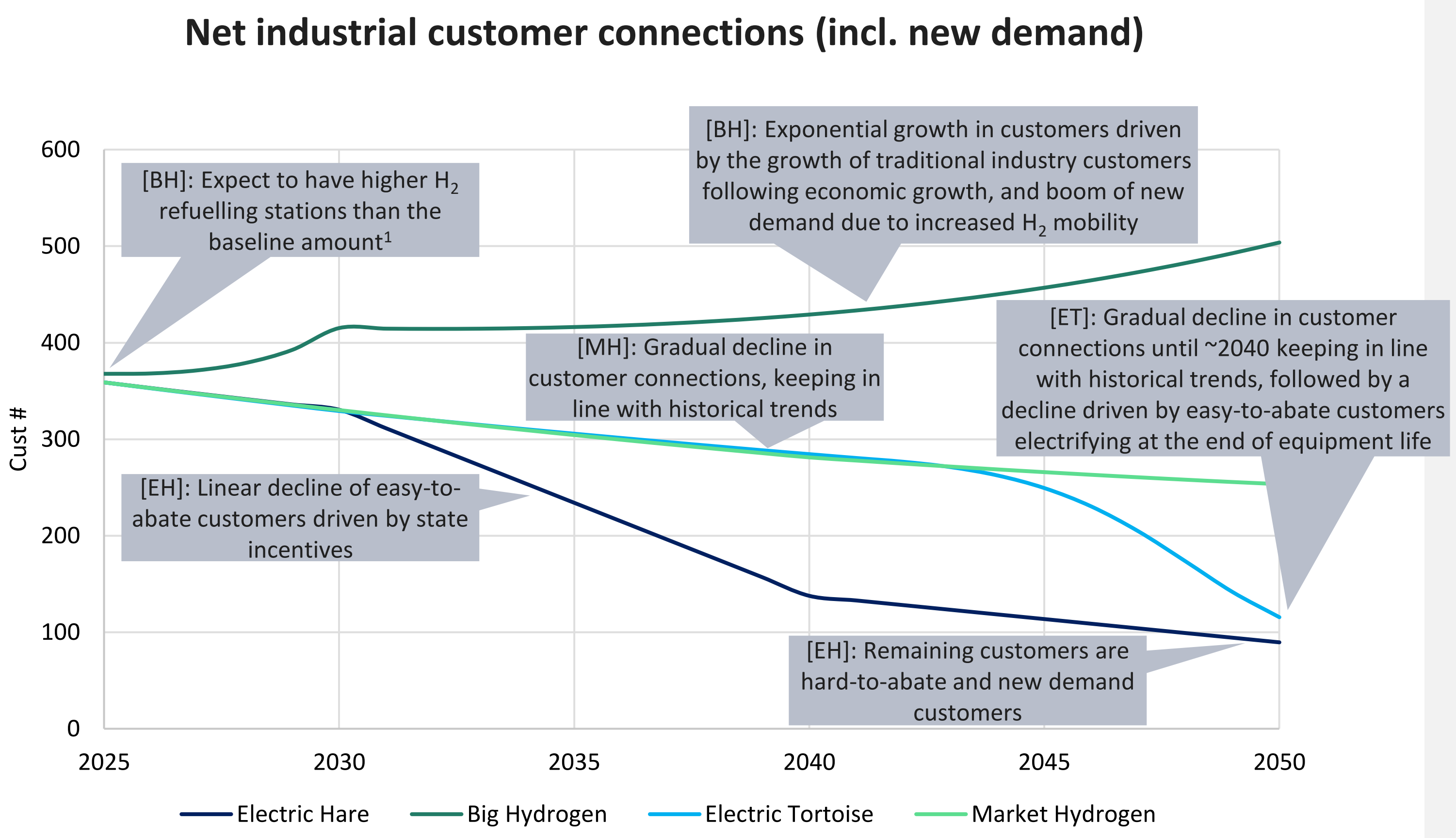


Notes: EH = Electric Hare, BH = Big Hydrogen, ET = Electric Tortoise, MH = Market Hydrogen
[1]: Survival curve for small commercial customers with 12-year average lifespan of appliances and 20-year lifespan for large commercial customers

Discussion of results

- Commercial customers are sub-segmented into two main groups:
  - Small commercial customers (<160 GJ/year)
  - Large commercial customers (> 160 GJ/year)
- Small commercial customers are assumed to be those offering general services to the community – e.g., local cafes, restaurants, grocery stores, etc.
  - As such, these customers are expected to grow following general population growth rather than economic growth
  - These customers are also expected to have gas uses that can be fully electrified
- As small customers are expected to follow population patterns, those in the Hunter and Illawarra regions are simulated to follow the behaviours of residents in these regions – i.e., remain gas loyal when customers in other regions begin electrifying
- On the other hand, large commercial customers are assumed to be those with larger production volumes/operational capacities such as hospitals, universities, and shopping malls.
  - These customers are expected to grow with economic growth
  - They are also further sub-segments as easy-to-electrify and hard-to-electrify

Traditional industrial customers decline across all scenarios, however new demand customers grow rapidly in Big Hydrogen



Discussion of results

- Industrial customers consist of three main sub-segments:
  - Able-to-electrify customers – those currently using gas for low heat uses
  - Hard-to-electrify customers – those currently using gas for high heat uses, gas-powered generation, feedstock, etc.
  - New demand customers – hydrogen refuelling stations
- Across the traditional industrial customers, historical disconnection rates surpass growth rates aligned to NSW economic growth, leading to a general decline in customer connections
- Aside from the Electric Hare scenario, where able-to-electrify customers begin electrifying and disconnecting from the gas network, they follow a survival curve with a 20-year average lifespan for the equipment
  - This results in a much more gradual reduction in customer connections than for residential and small commercial customers following a survival curve with a 12-year avg lifespan

Notes: EH = Electric Hare, BH = Big Hydrogen, ET = Electric Tortoise, MH = Market Hydrogen
[1] ~ 4x the amount of refuelling stations and trucks outlined in the Hume Highway Hydrogen initiative

04

Gas blending forecast

The scenario narratives are translated into a % by energy contribution from each gas to form the overall gas mix and wholesale price

Scenario narrative | Relevant drivers | WS price and blending profiles | Gas mix and WS price[3]

Key timelines and qualitative blends are identified for each scenario based on Blunomy's interpretation of the scenarios[1]

Drivers defined in the scenario narratives are used to develop price curves for the gases

Hydrogen

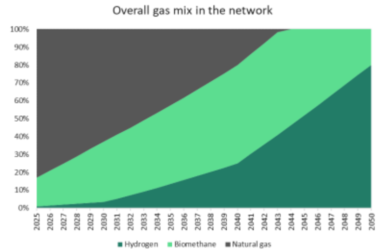
- Wholesale H2 price forecasts are primarily obtained from the Australian Hydrogen Market Study report[2], with two price series for 'Accelerated' and 'Base' cases.
- Min, avg and max of these price series are calculated to align with L, M and H relative prices (according to the scenario drivers)
- Hydrogen is in the overall gas mix only in Big Hydrogen and Market Hydrogen scenarios
- The amount of hydrogen in the mix for each scenario is determined based on the scenario narratives and its interpretation and discussed in the results

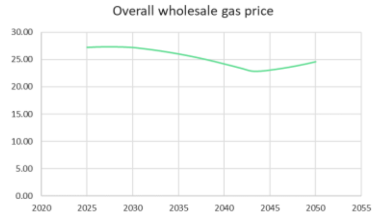
Biomethane

- Biomethane prices are based on previous Blunomy analysis of biogas potential and prices
- Min, avg and max of this price series are calculated to align with L, M and H relative prices (according to the scenario drivers)
- The potential biomethane amount for JGN is approximated as the ratio of NSW and Australian theoretical potential for biogas applied to the expected biogas amount (in PJ) in gas pipelines under the 'Targeted Deployment' scenario in Australia's Bioenergy Roadmap

Natural gas

- Wholesale NG price profiles are developed for each scenario based on the price drivers and relative prices (as L, M, H) at 2030 and 2050 listed in the expert panel report
- These have been quantified using AEMO prices forecast indices and a avg wholesale price observed in the National Energy Market (NEM) over the last 5 years
- Natural gas is used to make up any remaining gas demand in addition to the contribution from hydrogen and biomethane in each scenario





The overall gas mix[4] for a given scenario is derived from the individual contributions from hydrogen, biomethane and natural gas.

The wholesale price is then the weighted average of the three gases.

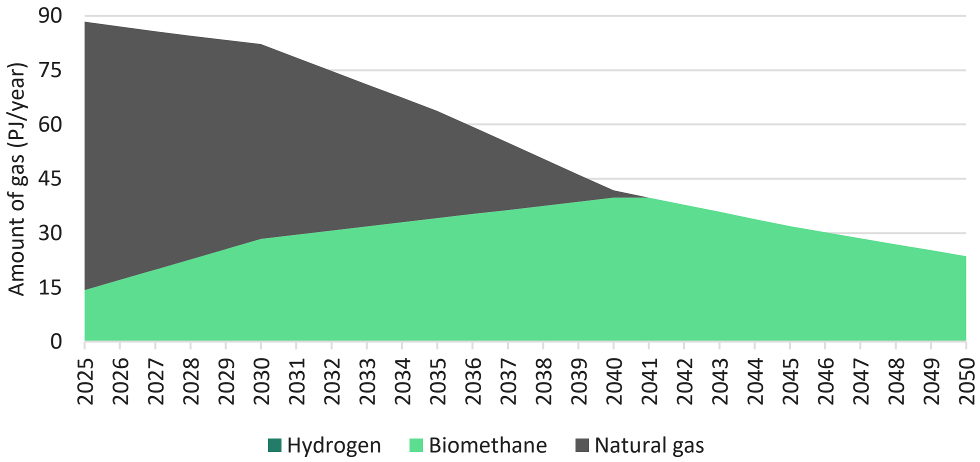
Overall mix and prices are discussed in the next slides.

Notes: [1] Done independent of JGN's asset management team [2] Developed by Advisian, 2021 [3] Illustrative mix and prices [4] the overall mix is for the entire gas distribution network that remains at each year within a scenario. It does not consider the blend of gas for a given section of a network (e.g., 100% hydrogen sections, etc.). Additionally, the reduction in energy demand (modelling results) is more than the energy reduction from H2 blending.

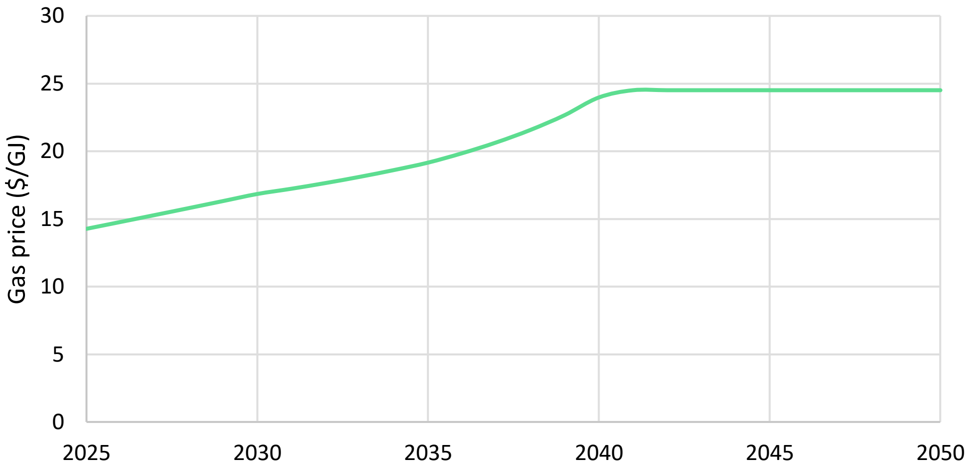
enea CONSULTING joins blunomy®

Electric Hare scenario expects to achieve 100% renewable gas in network by 2041, with a stable gas price beyond 2040

Overall gas mix in the network



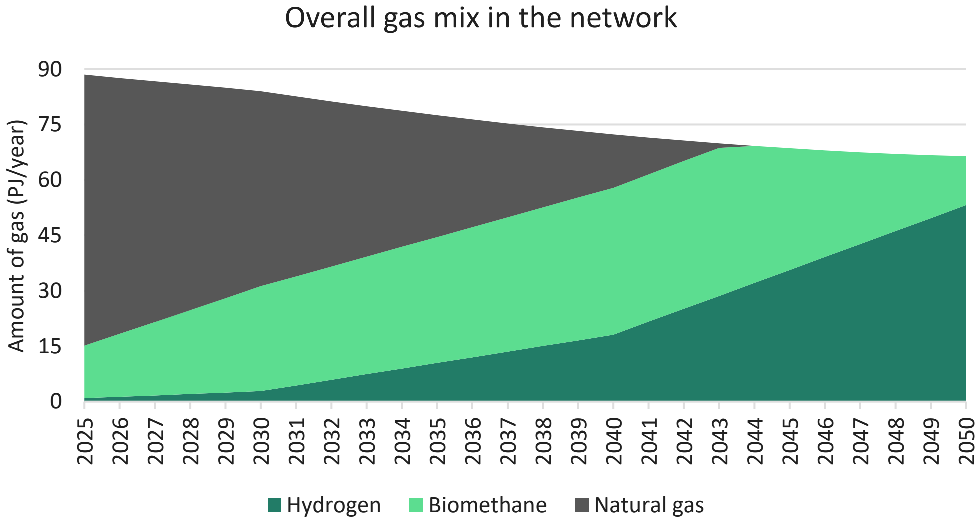
Overall wholesale gas price

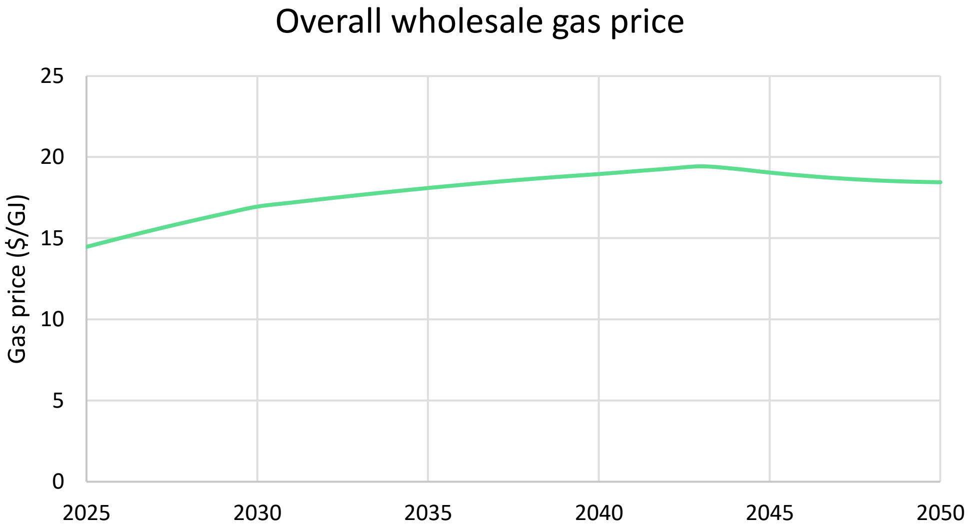


- The scenario expects decarbonisation to be rapid and driven by electrification while gas decarbonisation will be driven by biomethane
- Based on the biomethane available for the gas network and the anticipated total throughput in JGN, the network will be fully renewable in 2041 under the Electric Hare scenario
- Network is expected to have negligible hydrogen as the scenario states “Investment in the development and proliferation of hydrogen and other alternative green fuels do not result in any significant results”

- Natural gas prices are expected to increase with pressure to decarbonise, as shown in the increase from 2025 – 2040
- Overall decline in total throughput is also matched with increasing injection of biomethane into the grid
- As the gas distribution network gets to 100% renewable gas with only biomethane in 2041, gas prices stay at roughly the long term average production cost of biomethane.

The overall gas mix in Big Hydrogen is 100% renewable by 2044, with 80% hydrogen by energy in the network by 2050



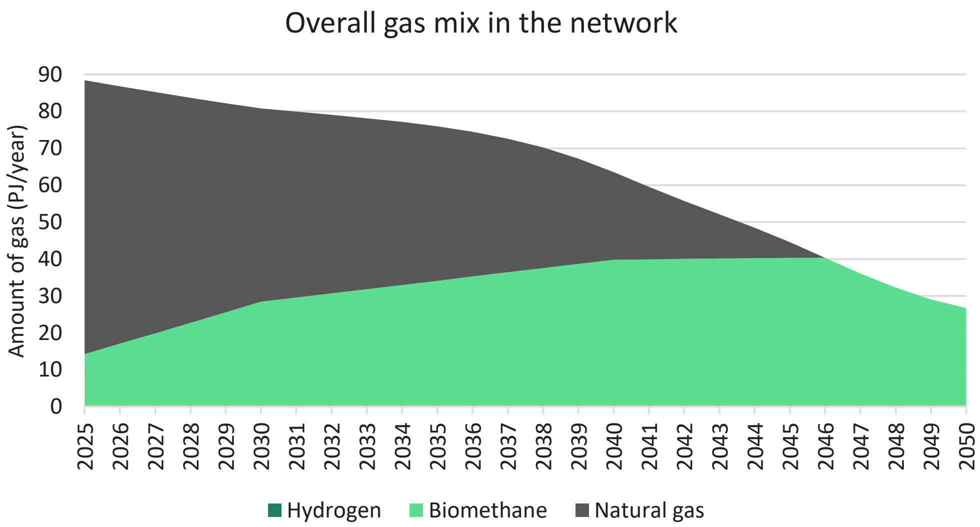


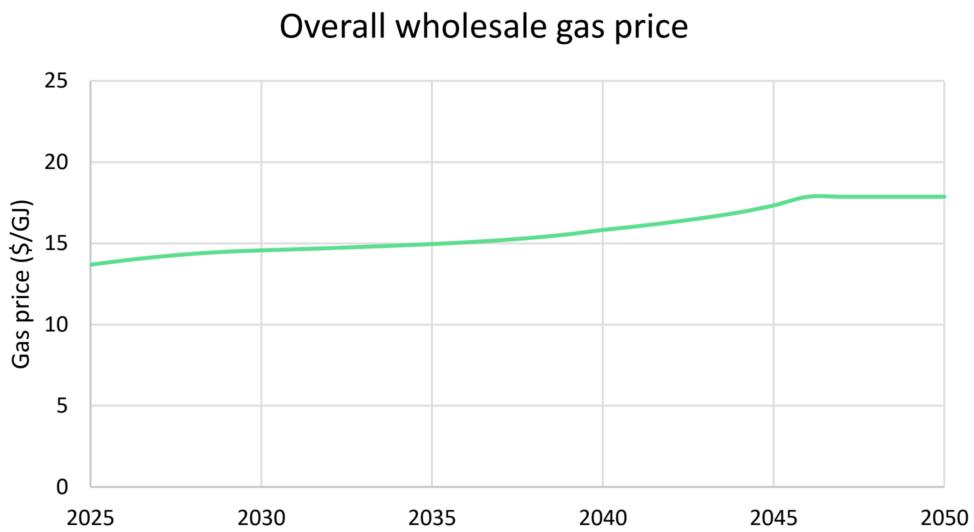
- The scenario expects an acceleration in renewable gas penetration and economic viability, especially higher volumes of hydrogen in the gas network
- The network is assumed to have ~1% hydrogen by 2025, 3.33% hydrogen by 2030, 25% by 2040 hydrogen and 80% by 2050 hydrogen (on an energy basis)
- Biomethane is a stepping stone to decarbonising the pipeline while hydrogen production scales up and as such, biomethane is used to make up remaining throughput unmet by hydrogen
- By 2050, natural gas is not expected to be in the main/majority of the pipeline as customers are expecting renewable gases and are willing to pay a premium for it

- Natural gas prices are expected to increase as renewable gases become more mainstream and preferred by customers
- As the development of the hydrogen industry is supported by the government, prices would be lower than that of natural gas but the increasing cost of natural gas overwhelms this gentle downward trend of H2 prices
- In 2043, due to the reducing throughput in the network per year, the gas network becomes 100% renewable and prices are driven by H2 and biomethane prices – and begin leveling out

Note: Gas is blended on an energy basis

Electric Tortoise expects to reach 100% renewable gas in network by 2046 with prices falling from 2025 – 2046



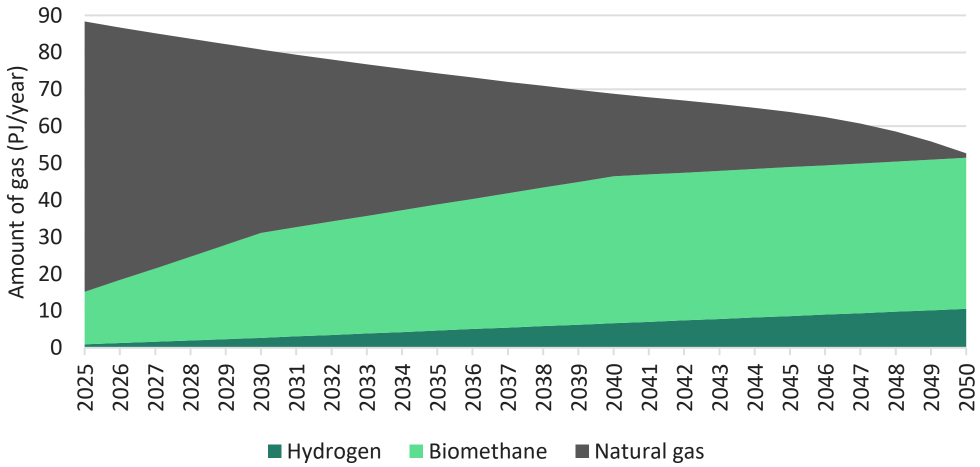


- The scenario expects a slow decarbonisation and hence gradual blending of biomethane into the network
- The network is assumed to have negligible hydrogen through the forecast period
- Biomethane is the primary means of decarbonising gas-use and gradually increases over time as total throughput in the network decreases.
- By 2046, the gas network reaches 100% renewable gas through biomethane injection starting with ~16% from 2025.

- As per modelling drivers in the scenario, natural gas prices are expected to fall over time even as gas usage gradually declines. Meanwhile, biomethane prices remains at moderate levels throughout the forecast period.
- Though natural gas prices are low, biomethane prices are higher than that of NG, and therefore in an increasingly renewable gas network, prices increase from 2025 – 2045.
- At 2045, the grid becomes 100% biomethane and therefore the price stabilises at that of the cost of biomethane production.

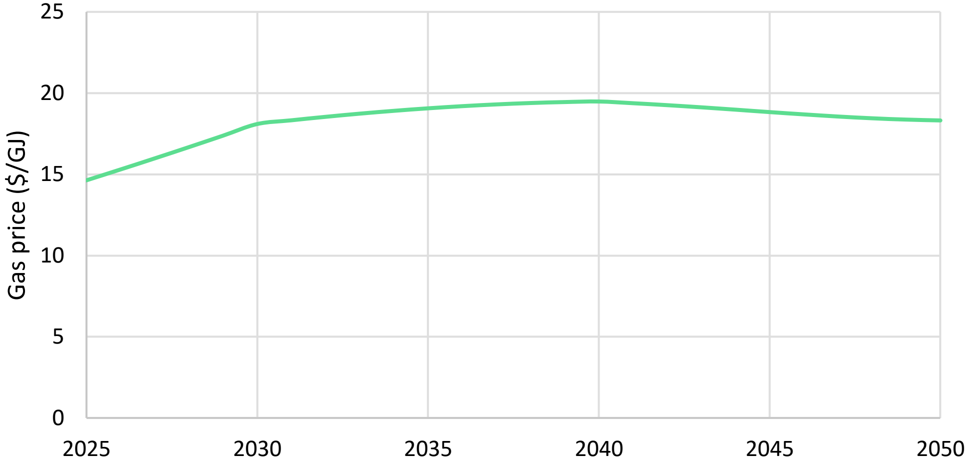
Market Hydrogen expects to reach substantial renewable gas by 2050, with prices steadily decreasing from 2030 onwards

Overall gas mix in the network



- The scenario expects gradual decarbonisation led by the market through a mix of various options starting with minimal hydrogen and some biomethane in the network
- The network is assumed to have ~1% hydrogen by 2025, 3.33% hydrogen by 2030, and 20% hydrogen by 2050 (on an energy basis)
- Within the forecast period, biomethane increases significantly from ~16% in 2025 to 78% in 2050
- As affordability remains a priority, by 2050, the network has biomethane supporting the transition to renewable gas.

Overall wholesale gas price



- Natural gas prices are expected to rise towards 2030, and due to the high prices of hydrogen, the blended gas prices increases up to ~$20 in 2040.
- Thereafter, both biomethane and hydrogen prices decline over the forecast period, leading to a gradual decline in blended gas prices towards 2050.

enea joins blunomy®

05

Willingness-to-pay forecast

05a - Detailed WtP modelling approach

05b – WtP forecast results

The WtP developed for existing residential and easy-to-abate C&I customers form the upper bound of WtP for each customer segment

Modelling WtP through TCO

JGN is interested in understanding the bounds of customer willingness-to-pay (WtP) for gas under each scenario defined by the expert panel.

The WtP is approximated using the total cost of ownership (TCO) of electric appliances levelized to the annual gas use. This approach considers:

- CAPEX and OPEX of electric appliances
- CAPEX of gas appliances
- AEMO electricity price forecast index (for each customer segment)
- Representative gas use for the customer segment
- Efficiency rates from electrifying gas use
- Residential DER uptake and resulting levelized cost of electricity (LCOE)

Electric appliance OPEX is based on the forecasted electricity price using price indices under different scenarios by AEMO. Blunomy compared the scenario drivers against the AEMO forecast figures to obtain the price trajectory for each scenario.

WtP under different conditions

WtP is calculated for existing and new/renewing customers[1]

- Existing (gas) customers have a higher WtP as their appliances are not at the end of its life, and therefore incorporate the full CAPEX of electrical appliance.
- New/renewing customers are considering connecting to the gas network or customers that are nearing the end of their gas appliance, respectively. These customers are likely to have a lower WtP as they have lower friction to electrify

WtP curves are also developed for residential customers with DER installed[2]. This considers:

- Avg capacity and self-consumption of rooftop PV and home battery systems
- Current LCOE of rooftop PV and home battery systems
- Residential DER system price evolutions (using publicly available data)
- DER uptake trends aligned to each scenario narrative

Weighted WtP using relative customer sizes

A weighted WtP curve is then developed for both existing and renewing customers, by considering the ratio of residential customers with and without DER installed and following the residential customer connections forecast developed.

For the customers considered on the network, once delivered gas price increases beyond the WtP of renewing customers, they begin disconnecting, and this point in time aligns with customer demand trends and scenario narratives. The WtP for 'existing customers' forms the upper bound WtP.

Note that hard-to-abate commercial & industrial customers, and gas-loyal households are not considered in this analysis and can be assumed to have infinite willingness-to-pay, capped at the demand levels forecasted.

Note: [1] Key difference between these two customer groups is the extent of that electrification CAPEX are included in the TCO consideration; existing customers incorporate the full cost while the new/replacement customers considers only the premium of electrical appliance over gas.
[2] DER impacts are only considered for residential customers

The WtP is developed based on the total annualised cost of ownership of electric appliances, levelised against the annual gas use cost

Define use case and quantify gas use	Electrify the gas use	Calculate TCO and WtP	Calculate weighted WtP
• Residential customers – total gas use for cooking, space heating and hot water in an average household • Commercial customers – gas use for a 0.1 MW boiler with 80% utilisation • Industrial customers – gas use for a 2 MW boiler with 80% utilisation	• Replace gas use appliances/equipment with electric counterparts – e.g., gas boiler replaced with heat pump for C&I customers • Calculate the annualised CAPEX of the electric appliance based on its average lifetime • Approximate the annual electricity consumption based on gas-to-electric efficiency rates • Develop electricity price curves for 2025 – 2050 using the current delivered electricity price indexed for each year (for customers without DER) or LCOE evolutions (for customers with DER)[1] • Calculate the annual electricity OPEX using the appropriate cost of electricity	• Calculate TCO from the annualised CAPEX of the appliance and the yearly OPEX • Calculate the WtP by levelizing the TCO against annual gas use for existing and new/replacement customers (see calculations below)	• The DER-weighted WtP calculations assumes a proportion of non-highrise residential customers will integrate DER each year for each scenario while highrise residential customers will not • The weighting is based on varying proportions of customer groups with DER based on a DER uptake trajectory customised to each scenario

$$\text{Existing customer WtP (\$/GJ)} = \frac{\text{TCO}_{\text{electric}}\ (\$/\text{year})}{\text{Annual gas consumption (GJ/year)}}$$

$$\text{New customer/replacement WtP (\$/GJ)} = \frac{\text{TCO}_{\text{electric}} - \text{CAPEX}_{\text{gas}} (\$/\text{year})}{\text{Annual gas consumption (GJ/year)}}$$

Notes: [1] It is assumed that the rooftop PV + home battery systems are already installed and the CAPEX of DER is not a consideration in the WtP for gas

The weighted WtP curves for existing and renewing residential customers are aligned to the scenario narratives and delivered gas prices

Wholesale gas price

As discussed in Section 4, Blunomy developed wholesale gas prices for:

- Natural gas
- Hydrogen
- Biomethane

The blends of natural and renewable gas were fixed based on the scenario narratives and the total throughput (from the demand modelling results) for each scenario.

Based on the gas prices and the blends, Blunomy calculated an overall blended wholesale gas price for each scenario, which was provided to JGN as part of the results.

End-customer gas prices

Using the customer connection results and wholesale gas prices provided by Blunomy as the results of the modelling exercise, JGN was able to develop an end-customer gas price, which considers:

- Wholesale gas price (for each scenario)
- Gas transmission network costs
- Gas distribution network costs
- Retail costs

These gas prices represent the expected trends in prices faced by customers connected to the gas network throughout the forecasting horizon, and varies in each scenario.

Retail electricity price and WtP

The WtP is calculated and then refined in two steps:

- The initial WtP is calculated using the current retail electricity price and AEMO price forecasts
- The electricity price is adjusted to ensure the intersection of weighted residential WtP with the end-customer gas price curve at time-horizons consistent with the scenario narratives.

This ensures that the intersections of the end-customer gas price and WtP are cohesive with customer connection trends in the demand modelling results, scenario narratives and scenario drivers.

Scenario-specific electricity price trends are used, while all other drivers remain constant across scenarios

Drivers of WtP	Electric Hare	Big Hydrogen	Electric Tortoise	Market Hydrogen
CAPEX of electrification		✓	✓	✓
Lifetime of electric appliances	✓	✓	✓	✓
Efficiency rates from converting gas appliances to electric	✓	✓	✓	✓
Electricity price forecast (residential or commercial)	*	*	*	*
Current retail electricity price based on residential bill or commercial price	✓	✓	✓	✓
Average annual gas use for households, and key contributing appliances	✓	✓	✓	✓
Average gas consumption for appliance, based on capacity and utilisation	✓	✓	✓	✓
CAPEX of gas appliances		✓	✓	✓
Green premium for gas WtP using green electricity % as a proxy		✓		✓
DER penetration rates	✓	✓	✓	✓
LCOE of DER (incl. future trajectories)	✓	✓	✓	✓

Across scenarios, the electricity prices are varied to reflect the scenario modelling drivers provided, the other factors incorporated are constant across the scenarios.

Except in the Electric Hare scenario, it is assumed that electrification is not subsidised, and therefore the CAPEX of electric appliances influences the customers' WtP for gas. In Electric Hare scenario, it is assumed that the CAPEX of electrification is 50% subsidised.

In the case of Big Hydrogen and Market Hydrogen, some sub-segments of customers are willing to pay a premium for renewable gases. A premium of ~23% is estimated based on retail premiums for green electricity.

Key

✓ Constant value used in all scenarios

* Varies across scenarios

06

Possible model improvements

Drivers for average throughput, customer segmentation regarding biogas and WtP assumptions could be refined in additional future iterations

As mentioned previously, Blunomy worked with Jemena in an iterative manner to develop the gas demand forecasting model.

In doing so, the tasks and features to focus on were prioritised through discussions with Jemena to optimise for time and resources available for the project.

The latest and final iteration of the model provided results satisfactory to Jemena for the purpose of this exercise. Some items that were not incorporated but could be modelled in a later iteration include:

- Improving drivers such as:
  - Considering average throughput for some customer segments based on end-use
  - Refining average throughput for residential customers by allowing for partial electrification
  - Broadening hydrogen mobility to include other vehicles (e.g., buses)
  - Refining WtP for C&I customers based on different use cases/processes
- Expanding customer segmentation by including new connections from:
  - Biomethane injection projects
  - BioCNG mobility
- Refining assumptions such as:
  - Green premium applied to the WtP in Big Hydrogen and Market Hydrogen
  - Growth and growth rate of hydrogen mobility including vehicles and refuelling stations
  - Non-highrise owned residential developments being the first to electrify (this proportion figure is the most sensitive parameters affecting customer numbers as a result of the assumption)
  - Proportion of hard-to-abate industrial customers would remain constant over the next years (this proportion figure is the most sensitive parameters affecting the total throughput)

07

Appendices

Appendix: LGA split by country-coastal provided by Jemena and used for estimates and modelling

Country
Bland
Cowra
Blayney
Orange
Bathurst Regional
Wollondilly
Lithgow
Hilltops
Cootamundra-Gundagai Regional
Junee
Coolamon
Narrandera
Leeton
Griffith
Yass Valley
Goulburn Mulwaree
Wingecarribee
Dubbo Regional
Forbes
Narromine

Coastal	
Sydney	Ku-ring-gai
Blue Mountains	Hornsby
Central Coast	Northern Beaches
Newcastle	Mosman
Cessnock	Hunters Hill
Lake Macquarie	Parramatta
Maitland	Hills Shire
Port Stephens	Burwood
Wollongong	Strathfield
Shellharbour	Cumberland
Kiama	Canterbury-Bankstown
Bayside	Blacktown
Waverley	Fairfield
Randwick	Campbelltown
Inner West	Liverpool
Canada Bay	Penrith
North Sydney	Camden
Willoughby	Sutherland Shire
Lane Cove	Singleton

Paris
Melbourne
Hong Kong
Singapore
Sydney
London

enea CONSULTING