THE ROLE OF GAS INFRASTRUCTURE IN AUSTRALIA'S ENERGY TRANSITION

Supporting Slides

BOSTON CONSULTING GROUP

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Context of this report

APA Group, Australian Gas Infrastructure Group, and Jemena are the three largest investors in Australia's gas infrastructure. Each has an individually stated commitment to achieving net zero emissions.

Aware that the energy transition will change the way energy is produced, transported and consumed, these organisations have commissioned BCG to compile a report on the potential role for gas infrastructure in the energy transition – **with a view to supporting the reliability, affordability and sustainability of the energy system.**

The report covers the role **of gas <u>infrastructure</u>, with a focus on transport infrastructure: pipelines, transmission, distribution**. It canvasses this infrastructure being used to transport natural gas (as it largely does today) and other energy-related gas streams that may develop in the future (such as biomethane, hydrogen and carbon dioxide) to deliver an **efficient, orderly and resilient energy transition**.

This report represents a **potential perspective as to how the energy transition may evolve, and is not a forecast**. Indeed, other eventualities may unfold based on a range of factors.

BCG recognises that significant work has been completed on the topic of the role of gas and gas infrastructure. In compiling the report BCG reviewed publications from a wide range of sources, including **government, industry, academia, non-government organisations, advocacy groups and community groups**, which are referenced, though this should not be read as endorsement of their analysis. BCG supplemented this research with additional analyses where they contributed to an understanding of the role of gas infrastructure.

While the three commissioning organisations have been able to provide feedback on drafts of the report, the BCG team assigned to the project retained full control over the content. The conclusions presented in this report are the views of that BCG project team.

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Summary | Gas infrastructure could play a pivotal role in an orderly energy transition

TODAY
1

Natural gas and its infrastructure form one of three pillars of today's energy system

Natural gas is **one of three core elements of our energy system**

Natural gas serves more than a quarter of Australia's energy needs, fulfilling end uses that require rapid, high-energy rates, including heating and peak generation for all types of customers

LOOKING AHEAD

However, its role needs to change to our evolving emissions context

Because **natural gas is a fossil fuel** and new, **highly efficient electric technology is available**, a changing and reduced role for natural gas and a different role for gas infrastructure must be considered and planned for

TRANSITION
2

Natural gas will play an important role in an efficient and orderly transition. It enables emissions reduction to occur sooner, and supports the transition to low-carbon gases

An approach to reducing emissions sooner and at lower cost involves 'renewifying first', maintaining customer choice of fuel

In this approach, **renewable electricity (RE) resource first displaces coal and liquid fuels,** achieving the greatest emissions/cost impact

Using gas infrastructure, natural gas continues to serve **critical end uses** like peak gas-powered electricity generation (GPG), industry and space heating. It also serves as a 'backstop', **de-risking the development of renewable electricity infrastructure or a disorderly exit from coal**

With natural gas, the **transition will be more orderly** and the **energy system** will be more reliable

This retains the **option to develop low-carbon gas** – with initial demonstrations progressing – and repurpose gas infrastructure

NET ZERO
3

Gas infrastructure could transport low-carbon gases, forming part of a least cost, integrated clean energy system in a net zero future

Low-carbon gas could provide total-cost competitive options to hard-to-electrify industry and some gas-using households, if sufficiently available at anticipated costs and at manageable network charges

Gas infrastructure **can be repurposed or augmented to deliver low-carbon gases** to customers

Studies in literature indicate that an integrated clean energy system that combines renewable electricity and low-carbon gas could be **equivalent or lower cost than a fully electric energy system**

The role of low-carbon gas in the system is **likely to differ by location** based on climate, electricity network capacity and type of customer base

Retaining gas infrastructure provides **redundancy, resilience and potential synergies** across the integrated clean energy system

WITHOUT CLEAR ACTION…
4

The energy system needs to **avoid near-term natural gas supply shortfalls**, minimise **fugitive methane emissions**, ensure adequate **cost recovery for regulated assets**, **integrate energy system planning**, and move **low-carbon gas down the experience curve**

Natural gas and its infrastructure form one of three pillars of today's energy system. However, its role needs to change to reflect our evolving emissions context

Natural gas and gas infrastructure form one of three pillars of today's energy system

Natural gas is a critical component of Australia's energy supply, and is supplied through gas infrastructure

- Today, natural gas represents 27% of Australia's primary energy supply for domestic consumption and materially serves most energy end uses
- Natural gas is used by a broad range of customers for electricity generation, mining, industrial, commercial and residential use, and for export
- Customers use natural gas for a range of end uses, but mainly for driving gas turbines, heating and chemical feedstock

Natural gas has specific characteristics that make it particularly useful for a range of end uses

- Reliable – especially in critical applications such as household heating, food preparation and industry
- Responsive – e.g. for water heating, or peak electricity generation
- Efficient storage capability – to serve peaking applications, including in-pipeline storage
- Low cost – historically, natural gas unit energy cost has been low
- Lower 'user-side' capital requirements – for generation equipment, transport and appliances
- Available technology – has historically been one of the available options (or the only option) for specific end-uses

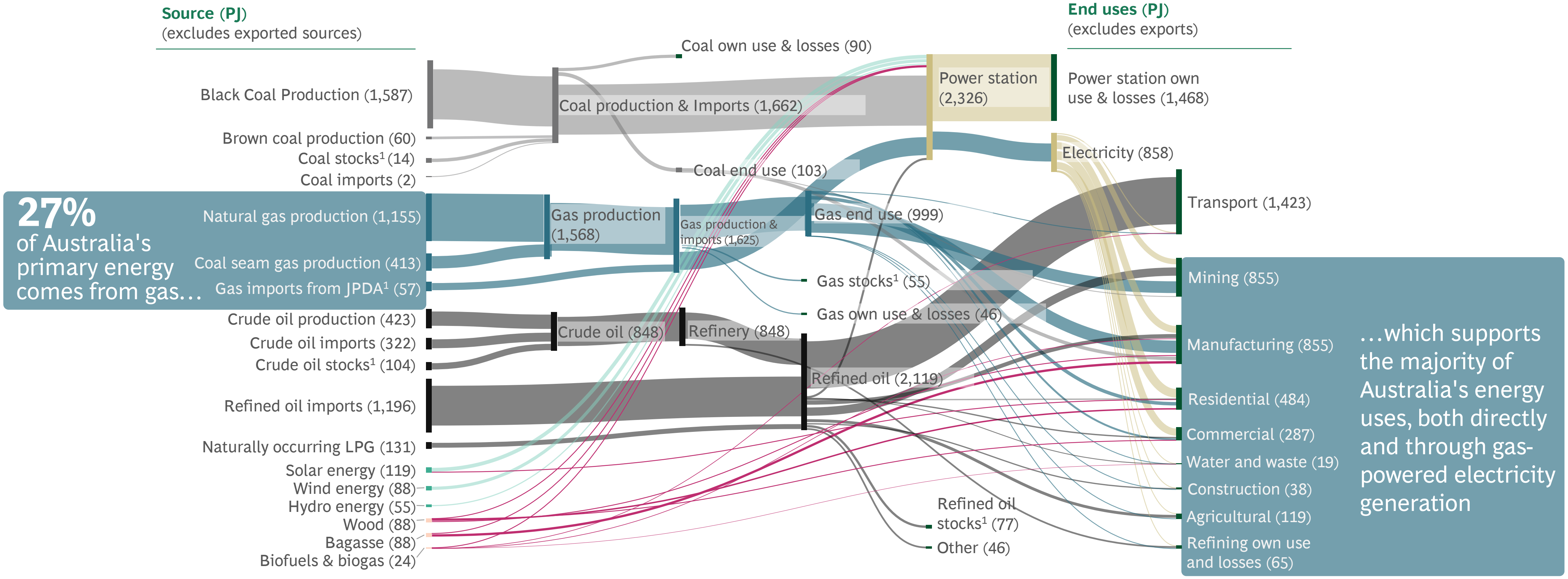
The context in which natural gas is used is changing due to action on climate change, electric appliance alternatives and cheaper renewable electricity

- Action is accelerating on climate change and emissions reduction; natural gas – as a fossil fuel – contributes to ~22% of Australia's energy-related and ~18% of Australia's total emissions
- Electric appliances, such as heat pumps, have become more efficient and lower cost to provide an alternative for customers, but with practical limitations
- Renewable electricity is becoming more cost-efficient to develop

Current natural gas end uses can be decarbonised using renewable electricity or low -carbon gases, including green and blue hydrogen, biomethane, synthetic methane or carbon capture and storage (CCS)

Today, natural gas represents 27% of Australia's primary energy supply for domestic consumption, supporting majority of domestic industry and households

Australia's energy flows

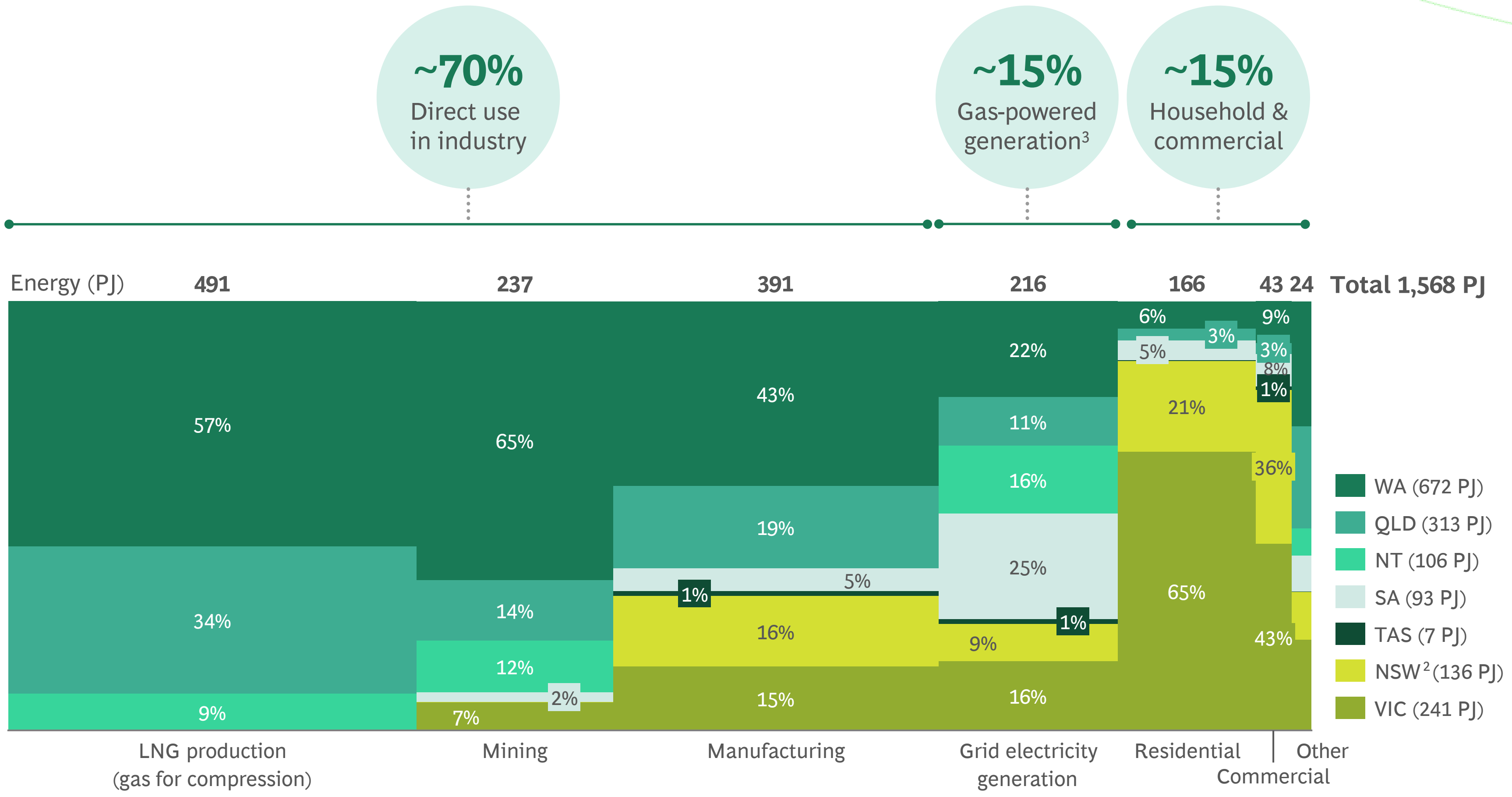


1. Includes discrepancies 2. JPDA = Joint Petroleum Development Area
Notes: Export values excluded; includes natural gas consumed by LNG production
Source: Australian Energy Statistics, Table A, Table F, Interactive Australian Energy Flows (2022); BCG analysis

Natural gas is used by a broad range of customers for electricity generation, mining, industrial, commercial and residential use, and for export

Australian annual domestic natural gas consumption[1]

~1,600 PJ



1. Natural gas exports and imports excluded 2. ACT gas usage is included within NSW totals 3. Does not include off-grid generation from LNG production (~120 PJ) and mining (~170 PJ)

Note: Total exports ~4310 PJ. LNG production based on difference between AES and AEMO GSOO in WA and QLD for GPG and mining/industrial sectors. NT LNG consumption estimated from LNG plant and LNG GPG gas consumption based on NT LNG exports. A portion of household and commercial energy demand follows baseload consumption pattern. Some industrial users are supplied via distribution networks.

Source: Australian Energy Statistics, Table F, Table J (2022); APPEA Key Statistics (2022); AEMO GSOO 2021; AEMO WA GSOO 2020; BCG analysis

Natural gas has specific characteristics that make it particularly useful for the range of energy end uses it currently serves

Natural gas end use		Reliable	Responsive	Lower unit cost per unit output	Lower capex	Only available technology	Past alternative	Future alternative to gas
Electricity	Mid-merit	✓	✓	✗	✓ *Generator*	~	Black Coal	Renewable Electricity
	Peaking	✓	✓ ✗	✓ ✗	✓	~	Liquid Fuels	Storage
Industrial	Feedstock	✓	✓	✓	✗ *SMR*	✓	None	Green H_2
	High-grade heat	✓	✓	✓	✓ *Equipment*	~	Liquid Fuels	Electric Arc
	Low-grade heat	✓	✓	✓ ✗	✓	~	Coal/Liquid Fuels	Heat Pump
Residential/ commercial	Space heating	✓	✓	✓ ✗	✓ *Appliance*	~	Electric resistance	Heat Pump
	Water heating	✓	✓	✓ ✗	✓	~	Electric Boiler	Heat Pump
	Cooking	✓	✓ ✗	✓	✓	~	Electric element	Induction
Commodity production	Mining	✓	~	✓ ✗	✓ *Transport*	~	Liquid Fuels	Grid
	LNG compression	✓	~	✓ ✗	✓	~		Electric Compressor

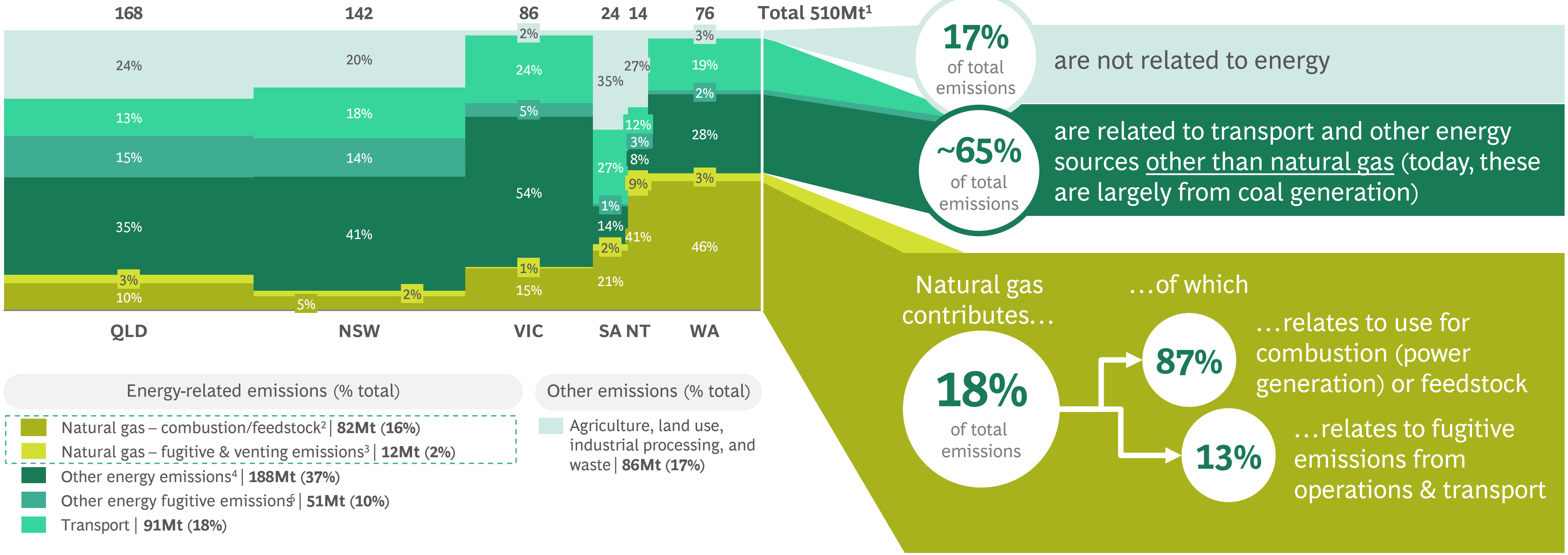
✓ Favourable characteristic ✓ ✗ Favourable to past/Unfavourable to future alternative ✗ Unfavourable characteristic

Note: Characteristics of gas have benefits beyond those shown; these are the primary characteristics that make gas suitable to these applications
Source: CSIRO, GenCost 2021-22; BCG analysis

However, natural gas – as a fossil fuel – contributes to ~18% of Australia's total emissions, and ~22% of domestic energy emissions – and needs to decarbonise

~90Mt of Australia's ~500Mt CO_2e emissions come from domestic natural gas use

Emissions (proportion of state total) (Mt CO_2e)[1]



1. Includes IEA underreported fugitive emissions; DCCEEW 2020 total is 500MtCO_2e 2. DCCEEW emissions account factor applied to domestic gas consumption (AES) 3. IEA Methane Tracker for onshore, offshore and gas pipelines & LNG facilities; converted to CO_2e using 100-year GWP of 28 4. Fugitive emissions subtracted from total energy emissions 5. IEA Methane Tracker total less natural gas fugitive emissions; converted to CO_2e using 100-year GWP of 28

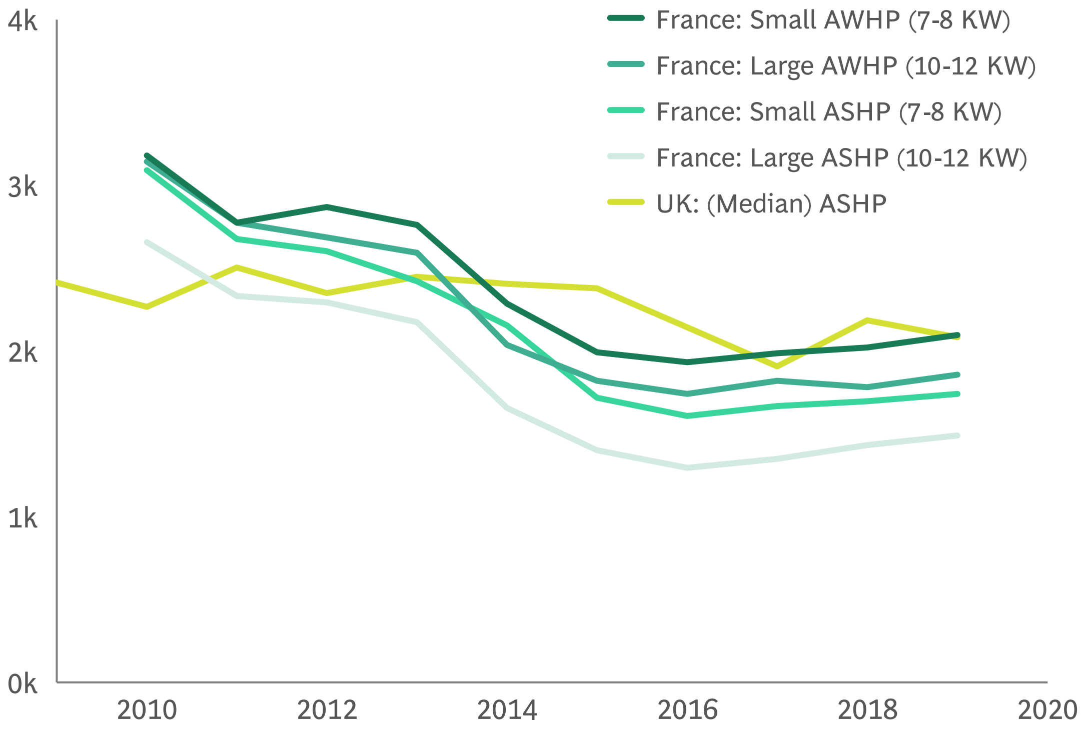
Note: Tasmania and ACT not shown; total emissions (-)2.6 Mt CO_2e. 2020 data used to align with Australian UNFCCC reporting cycles. Other energy emissions are predominantly coal for power generation, and also include emissions from oil in non transport sectors such as mining and manufacturing.

Source: DCCEEW, State and Territory Greenhouse Gas Inventories (2020); Australian Energy Statistics, Table F & I (2020); DCCEEW, Australian Greenhouse Accounts Factors (2022); IEA, Methane Tracker (2023); IPCC, AR6 WGI (2021); BCG analysis

Electric appliances, such as heat pumps, have become more efficient and lower cost to provide an alternative for customers, but with practical limitations

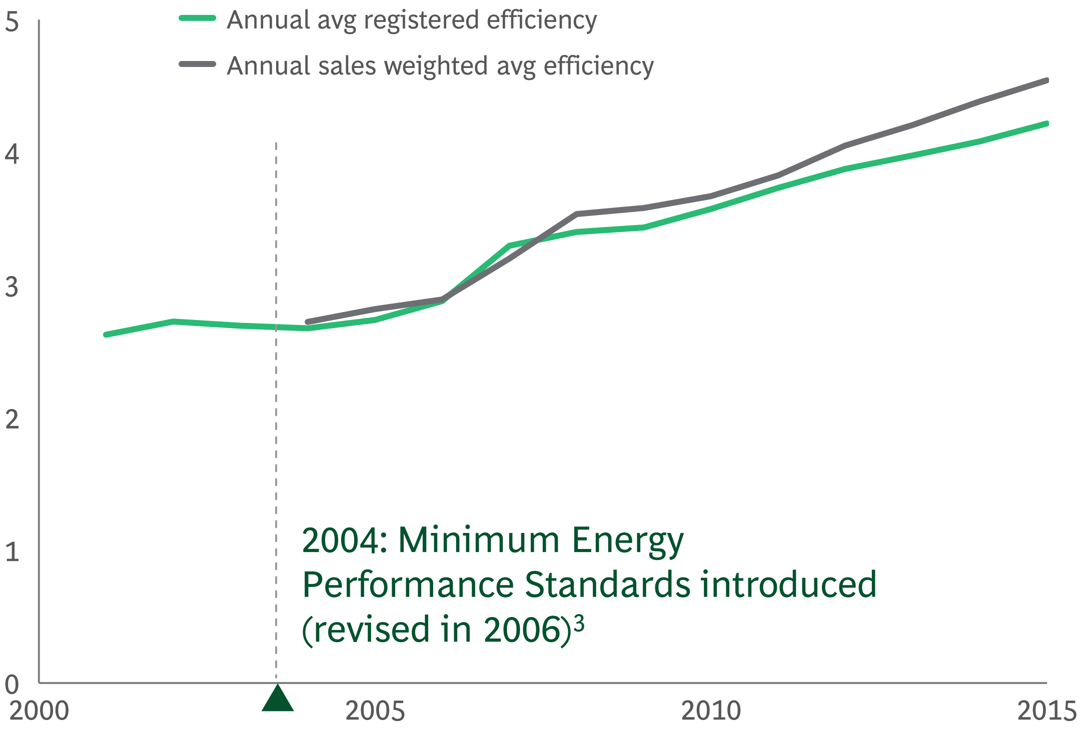
Heat pump costs have declined[1]

AUD$/KW



Heat pump efficiency has increased[2]

Cooling Energy Efficiency Ratio (EER)[4]



1. IRENA, Renewable Solutions in end uses. Costs have been converted from USD 2. Australian Equipment Energy Efficiency Committee, Decision Regulatory Impact Statement: Minimum Energy Performance Standards for Air Conditioners 3. EnergyConsult, A retrospective evaluation of the impact of MEPS in Australia: non-ducted air conditioning 4. Australian Equipment Energy Efficiency Committee, Decision Regulatory Impact Statement: Minimum Energy Performance Standards for Air Conditioners
Source: BCG analysis

Natural gas will play an important role in an efficient and orderly transition. It enables emissions reduction to occur sooner, and supports the transition to low-carbon gases

In the transition to a clean energy system, the growthof renewable primary energy sources will drive a realignment of the energy system architecture

- Variable renewable electricity will increasingly provide primary energy
- Electricity infrastructure and electrical end uses will increasingly contribute to the energy system

Literature anticipates that natural gas will play a role in the energy transition, but views vary on the nature and extent of this role – scenario estimates range from 40-90% of 2020 domestic demand

- The role of natural gas in this timeframe will depend on the rate at which grid-connected renewable electricity and storage are deployed, and the rate at which customers choose to move to electric end-user appliances

An approach to reducing emissions sooner and at lower cost focuses on ' renewifying' primary energy - with electrification driven by customer choice - rather than first electrifying all gas end-uses

- **Grid-connected renewable electricity will have the greatest impact if it is used to displace coal generation and liquid fuels, before displacing gas end uses**

In this transition period, natural gas can serve critical end uses that are hard or expensive (peaking applications in particular) for the system to electrify

- The current pipeline of renewable electricity development is not currently sufficient to decarbonise the grid and electrify other applications including all gas demand
- For some industrial applications, the technology to electrify doesn't exist or it is prohibitively expensive to electrify (e.g. industrial feedstock, high-grade heat)
- Accelerating the electrification of peaking applications (e.g. residential space heating, peak GPG) may incur additional infrastructure costs (e.g. storage, network)

Natural gas can continue to play a critical role for a range of end uses to support an efficient and orderly energy transition

- Natural gas supports hard to electrify and peaking end-uses: if these were electrified, it would increase peak electricity demand and electricity infrastructure needs
- Gas-powered generation will provide the electricity required during the day's peak energy usage
- Gas-powered generation needs to serve days of peak energy demand and provide 'backstop' generation (providing electricity generation when other sources cannot) when bulk energy supply is diminished
- Gas-powered generation enables the system to cope with a disorderly generation transition by serving as a backstop generator

While natural gas will support the energy transition, low-carbon gases are being demonstrated that may be able to support these natural gas end uses

Literature anticipates that natural gas will play a role in the energy transition, but views vary on the nature and extent of this role

Recent study	Use of gas in 2040	Range of 2040 gas use by scenarios	
NET ZERO AUSTRALIA Net Zero Australia: Final modelling results (2023)	In all scenarios, at 2040 domestic demand for natural gas declines to ~40-80% vs. 2020, with ~50-100% domestic pipeline gas	**~40-80%** vs. 2020 natural gas volumes	E+ Rapid electrification E+ / RE+ Full renewables E+ / RE- Constrained renewables E+ / ONS Onshoring E- Slower electrification
AEMO Gas statement of opportunities (2023)	By 2040, demand for domestic gas declines to 50-90% of 2020 consumption	**~50-90%** vs. 2020 natural gas volumes	Orchestrated step change (OSC) OSC: No Electrification OSC: Delayed VRE and Disorderly coal exit Diverse step change Green energy exports
Investor Group on Climate Change Changing pathways for Australian gas (2022)	Domestic gas demand reduces to 60-100% of 2020 volumes	**~60-100%** vs. 2020 natural gas volumes	Progressive uptake Accelerated uptake
frontier economics The benefits of gas infrastructure to decarbonise Australia (2020)	Gas demand ranges from 120% of 2020, down to zero under a forced full electrification	**~0-120%** vs. 2020 natural gas volumes	Electrification (assumes full natural gas displacement) Zero-carbon fuels Renewable fuels

Source: Net Zero Australia, Final Modelling Results (2023); AEMO GSOO 2023; Investor Group on Climate Change, Changing Pathways for Australian Gas (2022); Frontier Economics, The benefits of gas infrastructure to decarbonise Australia (2020); BCG analysis

- 80-100+% of 2020 volumes
- Roughly 50-80% of 2020 volumes
- Less than 50% of 2020 volumes

The role of gas infrastructure through transition depends on rate of renewable energy development and electrification of end-use

Three conceptual sequences

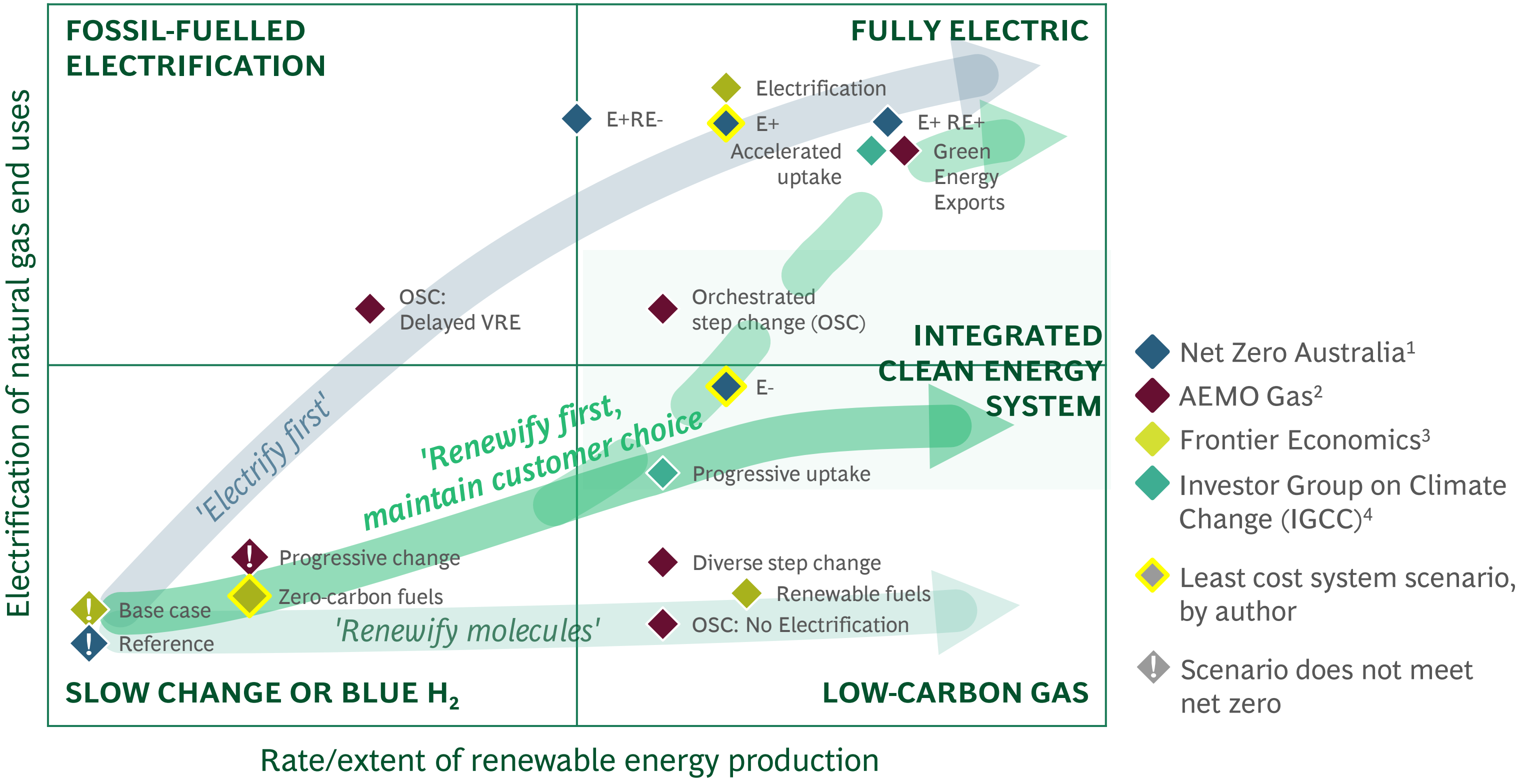
Energy transition scenarios from literature, 2025-2040, illustrative scenario placement

In **'Electrify first',** natural gas end-uses are **electrified before renewable electricity sources** are developed, with the potential for **fossil-fuelled electrification**

In 'Renewify first, maintain customer choice' to electrify or remain on gas **optionality is retained to reach net zero** by moving to an integrated clean energy system (comprising low-carbon gas and electricity) or moving to a primarily electrified system (represented by the dashed line)

- Targets RE deployment for most impactful applications in the near term
- Retains optionality and customer choice
- Potentially a least-cost system approach

'Renewify molecules' reflects a scenario in which rapid development of renewable gases allows customer to choose like-for-like substitution of natural gas

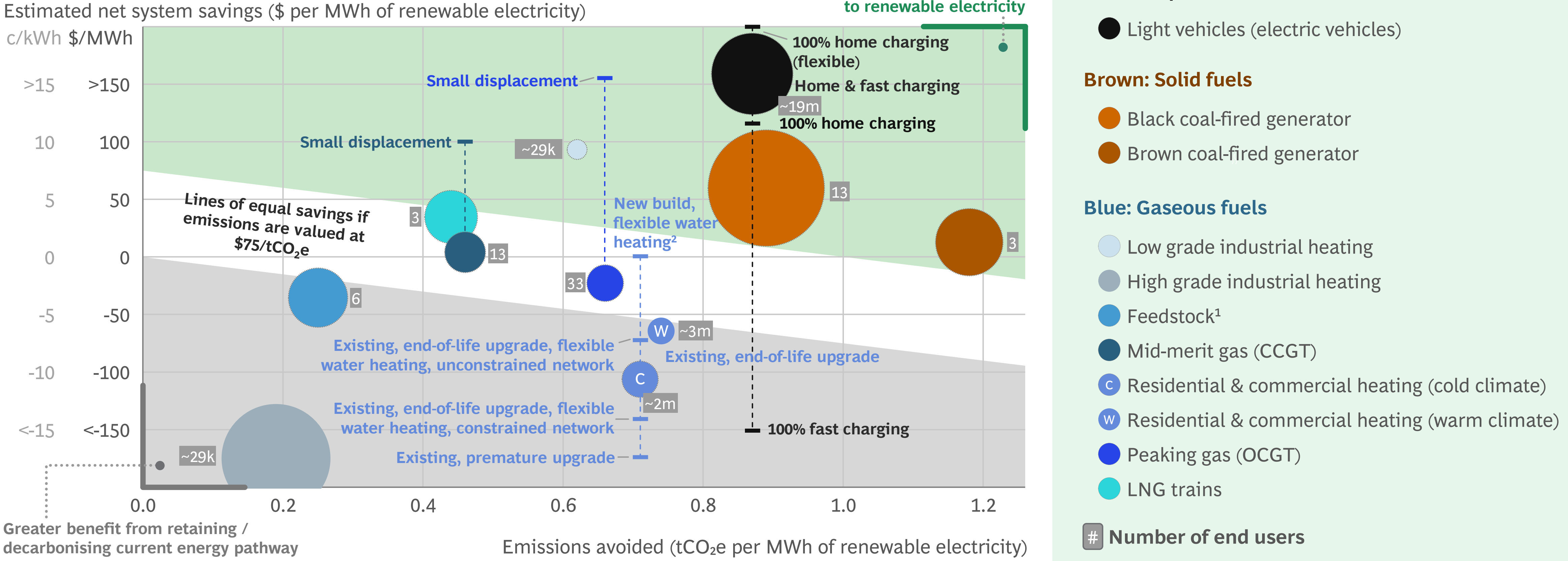


1. Net Zero Australia: Interim Results (2022); 2. AEMO: Gas Statement of Opportunities (2023); 3. Frontier Economics: The Benefits of Gas Infrastructure to Decarbonise Australia (2020); 4. Investor Group on Climate Change (IGCC): Changing Pathways for Australian Gas
Source: BCG analysis

Grid-connected renewable electricity will have the greatest impact if used to displace coal generation and liquid fuels before displacing gas end uses

Benefits of deploying 1 MWh of grid-connected solar/wind

Excludes renewable energy generation and transmission costs for all end uses



Note: Bubble size represents total annual volume of renewable electricity required to meet demand

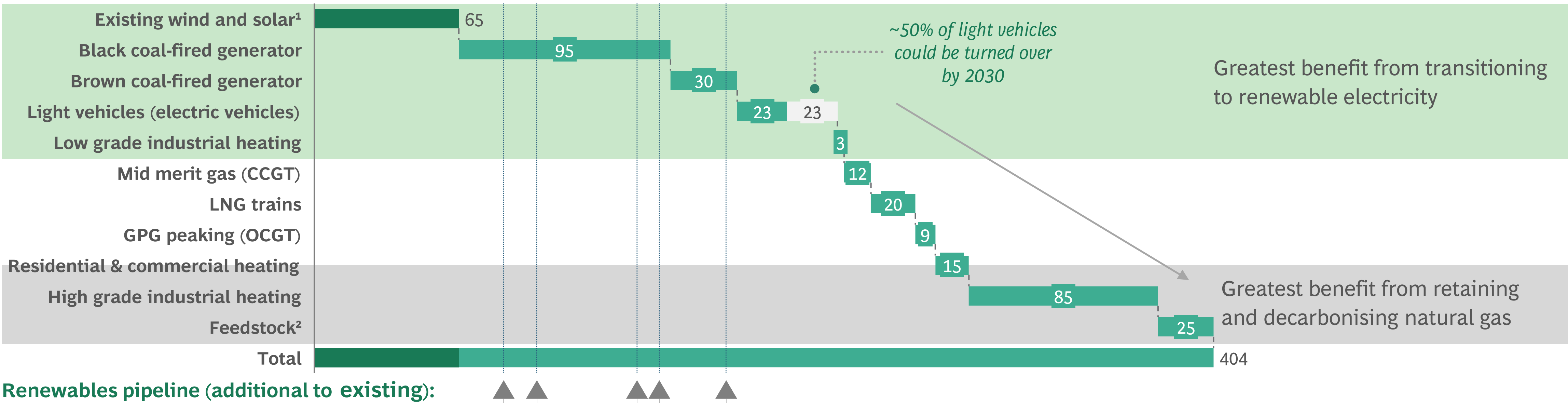
1. Based on methane gas substituted with green hydrogen produced from grid-connected electricity 2. New build dwellings only contribute ~2% to total number of dwellings in Australia each year; ABS, Estimated dwelling stock (June Quarter 2022), Table 01

Source: BCG analysis

In the transition period, natural gas can serve critical end uses that are hard or expensive for the system to electrify (peaking applications in particular)

Illustrative potential order of transition for the greatest system savings and emissions reduction benefits

Potential renewable electricity applications (TWh/year), coal and gas generator figures include NEM and SWIS



Renewables pipeline (additional to existing):

~20 TWh/year	~35 TWh/year by 2025[3]	~80 TWh/year[4]	~90 TWh/year by 2030[5]	~120 TWh/year
Morgan Stanley: NEM new entrant solar and wind	AEMO: NEM pipeline of anticipated and committed solar and wind projects	total state-based renewable energy targets by 2030	S&P: Aus. pipeline of grid-connected solar and wind planned and under construction	Required to meet goal of 82% renewable electricity by 2030

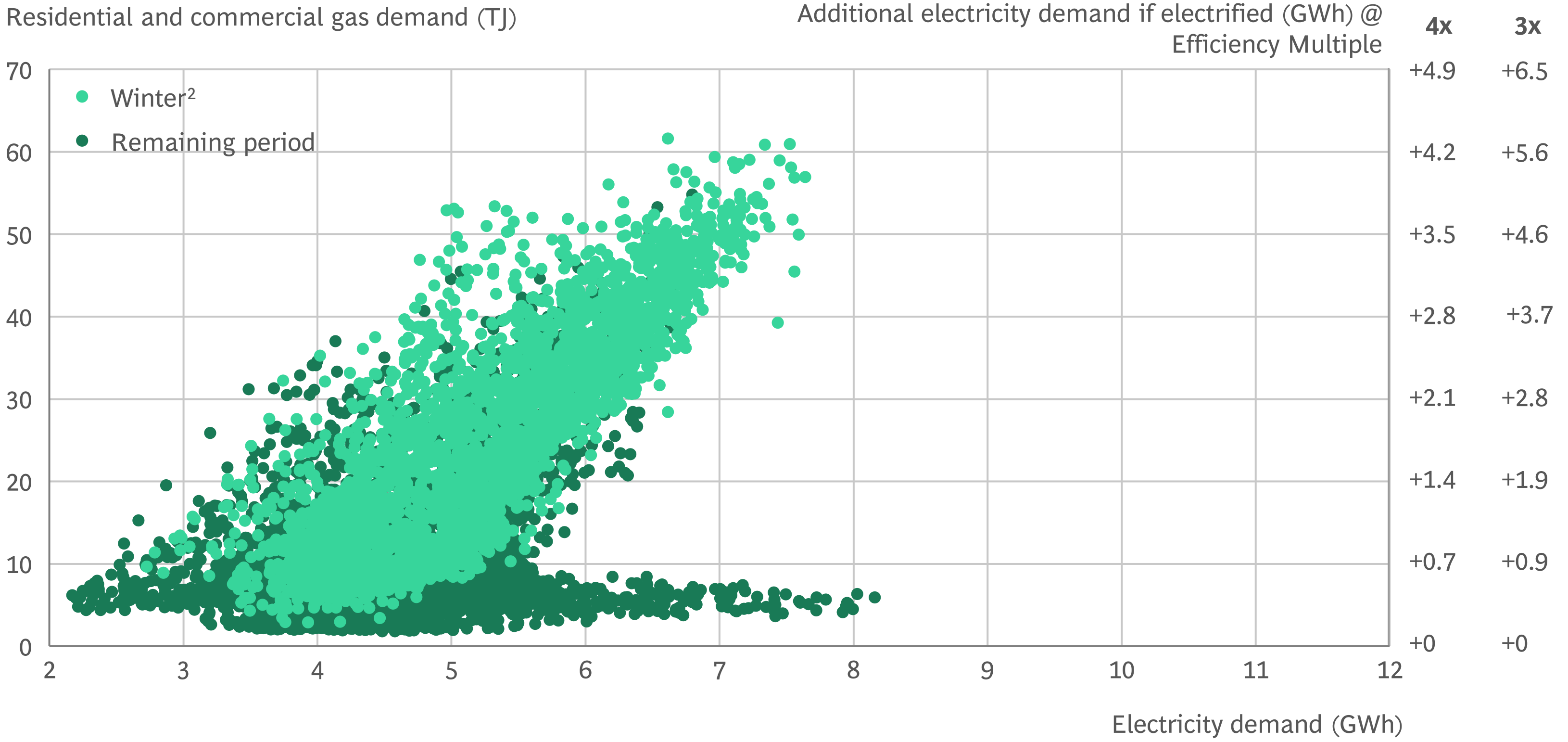
Target or goal

1. Includes onshore wind, utility scale solar, rooftop solar 2. Based on methane gas substituted with green hydrogen produced from grid-connected electricity 3. Further ~2 TWh/year by unspecified date; 2025 figure includes ~10 TWh/year additional rooftop solar PV by 2025 in the NEM 4. Includes additional ~5 TWh/year rooftop solar PV by 2030 in NSW, as the NSW renewable energy target does not include small-scale generation 5. Further ~15 TWh/year by unspecified date
Note: AEMO and S&P use different project phase definitions to categorise project status
Source: Morgan Stanley, AEMO, S&P BCG analysis

Natural gas supports peaking end uses which, if electrified, would increase peak electricity demand and electricity infrastructure needs

Natural gas demand is correlated with electricity demand in winter in cold climates

Hourly distribution-level gas demand vs total electricity demand, VIC, 2021



Critical role in meeting **residential and commercial peak energy demand**

Electrifying peaking natural gas end uses would increase peak electricity demand by up to ~50%[1], requiring electricity distribution network and firming infrastructure (GPG or storage)

The augmentation of electricity network might not be proportional to increase in peak demand, given greater network capacity in winter

1. Accounting for a round approximation of relative efficiencies of electric compared to gas appliances (at 4x) 2. Winter based on 16 May 2021 to 15 September 2021
Note: DWGM distribution system net service load data includes residential and commercial gas demand
Source: DWGM Net Service Load Data for distribution network (2021); AEMO Market Clearance Data; BCG analysis

Gas infrastructure could transport low-carbon gases to form part of a least cost, integrated clean energy system in a net zero future

In a future integrated clean energy system, low -carbon pathways could provide alternatives to natural gas and increase network resilience

If low-carbon gas prices reduce as anticipated and networks costs are managed, they could provide total cost competitive offers for some customers to decarbonise

For **residential and commercial customers**, decarbonisation is highly individual and driven by their choice

- Today, the most cost-efficient solution for customers is highly contested in literature
- This analysis for a 'central' case indicates that natural gas is marginally least-cost solution for some existing homes today; electric is favoured for new builds
- However, the decision is highly individual, based on factors such as appliance and installation cost, house type, size, consumption, and fuel pricing
- The most cost-efficient option may be different for individual customers than at a whole-of-system level
- Low-carbon gases could be competitive future options on a total-cost basis for some gas connected households if low-carbon gases become available, prices reduce as anticipated, and network charges are managed

For **industrial customers**, the most cost-efficient way to decarbonise depends on particular technologies

- Literature shows most low-grade heat can be electrified at low cost, but high-grade heat and feedstock will likely require low-carbon gas
- High-grade heating and feedstock can cost-effectively use natural gas with offsets in the near term, and could use low-carbon gas in the long term
- Low-grade heating is most cost-effectively served by electrification
- For other customers, retaining gas infrastructure may create options to decarbonise with low-carbon gas
- For remote mining, the future clean energy system has unique considerations, with a clear role for gas infrastructure across different decarbonisation pathways

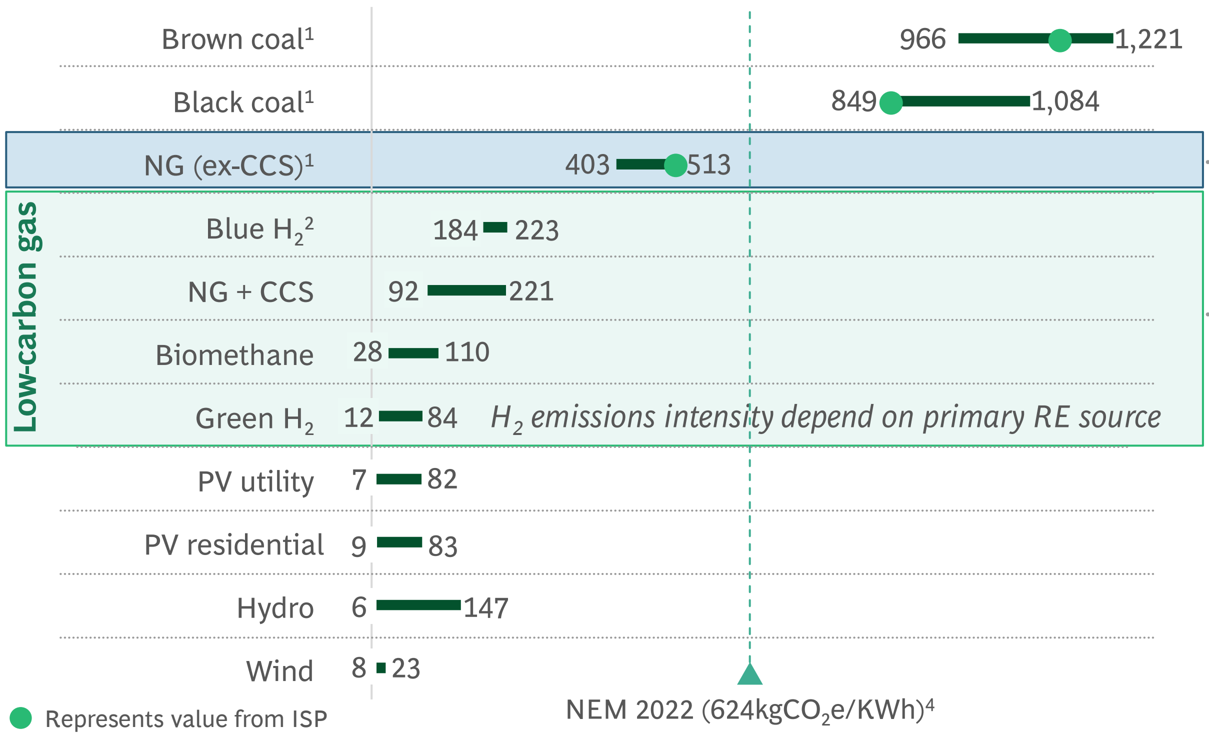
Studies in the literature anticipate a net zero future with low-carbon gas infrastructure could be equivalent or lower cost than a fully electric system, as reduced customer/network investment offsets higher fuel unit costs

- A small number of studies present a range of total system costs under different scenarios. In those, scenarios that incorporate some level of low-carbon pipeline gas have similar or lower total system costs. The range of system costs is driven in different analyses by avoided customer-side spend, avoided electricity network investment, and avoided decommissioning costs balanced against fuel costs
- At a system level, the end-state least-cost net zero solution for distribution-connected customers may differ by location based on climate, electricity network capacity, customer types and proximity to low-carbon gas sources
- Elements of existing gas infrastructure could be repurposed to accommodate low-carbon gases; existing studies show that distribution networks can largely accommodate hydrogen
- Case studies suggest that system and customer infrastructure could transition to low-carbon gases — provided adequate preparation

Current natural gas end uses can be decarbonised using renewable electricity or low-carbon gases

Example of lifecycle emissions intensity for an energy application

Lifecycle emissions intensity for electricity generation ($kgCO_2e/kWh$)



Natural gas emissions are lower than combusting coal or liquid fuels, but far greater than RE sources

Low-carbon gas can compare to renewable electricity when accounting for **full lifecycle emissions** (and significantly lower than coal and unabated natural gas)

Other potential forms of **low-carbon gas** could be considered including synthetic methane manufactured from green hydrogen and direct air capture carbon dioxide

1. Black coal, brown coal & NG from AEMO ISP 2022 average of generator types. CCGT average 462 kg/MWh, OCGT average 773 $kgCO_2/MWh$. 2. Blue hydrogen emissions intensity range determined by applying a 0.4% factor of fugitive losses of methane consumption in emissions calculation by Howarth & Jacobson 3. Based on AEMO ISP

Note: Offsets are a near-term option for 'carbon neutral', however SBTi and other emissions target-setting frameworks set a minimum threshold for offsets (e.g. on average 10%) that means 100% offsetting is not a viable long-term net zero solution, though some residual natural gas with offsets may remain in the system

Source: National Renewable Energy Laboratory; Intergovernmental Panel on Climate Change; UN Economic Commission for Europe; Howarth & Jacobson: How Green is Blue Hydrogen?; AEMO ISP; OpenNEM; BCG analysis

If low-carbon gas prices reduce as anticipated, they could provide competitive offers for customers to decarbonise

Summary of least cost options, by customer group, if low-carbon gas prices reduce[1]

	Customer	Near-term least cost option	Long-term decarbonisation pathway
RESIDENTIAL	Residential[2]	Highly individual; **natural gas with offsets** is the cheapest for some, except new builds	**Low-carbon gases could be total-cost competitive, for some existing gas using customers,** at anticipated prices and if the network charges are managed
INDUSTRIAL	Low-grade process heat	**Electrification** is likely more cost-effective than natural gas	**Electrification** is likely more cost-effective than low-carbon gases
INDUSTRIAL	High-grade process heat	**Electrification is not economic** with existing technologies	**Low-carbon gas** will likely be required
INDUSTRIAL	Feedstock	**Natural gas** to remain a feedstock	**Low-carbon gas** will likely be required, or natural gas with CCS
INDUSTRIAL	Peak electricity generation	**Natural gas** to remain a fuel for GPG	**Renewable electricity and storage**; remaining back-up capacity fuelled by hydrogen or biomethane
OTHERS	Transport, aviation, etc.	Alternatives to liquid fuels are high cost	**With further tech developments, battery-powered vehicles or low-carbon fuels could** displace liquid fuels (and coal, e.g. for steel)

1. Based on forecasts of \$2-3/kg for green hydrogen, and \$15/GJ for biomethane
2. Decisions for commercial customers will be most similar to residential customers, but with different considerations (e.g. energy use profile) not considered in this report

Source: BCG analysis

Electrification
Renewable electricity with storage
Low-carbon gas (inc. CCS)
Natural gas
Option exists, but generally not economic or available

Residential | Total customer cost is highly individual: lower for gas in existing cold-climate homes; lower for electric for new builds in 'central' cases

Least-cost solution is highly individual, depending on costs, volumes and individual characteristics

Existing homes: removal and disconnection costs mean natural gas has the lowest total cost of ownership over 10 years, in central case particularly if appliances are not already at end-of-life

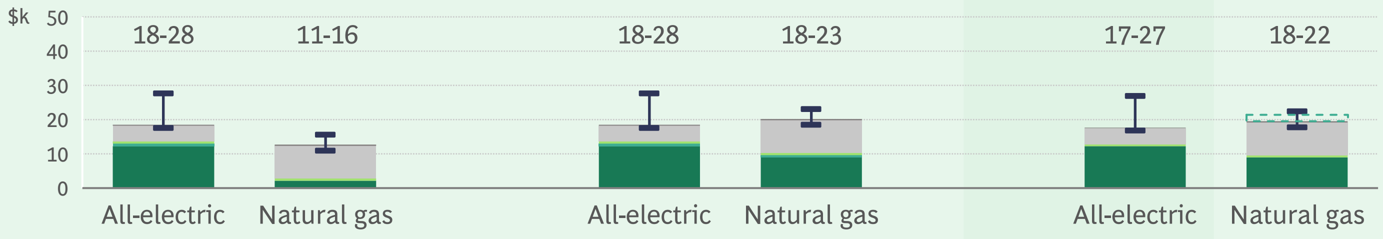
Warm state (NSW, today)

COP = 3.75 (space), 4.10 (water) | 21GJ pa

Existing house: Early replace
1.4m existing housing stock[1]

Existing house: EOL appliance
<0.1m estimated at EOL[1]

New builds
<0.05m new builds each year[1]



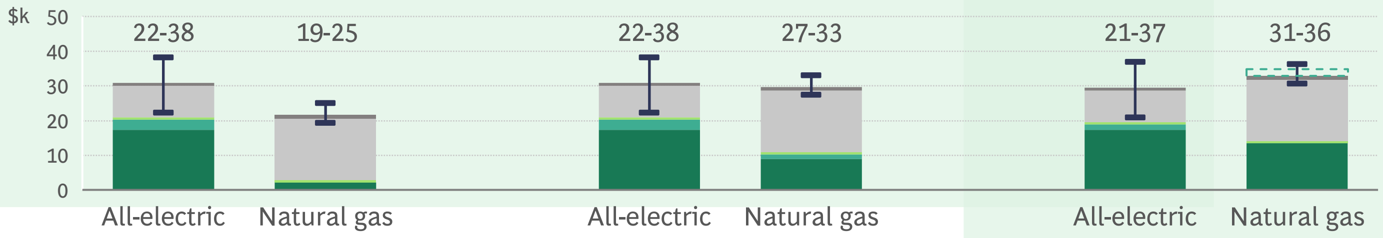
Cold state (VIC, today)

COP = 3.25 (space), 3.80 (water) | 56GJ pa

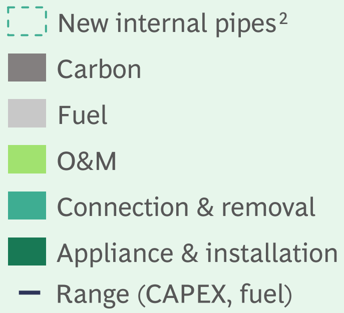
Existing house: Early replace
2.8m existing housing stock[1]

Existing house: EOL appliance
<0.2m estimated at EOL[1]

New builds
<0.06m new builds each year[1]



New builds: electrification has lower cost for new build houses in the central case



Note: Analysis does not translate directly to purchase decisions: it excludes subsidies, and doesn't consider other purchase criteria

1. ABS (2022). Around 83% (VIC) and 43% (NSW) homes have mains gas connections (2014 ABS Energy Use and Conservation Survey) 2. Dotted box shows cost of gas pipework in new builds, for reference

Note: Inclusive of space heating, water heating and cooking. Costs reflect 10-year NPV using real discount rate of 3%. Capital costs based on Frontier (2022) Archetype 1, Option 2 (NSW) and Option 1 (VIC), low range quotes for conservatism. Compared to Frontier, removal, rectification and power supply upgrade costs ammortised over longer time-frame and for option 1, the cost of 1 split system is removed from Archetype 1 appliance costs to reflect a 3-bedroom house (the most common in VIC), and GST is included. Electricity and gas costs based on BCG analysis of retail tariffs including rate increases expected in Jul-Aug 2023, triangulated against VIC Gas Substitution Roadmap savings; all-electric homes save ~$550 (NSW) and ~$1,000 (VIC) annually on energy bills, assumed constant over 10 years. All-electric homes are grid-connected and no subsidies are considered.

Source: Frontier Economics, Cost of switching from gas to electric appliances in the home (2022); ATA and Reneweconomy, Household fuel choice in the NEM (2018); BCG Analysis

Residential | Individual factors include appliance and installation cost, house type, size, consumption, and fuel pricing

Total cost of ownership will depend on a balance between fuel costs over time and upfront capital costs

Upfront cost of switching to **all-electric will vary based on appliance configuration and connection costs**

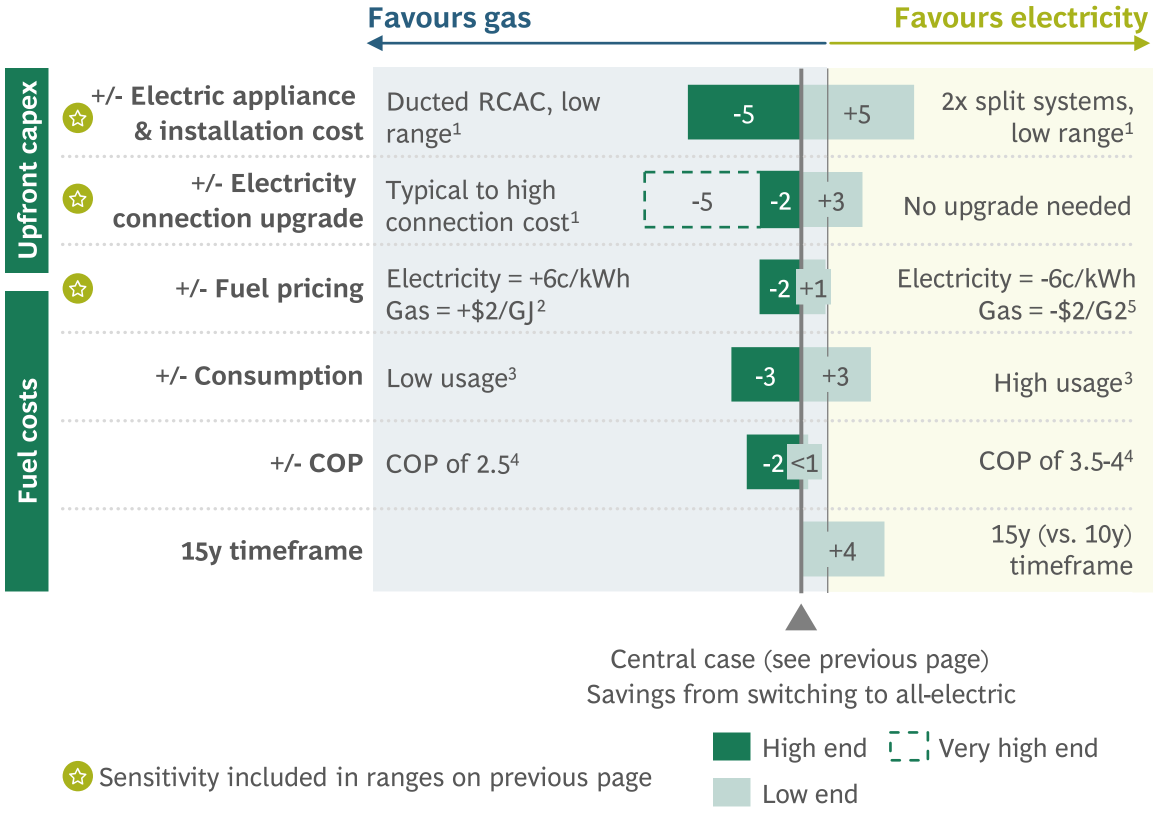
Relative fuel costs will vary depending on wholesale and time of use pricing, consumption levels, and the efficiency of appliances

For existing homes in cold climates, these **factors can each influence the relative cost of ownership by up to $5k** and change the least-cost option for an individual household

These factors are not all independent; for example, homes with high quotes for upfront capex are likely homes with high gas consumption; or lower capex electricity options may have lower efficiency

Cold state (VIC), today, existing house: end-of-life appliances

Relative total cost of ownership, all-electric savings versus natural gas with offsets



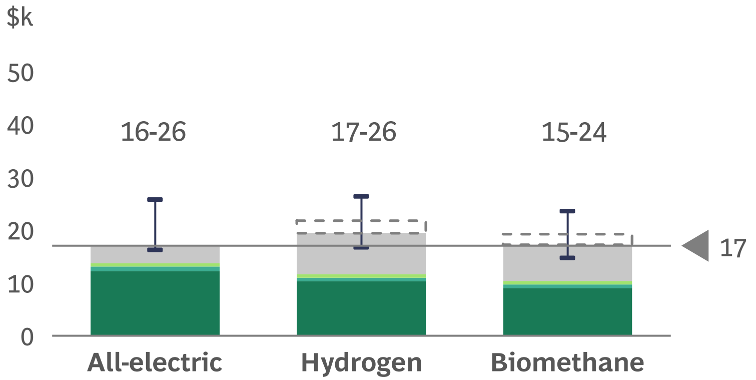
1. Frontier (2022), high range = option 3 (ducted RCAC), low range; low range = option 2 (2x split systems), low range; Archetype 1, option 1 power supply upgrade low to typical ranges; connection cost ranges based on option 1 low, typical, and high ranges 2. Pricing range based on wholesale cost ranges and electricity price sensitivity based on peak time of use tariffs 3. Based on ATA consumption ranges; 4. ATA, Household fuel choice in the NEM (2018) 4. Based on analysis of ATA/Reneweconomy (2018) and IRENA, Renewable solutions in end uses: Heat pump costs and markets (2022)

Source: BCG analysis

Residential | Low-carbon gas could be competitive in the future if costs reduce and network charges are managed – especially for costly-to-electrify households

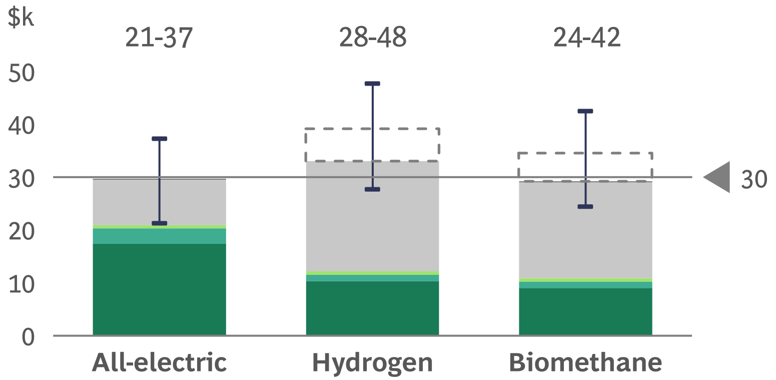
Warm state (NSW), 2040, EOL appliances

COP = 3.75 (space), 4.10 (water) | 21GJ per year



Cold state (VIC), 2040, EOL appliances

COP = 3.25 (space), 3.80 (water) | 56GJ per year



Biomethane price
$15/GJ wholesale, $37-48/GJ retail[2]

H_2 price
$2.5/kg wholesale, $40-51/GJ retail[2]

Assumes green H_2 produced centrally and distributed via natural gas networks

Network charge increase[1] | Fuel | Connection & removal | Range (CAPEX, fuel costs)
Carbon | O&M | Appliance & installation

Low-carbon gases could be cost-competitive with electricity for some customers. Central assumptions:

- $2.5/kg wholesale for green H_2
- $15/GJ wholesale for biomethane

To achieve this competitiveness:

- Low-carbon gases would need make significant cost reductions relative to today – as anticipated
- Network tariffs differentials would need to remain at current levels for each to be competitive with electricity[2]
- No step-change in appliance efficiency/cost differential beyond already included additional cost for hydrogen appliance

1. Network charge increase reflects -50% distribution-connected customers, per GSOO OSC scenario in 2040 2. Hydrogen wholesale costs based on Advisian, CEFC: Australia Hydrogen Market Study, biomethane wholesale from Future Fuels CRC and Deloitte, Decarbonising Australia's gas network, and marginal electricity prices assumed at 25 c/kWh. Low heating value used for energy conversions and high heating value for price calculations
Note: Inclusive of space heating, water heating and cooking. Costs reflect NPV over 10 years, using real discount rate of 3%. All-electric homes are grid-connected and no subsidies are considered.
Source: Frontier Economics, Cost of switching from gas to electric appliances in the home (2022); ATA and Reneweconomy, Household fuel choice in the NEM (2018); BCG Analysis

Estimates in literature show that leveraging existing gas infrastructure could support a low-cost net zero future energy system

	Lowest system cost scenario	Savings versus other scenarios	Implications for gas infrastructure
Final modelling results (2023)[1] NET ZERO AUSTRALIA	(E-) Slower electrification *similar cost to* (E+) Rapid electrification *Note: also assumes slower EV uptake*	**<2%** Total domestic system costs (% vs. E+, 2020-2050)	• Marginally lower, but similar vs. E+ Scenario (~2%, \$5b/year): *E+ and E- have similar total domestic cost trends* • Minimises demand-side (customer) cost offset by higher fuel cost. *If appliances reach parity sooner than modelling E+ could be lower total cost* • ~95% of gas distribution network RAB value in 2050 versus ~30% in E+ • Gas infrastructure transports natural gas (offset with DAC) and biomethane
Benefits of Gas Infrastructure to Decarbonise Australia[2] frontier economics	Zero-carbon fuels scenario	**~\$2-15b** savings vs. other scenarios (\$b per year, 2050)	• Increased gas transmission network capacity • Gas infrastructure transports blue H_2 and natural gas (w/ CCS) • Assumes investment in electricity distribution network is required, cost is estimated to be proportional to increase in peak demand Note: this potentially overestimates the cost of electrification as some networks have excess capacity today
Towards 2050: Gas infra in a net zero emissions economy[3] INFRASTRUCTURE VICTORIA	Energy efficiency scenario *Note: behind-the-meter costs not included*	**~\$1-5b** savings vs. other scenarios savings vs. other scenarios[4] (\$b per year, 2050)	• Around 40% of total gas consumption in 2050 vs. 2022 • Gas infrastructure largely transports offset natural gas (~45PJ by 2050) and biomethane (~30PJ by 2050), with small amounts of hydrogen (<5PJ) • 26% of gas transmission pipelines are decommissioned, versus 36-85% in other scenarios

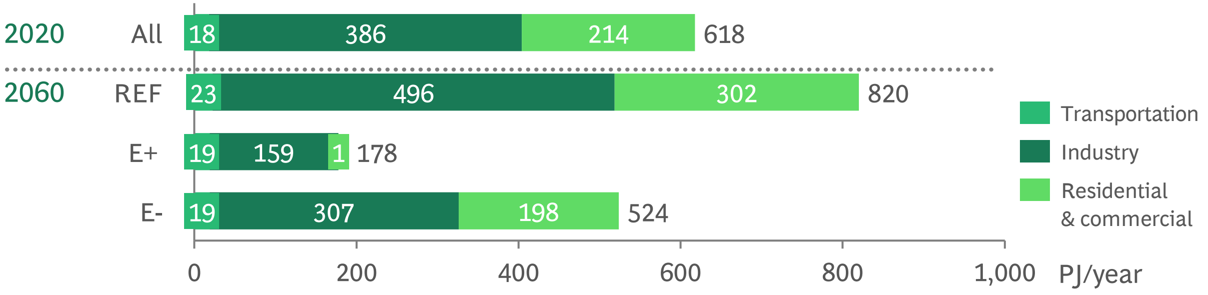
Leveraging gas infrastructure could lower system cost

- Existing distribution networks could be directly transitioned for low-carbon gases
- Electrification may require electricity network and storage investment if there is insufficient existing capacity
- Avoids customer-side capital and network decommissioning costs
- If new transmission infrastructure is required for remote sources, gas pipelines remain more cost-effective than powerlines for bulk energy transportation/storage[4]

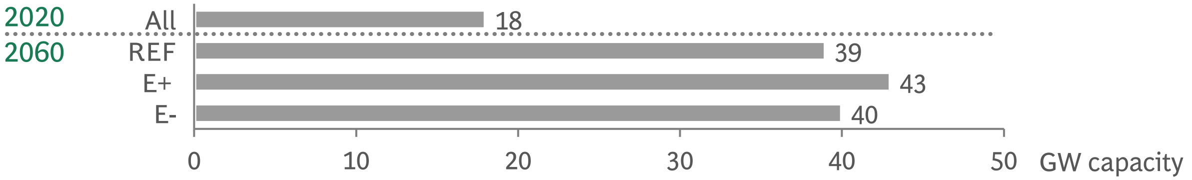
1. Net Zero Australia, Final Modelling Results (2023) 2. Frontier, The benefits of gas infrastructure to decarbonise Australia (2020) 3. Infrastructure Victoria, Towards 2050: Gas infrastructure in a zero emissions economy 4. APGA, Pipelines vs. Powerlines: a summary (2023)
Note: Scenario comparisons refer to scenarios within each literature study, and not across studies
Source: BCG analysis

Recent Net Zero Australia modelling illustrates the potential role for low-carbon gas in a low system cost scenario

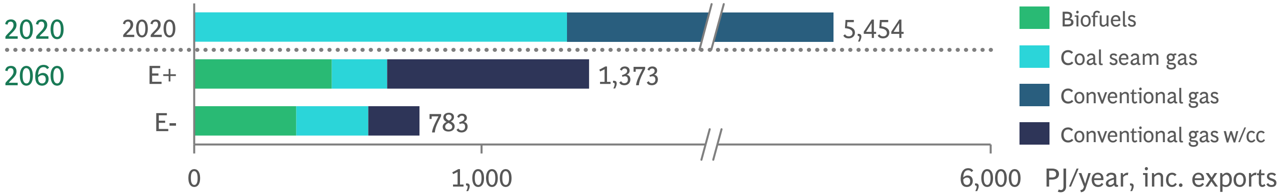
Domestic pipeline gas demand in 2060 ranges from ~30–85% of 2020, with 0–92% residential & commercial volumes[2]



GPG capacity increases by 2-3x to 2060



Volumes of pipeline gas supply (inc. exports) vary



Of the core scenarios, E- is narrowly lowest cost, and minimises demand-side costs

	E+ Strong electrification	E- Slower electrification
Core assumptions		
Electrification	Nearly full electrification of transport and building stocks by 2050	Nearly full electrification of transport and building stocks by 2100
RE constraints	Maximum build rates per year[1]	Maximum build rates per year[1]
Total domestic energy system costs		
Annual (2060)	$320B/year	$315B/year
NPV (2020-2050)	$4.9T	$4.8T
Demand-side (2060)	~$35B/year[3]	~$30B/year[3]

1. Initial growth rate constraint of 2.5GW/year (large-scale solar PV), 1GW/year (onshore wind), allowed to grow at 30% YoY in the 2020s, 20% in the 2030s, and 10% in the 2040s and 2050s. Offshore wind initial growth rate of 0.5GW/year from 2026, compounding by 30% until 2037, 20% until 2047, and 0% thereafter. 2. In all net zero scenarios, "pipeline gas" is natural gas (with emissions offset with DAC), traditional biogas, or synthetic methane produced using biomass (with some CCS). Hydrogen is only modelled in the gas transmission network, with no option modelled for hydrogen in the distribution network 3. Includes e.g. vehicles, home appliances; values visually interpolated
Source: Net Zero Australia: Final Modelling Results (2023); BCG analysis

At a system level, the least-cost net zero solution for distribution-connected customers is likely to differ by location

Favours low-carbon gas	Factor	Favours electrification	
Cold	Climate	Warm	**Warm** = lower peak energy demand from electrification, likely summer peak limiting additional infrastructure requirements
Constrained	Electricity network capacity	Unconstrained	**Unconstrained** = lower distribution network cost to electrify
Frequently coal / natural gas	Marginal electricity supply	Frequently renewables	**Renewables** = limited better use for renewable electricity
Concentrated industrial	Customer profile	Standalone residential	**Industrial** = more users with demand for low-carbon gas with limited alternative, can be leveraged for other customers
Readily available / proximate	Biomass availability	Limited	**Available** = lower cost to develop & transport
Readily available / proximate	Hydrogen production proximity	Limited	**Available** = lower cost to transport

Elements of existing gas infrastructure could be repurposed to accommodate low-carbon gases; existing studies show that distribution can accommodate hydrogen

Distribution networks largely need minimal modifications for hydrogen, particularly for blends

Transmission (Tx) may require more modification, although further study is needed

Feasibility depends on age, region, material and component type, and operating conditions (pressure and capacity)

Feasibility studies of H_2 compatibility in existing gas networks

Distribution

	VIC (Infrastructure Victoria, Advisian)	VIC & SA[3] (Australian Gas Infrastructure Group)	VIC & SA[3] (Australian Hydrogen Centre)	NSW (GPA Engineering, Jemena)	ACT (evoenergy)
10% blend	Limited modification	Largely H_2 ready (~$10mn modification required[4])	Minimal modification	Limited modification[1]	Not assessed
100%	Greater modifications		Some modifications	Compatible with modifications, further studies required[4]	No need to adjust pressure, but further testing required

Transmission

H_2 content	VIC[3] (Infrastructure Victoria, Advisian)	WA (Parmelia Gas pipeline) (apa)	WA (Dampier to Bunbury pipeline) (Australian Gas Infrastructure Group)	Germany (Cerniauskas et al.)
10% blend	Range of modifications	Technically viable, operational capacity being tested	No significant impacts up to ~9% blend	Not assessed
100%	Greater modifications		Not assessed	Major modification required, but 20-60% cheaper than building new Tx[2]

Strong compatibility · Moderate compatibility · Lower compatibility or to be confirmed

1. Pipelines under integrity management or cyclic loading are exceptions and may require major modifications 2. National Renewable Energy Laboratory, Hydrogen Blending into Natural Gas Pipeline Infrastructure: Review of the State of Technology 3. Statewide assessment 4. Company has supplied information to indicate that compatibility has been further investigated since previous 2019 study

Source: Infrastructure Victoria, Towards 2050: Gas infrastructure in a net zero emissions economy; Advisian, Asset Life and Adaptability Review - IV 12; APA, Australia's First Hydrogen Pipeline Conversion Project; AGIG, Dampier to Bunbury Natural Gas Pipeline Public Knowledge Sharing Report; Jemena, Revised 2020-25 Access Arrangement Proposal Attachment 8.5; Australian Hydrogen Centre, For renewable hydrogen in existing Victorian and South Australia gas networks - Summary report; National Renewable Energy Laboratory, Hydrogen Blending into Natural Gas Pipeline Infrastructure: Review of the State of Technology; Gaykema, Skryabin, Prest and Hansne, Assessing the viability of the ACT natural gas distribution network for reuse as a hydrogen distribution network; Multinet Victoria, Five-year plan for our Victorian distribution Network, July 2022; BCG analysis

Three stages of action would be needed for gas infrastructure to play this role in supporting the energy transition and providing an option for the net zero future

In the near-term, natural gas could contribute to the reliable, affordable and lower-emissions energy transition

- ✓ Avoid near-term supply shortfalls
- ✓ Meaningfully abate fugitive and operational emissions

As the system transitions, system planning should become truly integrated – ensuring that planning, regulatory and pricing mechanisms are aligned

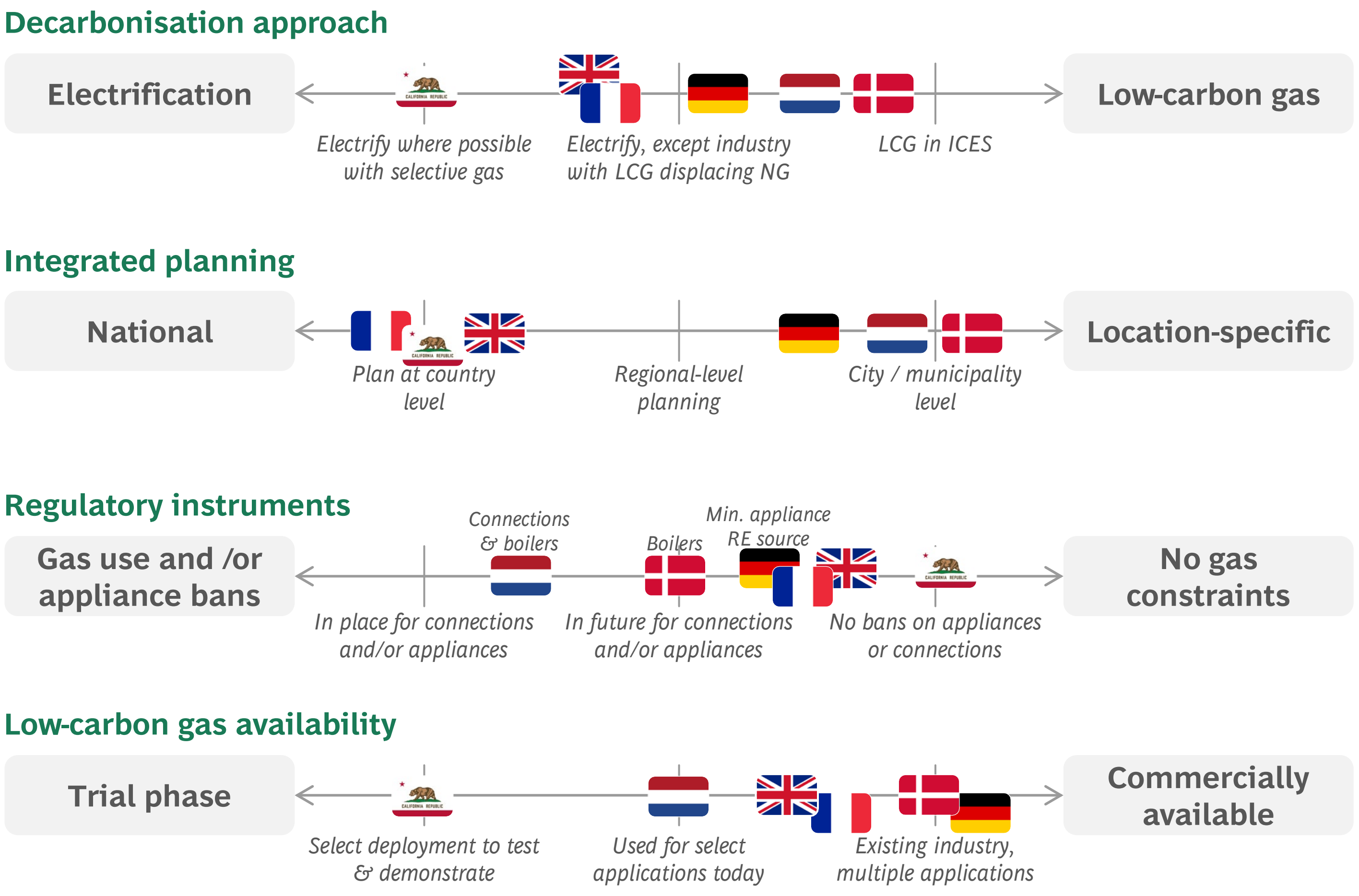
- ✓ Align and manage trade-offs between energy systems
- ✓ Align regulatory and pricing mechanisms
- ✓ Be sufficiently granular at regional and network levels

For Australia's least-cost integrated clean energy system, there is a need to develop competitive low-carbon gas supply and demonstrate gas infrastructure readiness

- ✓ Achieve total-cost competitiveness for customers
- ✓ Scale green hydrogen, biomethane feedstock and adapt infrastructure

Other jurisdictions are pursuing low-carbon gas to support electrification

Other jurisdictions are pursuing low-carbon gas to support electrification, with the exception of warmer climates, with increasingly location-specific planning



California

Source: BCG analysis

- All seek to electrify where feasible
- Low-carbon gas generally for hard to electrify uses (particularly industry), plus district heating

- Denmark and Netherlands conducting energy planning at municipality level; Germany at city level

- Netherlands connection and appliance bans; Denmark appliance bans
- Germany, France and UK applying appliance efficiency requirements
- Hybrid heat pumps supported in Netherlands and Germany

- Biomethane industry more progressed than hydrogen; H_2 predominantly trials though not yet demonstrated at scale

Infographics of gas infrastructure during the energy transition

Best viewed in A3 when printed

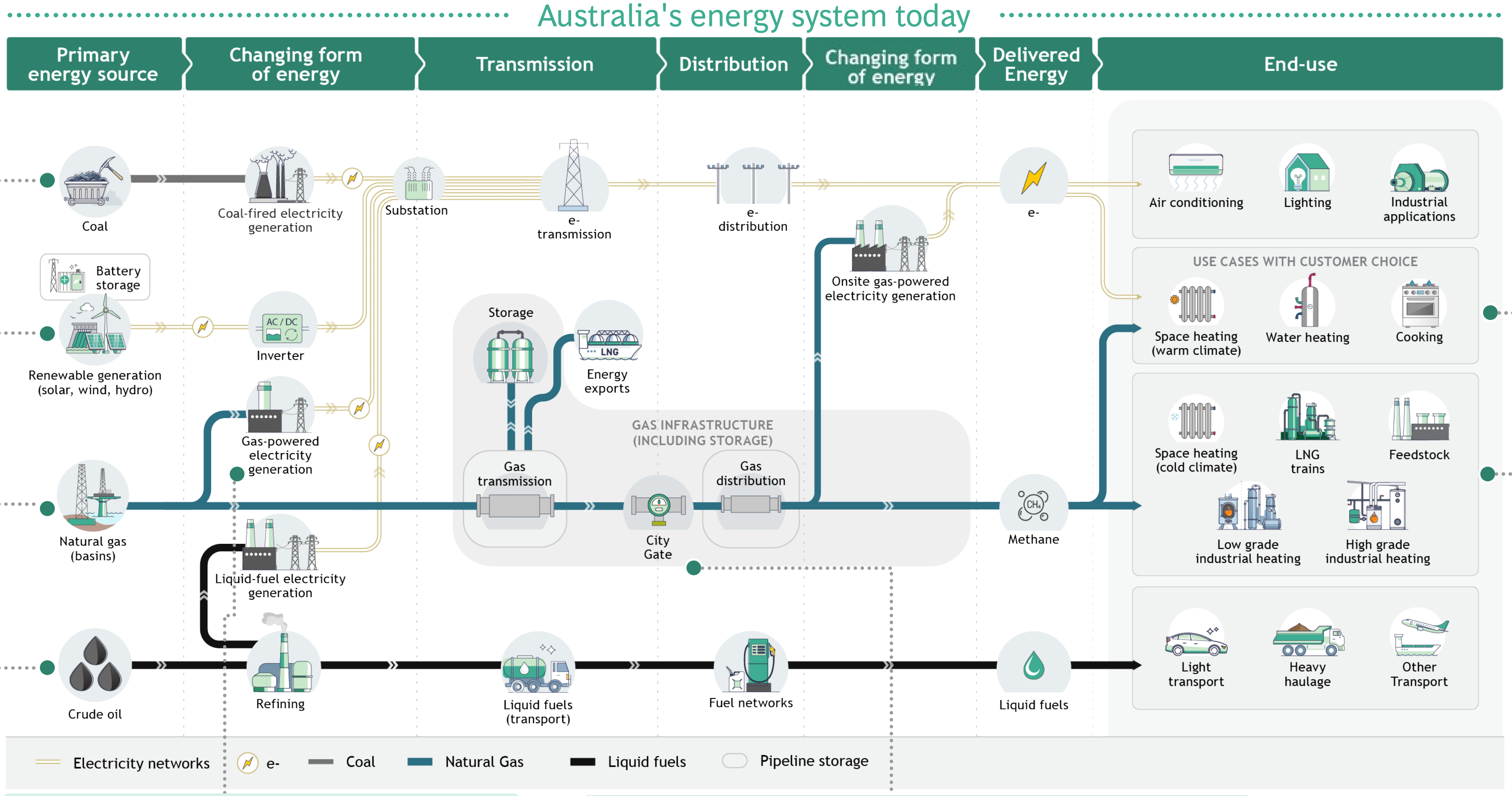
Natural gas (and gas infrastructure) is one of the three pillars of today's energy system

Coal contributes to **~29%** of Australia's primary energy supply[1]

Renewable energy contributes to **~8%** of Australia's primary energy supply[1]

Natural gas contributes to **~27%** of Australia's primary energy supply[1]

Oil contributes to **~36%** of Australia's primary energy supply[1]



Natural gas provides electricity during **critical peaks:** 6-10% of generation and 20-25% of dispatchable capacity[2]

~40,000 transmission and **~90,000km distribution** gas pipeline infrastructure assets (of which >$17bn fully regulated) that transport natural gas today[3]

Natural gas customers: 5.1m residential 190k small and large business[4]

11% of natural gas is consumed by **households**[5]

Natural gas provides **~34% of end-use household energy,** primarily for heating, 60% in Victoria[5]

28% of natural gas is used for **low-grade heat, high-grade heat and feedstock**[5]

31% of natural gas is used for **LNG production** (compression)[5]

1. Australian Energy Statistics 2. OpenNem 3. AER, Regulated Gas Pipelines; Access arrangements used for WA. Does not include value of assets under light regulation or unregulated assets. 4. Totals do not include NT and TAS customers; AER; Economic Regulation Authority; Essential Services Commission
5. Australian Energy Statistics; APPEA, Key Statistics 2022; AEMO GSOO 2021; AEMO WA GSOO 2020; Australia Institute, On the make (2020); Energy Consult, Residential Energy Baseline Study Australia (2015)
Source: BCG analysis

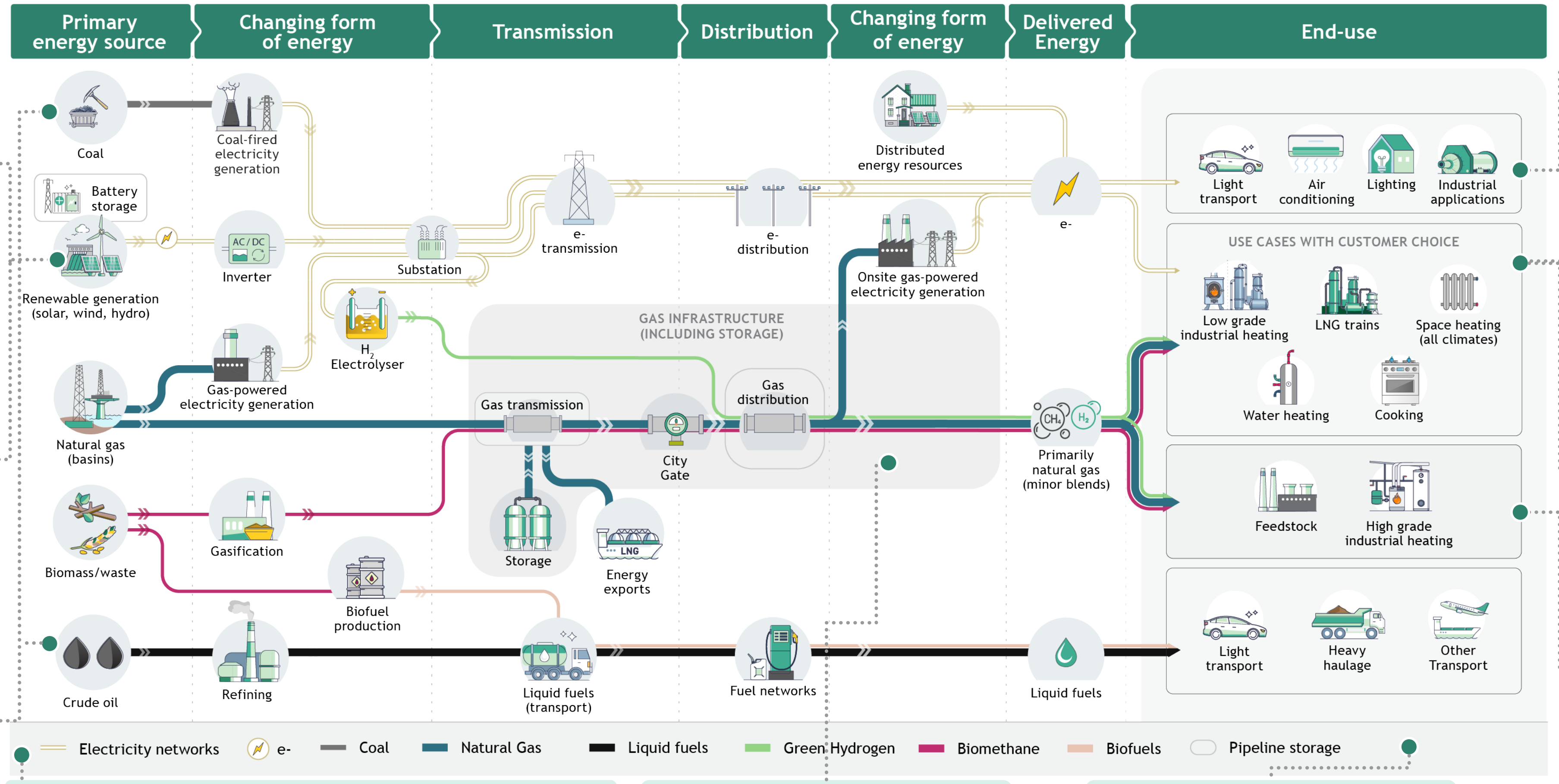
In the transition to a clean energy system, the growth of renewable primary energy sources will drive a realignment of the energy system architecture

Renewable electricity build will accelerate, with ~25 TWh/year of wind and solar planned, plus ~40 TWh/year of rooftop PV forecast by 2030.[1] The renewable **build rate will be critical to the pace of transition**

Wind and solar will be **Australia's cheapest sources of renewable primary energy,** projected to cost $50-70/MWh compared to biomethane/green hydrogen at $75-95/MWh in 2025[2]

Displacing coal-fired electricity generation and liquid fuels with renewable electricity delivers the greatest system savings and emissions reduction

The energy system in transition



Increasing connection between gas and electricity energy systems e.g. gas is used to produce hydrogen and firm renewable electricity

Gas infrastructure supports **targeted blending of H_2 and biomethane**

System interdependencies highlight the need for **integrated system planning**

Transport: ICEs (liquid fuels) start being replaced by EVs (electricity)[3]

Households **have greater choice** with electric appliances becoming more **cost competitive** in most cases (NG + offsets remains a cost competitive option)[5]

LNG trains: Gas turbine compressors could be replaced by electric drive motors[4]

Natural gas will continue to serve end uses that are **hard-to-electrify** or deliver **lower system savings** from transitioning to renewables[6]

1. AEMO NEM Generation Information; AEMO NEM ISP Generation Outlook 2022 (Step Change scenario) 2. Wind and solar LCOEs from CSIRO, GenCost 2022-23 with blended average LCOE calculated based on 60% wind and 40% solar mix; green hydrogen cost is from Advisian and CEFC, Australian Hydrogen Market Study; biomethane cost is from IEA, Outlook for biogas and biomethane, and from Deloitte, Decarbonising Australia's gas network 3. CSIRO, Electric Vehicle Projections 2021; Advisian, Australian hydrogen market study 2021 4. IEA; ABB; company data; RFF; OIES 5. Grattan, Flame out (2020); Frontier, Cost of switching from gas to electric appliances in the home (2022); ATA/Reneweconomy, Household fuel choice in the NEM 6. ARENA. Renewable energy options for industrial process heat
Source: BCG analysis

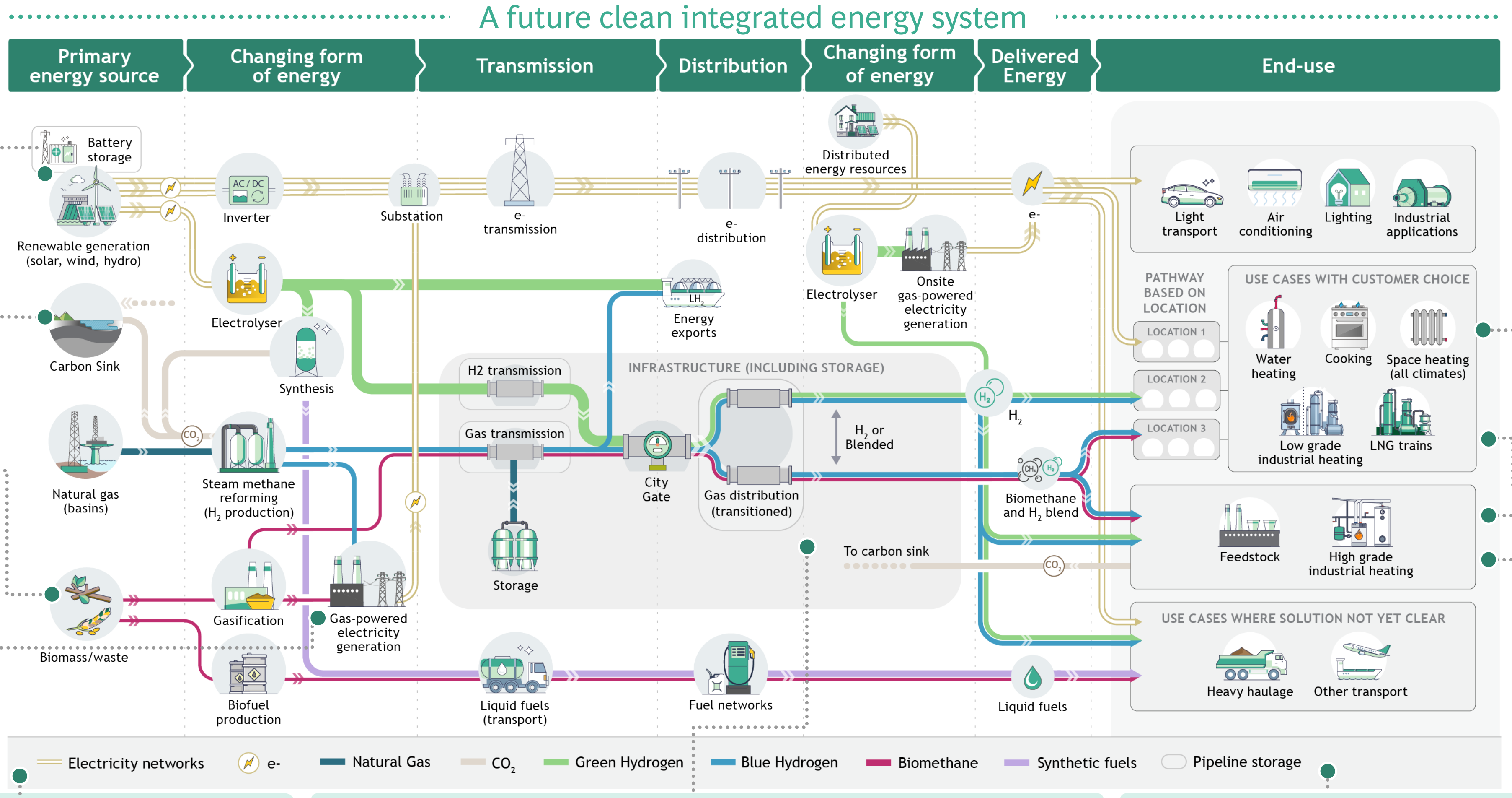
In a future integrated clean energy system, low-carbon pathways could provide alternatives to natural gas and increase network resilience

Primary energy source maximises use of **renewable energy** where **cost effective** and **available**, and then uses low-carbon gas

Carbon sinks are used to store captured CO_2 from steam methane reforming or GPG

Biogas (from biomass) can be upgraded to **biomethane** – demand will be contested by other end uses

Gas-powered generation remains; **least-cost future energy systems have ~5-11% GPG capacity**[1]



At anticipated costs, customers will have **competitive, low-carbon options to choose from** across electricity and low-carbon gas (H_2 and biomethane)[3]

Individual **customer choice will depend** on a number of factors

Decarbonisation pathway will be **subject to location** (e.g. infrastructure availability, energy source proximity)

High-grade process heat and feedstock can be served with **low-carbon gas** (H_2 and biomethane)[4]

Greater **interconnectedness increases system resilience** through features such as green hydrogen storage

Gas distribution can transition to **transport low-carbon gases** with some **minor modification** while **greater modification** needed for **transmission networks** or **additional pipelines**

A system using low-carbon fuels incurs **less than 50% incremental annual costs (vs. today)**, compared to electrification alone[2]

1. Gilmore, Nelson and Nolan, Firming technologies to reach 100% renewable energy production in Australia's National Electricity Market; based on lowest average energy cost for a 100% VRE system. 2. Frontier Economics, The benefits of gas infrastructure to decarbonise Australia; 3. Advisian and CEFC, Australian hydrogen market study (2021); 4. ETI, Pathways to industrial decarbonisation (2023); ARENA, Renewable energy options for industrial process heat (2019)
Source: BCG analysis

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