Australia's Bioenergy Roadmap

Appendix – Future Prospects for Bioenergy

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Australian Government
Australian Renewable Energy Agency

ARENA

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1. Key findings

	Potential contribution	
Benefits	**2030**	**2050**
GDP Impact: additional annual GDP	$10 billion	$14 billion
Jobs	26,200	35,300
Emissions abatement: per cent of 2019 national emissions	9%	12%
Liquid fuel security: extra days of consumption cover from 2019 levels[1]	27 days	63 days
Waste recovery: per cent of 2019 landfill waste diverted	6%	7%

Bioenergy is a sector with significant growth potential and benefits.

Australia's Bioenergy Roadmap demonstrates that there is significant potential for bioenergy to contribute to the economy, particularly in regional areas.

The bioenergy sector also has the potential to contribute to accelerating emissions reduction, liquid fuel security and waste recovery. It could achieve this through contributing up to **20 per cent of the country's primary energy demand by 2050 under the Targeted Deployment scenario.**

- **GDP contribution:** The economic impact modelling estimates that expanded bioenergy output could add a further $11 billion per annum to Australian GDP by 2030 and $15 billion per annum by 2050.
- **Jobs:** Growth in bioenergy is estimated to deliver an additional 26,200 to 35,300 jobs depending on the growth scenario.
- **Regional economies:** Regional areas are likely to experience the greatest benefit from increased bioenergy activity.
- **Emissions reduction:** The bioenergy sector could be a significant contributor to Australia's emissions reduction ambitions with the potential to abate up to 46 $MtCO_2$-e p.a. by 2030 and 67 $MtCO_2$-e p.a. by 2050, representing 9 per cent and 12 per cent of the country's 2019 total emissions.
- **Liquid fuel security:** Through producing liquid fuels, bioenergy could replace up to 4,513 ML p.a. of fossil fuels by 2030 and 10,551 ML p.a. by 2050. Based on 2019 data, this could increase liquid fuel consumption cover from its historic average of 27 days to 63 days by 2050.
- **Waste recovery:** Finally, through utilising waste streams for higher-value products, bioenergy has the potential to reduce organic waste to landfill by 1.3 Mt p.a. by 2030 and 1.6 Mt p.a. by 2050, representing 6 per cent and 7 per cent respectively of the total waste that went to landfill in 2019.

1. This represents an extra 4,513 ML of biofuel per annum and is based on daily consumption of diesel, petrol and aviation fuel of 167.1 ML/day (2018-2019 Australian Petroleum Statistics).

Table 1 provides the potential uptake of bioenergy in the three markets where bioenergy has a competitive advantage.

Table 1 – Total energy from bioenergy and bioenergy's share of each market

Market	BAU Scenario						Targeted Deployment Scenario					
	Current		2030		2050		Current		2030		2050	
	PJ	%	PJ	%	PJ	%	PJ	%	PJ	%	PJ	%
Industrial Heat	108	15%	127	17%	145	17%	108	15%	244	33%	279	33%
Pipeline Gas	0	0%	40	9%	42	9%	0	0%	105	23%	152	33%
Industrial Heat	0	0%	0	0%	66	12%	0	0%	70	18%	255	45%

- **Some critical levers will determine the growth trajectory of bioenergy markets.** The modelling is built upon the extensive research and consultations on feedstocks, technologies, markets and low-emissions alternatives or incumbent fuel pricing combined with demand modelling techniques and scenarios. This work demonstrated that key determinants guide the extent to which the potential benefits will materialise.
    - **Feedstock constraints restrict growth.** Demand for bioenergy resulting from policy and cost drivers is constrained by feedstock availability under all modelled scenarios.
    - **Policy support drives growth.** Scenarios that include strong policy support result in more favourable cost-competitiveness and show significantly higher and earlier uptake of bioenergy.
    - **Cost reductions improve the competitiveness of bioenergy.** Although bioenergy technology is relatively mature, further reductions to the capital costs, operating costs and feedstock costs have significant impacts on the scale of bioenergy uptake.
    - **Realisable feedstock volumes.** Comprehensive assessments are required to more acurately understand feedstock locations, types, quality, availability, feasibility and prices for bioenergy usage.
    - **Incumbent fuel prices.** The future changes in alternative fuel pricing also have has a significant impact on the price-driven demand analysis and may vary significantly from the assumption used in the modelling.

2. Appendix overview

This appendix introduces the Bioenergy Model that has been developed as part of this Roadmap. The Bioenergy Model explores potential future scenarios of the Australian bioenergy industry from 2021 to 2050.

The outcomes of the Bioenergy Model were fed into Deloitte's Computable General Equilibrium (CGE) model to assess economic and employment impacts.

This appendix provides an overview of the modelling methodology and assumptions, the demand modelling results, the economic modelling results and a summary of the quantification of all the benefits resulting from the growth.

3. Modelling overview and methodology

In this section, the two key components of the Bioenergy Model are detailed: the cost and demand components. An overview of the four scenarios developed to test a range of possible futures and clarity on the key market drivers is then provided. Finally, the methodology used to assess economic and employment impacts from the outputs of the Bioenergy Model, based on Deloitte's CGE model, is described.

Representative production pathways have been selected for each end-use market. Though these pathways do not reflect the cost of every specific technology, they provide a robust basis for the purpose of this modelling exercise. The pathways analysed in the Bioenergy Model were identified as being the most prospective (see Table 2).

Table 2 – Bioenergy production pathways

End-use market	Production pathways
Pipeline Gas	• Biomethane from Anaerobic Digestion • Biomethane from Landfill Gas
Road Transport (Petrol)	• 1G Bioethanol – Sugarcane • 2G Bioethanol – Cellulosic Bioethanol
Road Transport (Diesel)	• Renewable Diesel
Aviation	• Biojet fuel
Industrial Heat	• Industrial Heat Generation from Biogas • Industrial Heat Generation from Solid Biomass
Off-Grid Electricity	• Power Generation from Biogas • Power Generation from Solid Biomass
Grid Electricity	• Power Generation from Biogas • Power Generation from Solid Biomass • WtE – Waste Incineration

Cost component

The cost component of the Bioenergy Model seeks to determine the cost of delivering bioenergy to the consumer.

The delivered cost of bioenergy refers to the cost of producing bioenergy with a specific technology type. Each technology type that is explored in the Bioenergy Model has different capital and operating expenditure trajectories, different feedstock requirements and plant-specific attributes.

- **Capital and operating expenditure (CAPEX/OPEX) -** CAPEX is the cost associated with building a bioenergy facility. OPEX is the non-feedstock operating costs, such as maintenance costs. CAPEX costs are assumed to be incurred in the year the facility is built and OPEX costs are incurred every year thereafter that the plant is operational.
- **Feedstock-specific assumptions (costs, calorific content, volume allocation, constraints) -** The delivered cost of bioenergy relates to the feedstocks, each of which has varying calorific content, cost and volumetric constraint. This constraint is limited by competing uses for that feedstock, the costs associated with collecting and transporting that feedstock to a bioenergy facility and the total production of that feedstock on a national level.
- **Plant-specific assumptions (capacity, lifespan, operating hours, production rate and efficiency) -** Each type of bioenergy production facility has its own set of assumptions that affect the delivered cost of bioenergy. Whilst most of these remain constant regardless of the scenario, they have implications on the total amount of bioenergy each type of facility can produce, and hence the associated CAPEX required. These assumptions align with Levelised Cost of Energy (LCOE) estimates for specific bioenergy technologies.

- **Other (technology-specific discount rates) -** Other production-specific assumptions include discount rates that are specific to each technology type. These assumptions are agnostic to the scenarios. Discount rates are variable based on how mature the technology is. Discount rates affect the cost of delivered bioenergy by changing the rate that future costs and production are discounted to the year a facility was built.

Importantly, the delivered cost of bioenergy calculated in the Bioenergy Model aligns with that in the literature. The forecast delivered cost for each production pathway varies over time as the technology matures and economies of scale drive improved economics. Table 3 shows the BAU scenario modelled costs for the seven markets that were selected for detailed modelling. The table also includes the forecast costs for the equivalent incumbent fuels to indicate when bioenergy could become cost-competitive under this scenario.

Table 3 – Prices in 2020 and 2050 reductions under the BAU scenario versus incumbent costs. Prices exclude fuel excises or tax credits.

Market	Pathway	2020 LCOE ($/GJ)	2050 LCOE ($/GJ)	LCOE % change through to 2050	Incumbent costs in 2020/2050 ($/GJ)
Aviation	Sustainable Aviation Fuel	$59	$30	- 49%	$23/$35
Grid Electricity	Power Generation from Biogas	$43	$28	- 33%	$17/$28
	Power Generation from Solid Biomass	$39	$34	-14%	
	WtE – Waste Incineration	$30	$21	-31%	
Industrial Heat	Industrial Heat Generation from Biogas	$15	$12	- 24%	$9/$12
	Industrial Heat Generation from Solid Biomass	$6	$6	-9%	
Off-Grid Electricity	Power Generation from Biogas	$43	$28	- 33%	$38/$50
	Power Generation from Solid Biomass	$39	$34	-14%	
Pipeline Gas	Biomethane from Anaerobic Digestion	$25	$17	- 30%	$9/$12
	Biomethane from Landfill Gas	$12	$9	-23%	
Road Transportation (Diesel)	Renewable Diesel	$30	$27	-10%	$27/$38
Road Transportation (Petrol)	1G Bioethanol – Sugarcane	$24	$22	-9%	$29/$39
	2G Bioethanol – Cellulosic Bioethanol	$38	$24	-37%	

For markets where there is only one modelled production pathway, the delivered cost is used to compare against the cost of the incumbent fuel. For other markets where there are multiple production pathways modelled, such as Road Transport, the Model first drives competition between these respective production pathways to establish the ratio of methods and the consequent weighted average bioenergy delivered cost.

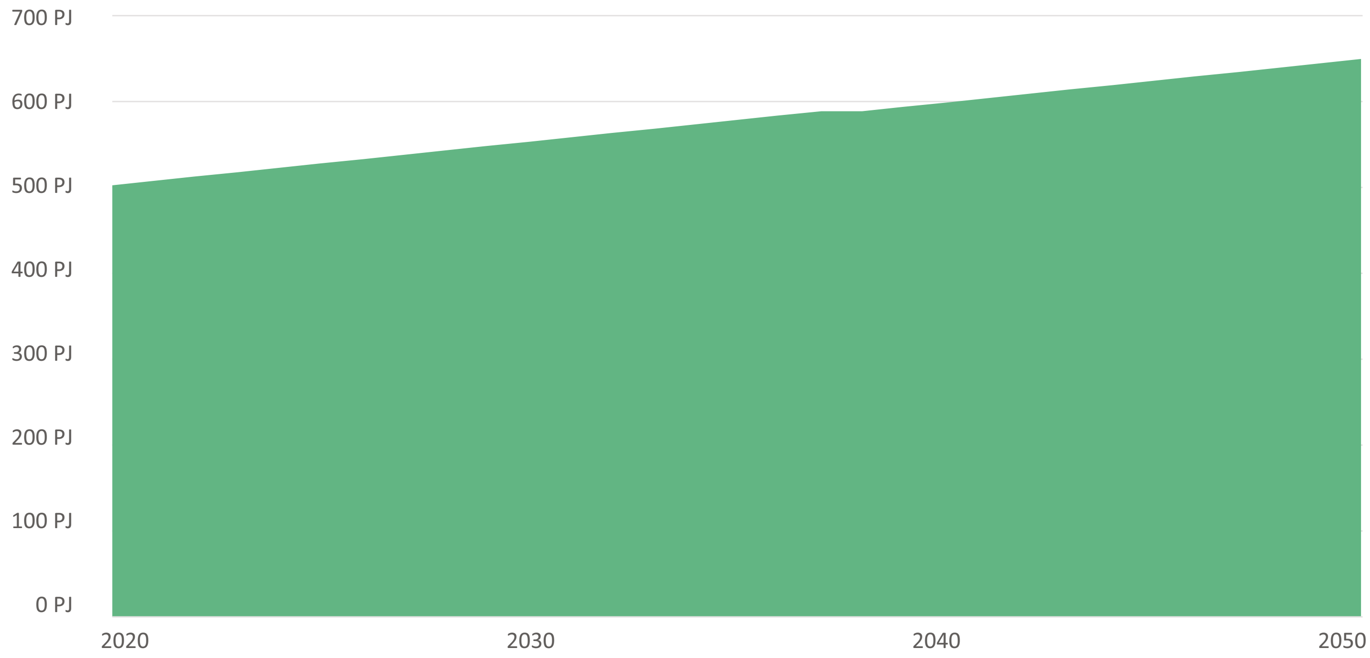
Demand component

The output of the cost component of the Bioenergy Model – the delivered cost of bioenergy – is a core input for the demand component of the Bioenergy Model. The demand component seeks to determine the proportion of the market that bioenergy could capture, given its delivered cost and various policy levers that may encourage or discourage higher uptake of bioenergy in the market.

Modelling for demand includes five key stages:

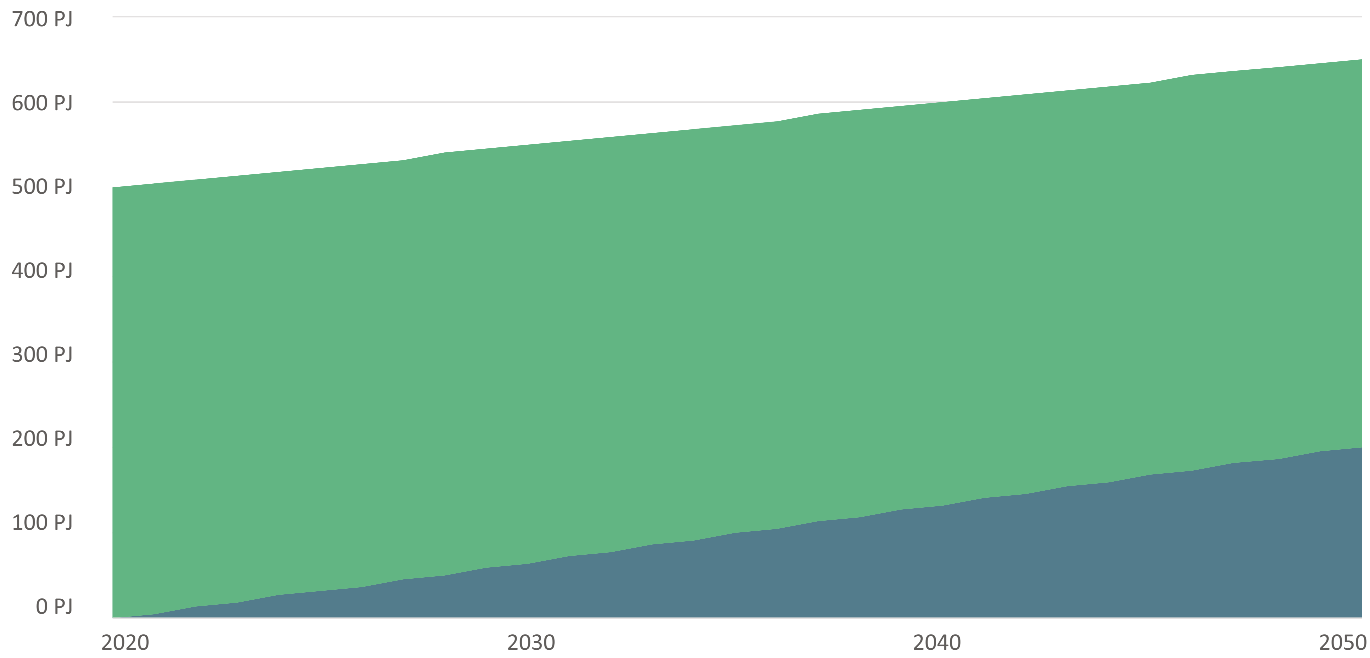
- **Stage 1 – Forecast the size of the total downstream market**
- **Stage 2 – Determine the competing space for bioenergy by excluding the portion of the downstream market estimated to be captured by alternative decarbonisation solutions**
- **Stage 3 – Determine demand for bioenergy driven by policy**
- **Stage 4 – Play out price competition between bioenergy and incumbent fuel, which determines market uptake of bioenergy**
- **Stage 5 – Adjust growth due to feedstock constraints.**

Stage 1 – The total energy demand for each downstream market and the incumbent fuel



In the first stage, the size of the total downstream market is estimated using public sources. The total energy demand of the total downstream market includes the demand met by all different production methods, including the incumbent fuel, bioenergy (both policy and price driven) and alternative decarbonisation solutions – such as electrification or hydrogen. In the above figure, this is indicated by the green area.

Stage 2 – The alternative decarbonisation pathway wedge



In the second stage, an estimation of the downstream market captured by alternative decarbonisation solutions is made using public sources.

The approach within the Bioenergy Model carves out that portion of the downstream market against which bioenergy cannot compete, coloured blue in the above figure. As an illustrative example, for pipeline gas, that means the portion of the market that will be electrified is carved out, leaving the portion of the market where the price dynamics of hydrogen, bioenergy and natural gas play out against each other.

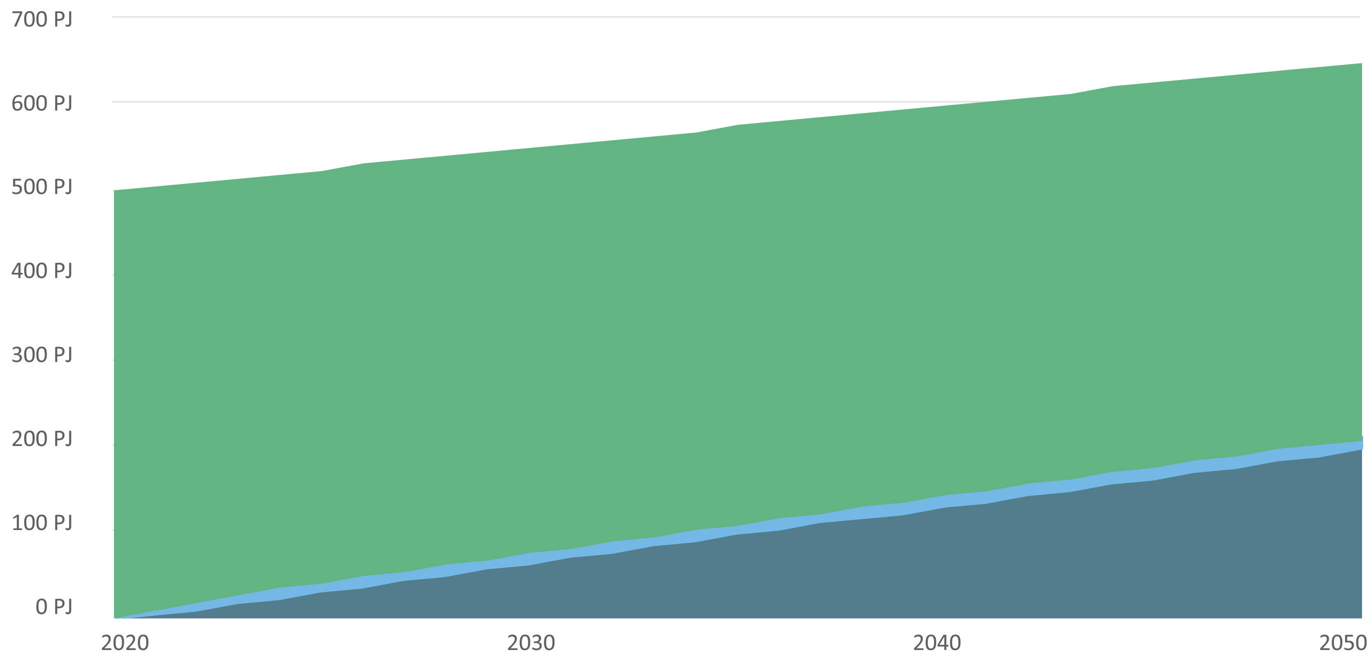
The remaining area, still indicated by the dark green area in the above figure, represents the competing space that bioenergy could potentially capture subject to economic and/or policy drivers within each specific downstream market.

The following table shows the assumed alternative decarbonisation pathways that are modelled for each of the downstream markets.

Table 4 – Assumed alternative decarbonisation pathways for downstream markets

Downstream market	Assumed alternative decarbonisation pathways
Pipeline gas	Electrification of applications
Industrial heat	Electrification of applications, hydrogen
Road transport (Petrol)	Electric vehicles and hydrogen fuel cell vehicles
Road transport (Diesel)	Electric vehicles and hydrogen fuel cell vehicles
Aviation	Electric aviation
Off-grid electricity	Firmed solar PV and wind generation
Grid electricity	Solar PV and wind generation

Stage 3 – The policy-driven bioenergy wedge

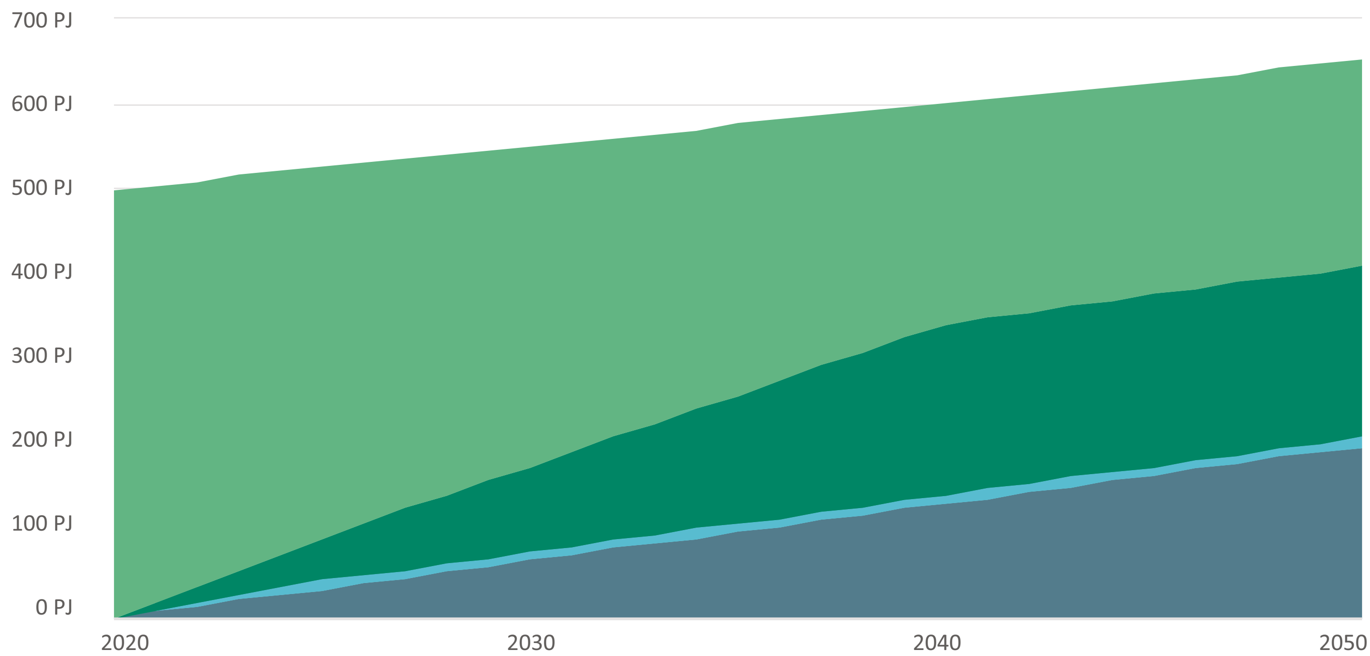


In the third stage, bioenergy that is driven through policy levers, such as government mandates, are included. Policy levers are shown in the light blue segment of the above figure. Policy drivers are incorporated into the Bioenergy Model as general policy support that encourage greater market uptake rather than defining specific legislative measures.

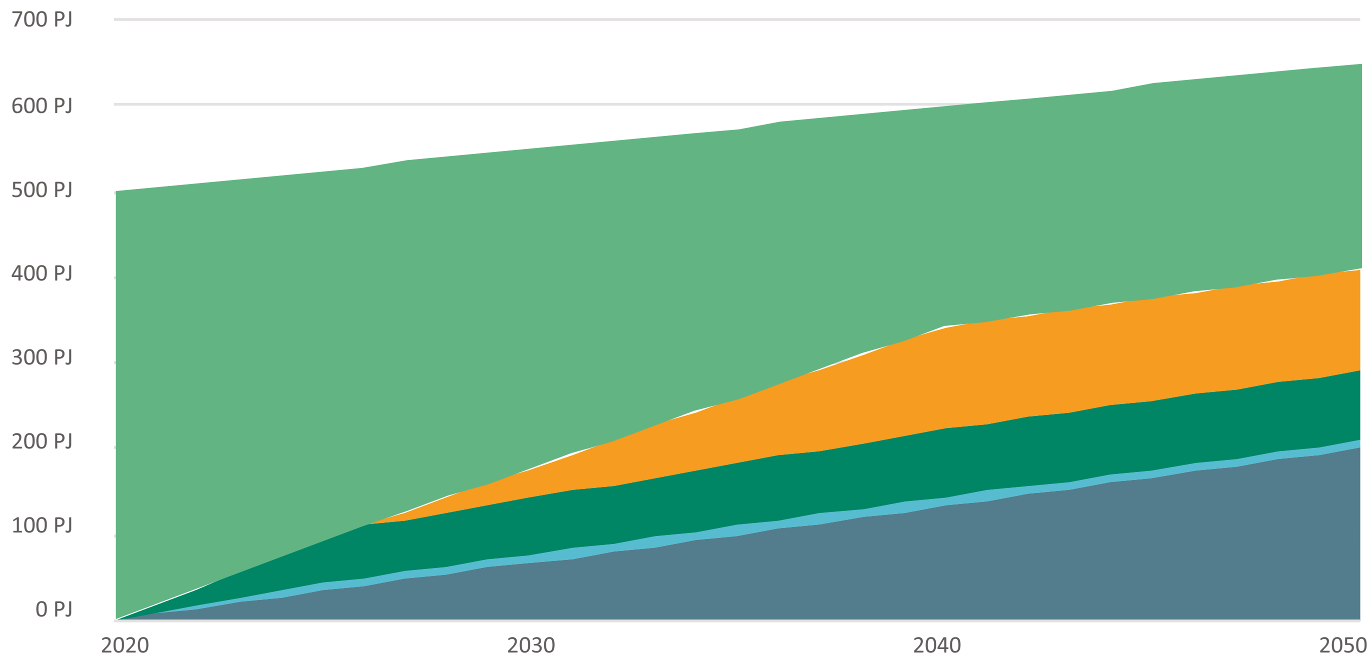
Policy-driven bioenergy is largely immune to the cost-competitiveness of bioenergy, as policy mandates override the competitive dynamics that would normally operate in a competitive marketplace.

Policy drivers are dependent on scenarios where under the Broad Use and Targeted Deployment scenarios, relatively high bioenergy mandates for various downstream markets, such as mandating bioenergy for a certain percentage of vehicle fuel sales, would increase uptake in bioenergy regardless of its price. Policy drivers are largely non-existent for any downstream market in the BAU and Industry Stagnation scenarios.

Stage 4 – The price-driven bioenergy wedge



Stage 5 – Feedstock constraint



Feedstock availability and accessibility is a key constraint to the growth of the bioenergy industry in Australia. Although the potential resource available for bioenergy may be immense, the feasibility of securing those resources may be limited by technical, sustainability or economic constraints. For example, there are costs associated with the collection of resources and transportation to bioenergy facilities which may be cost prohibitive given the distributed nature of the resource.

The Bioenergy Model recognises this in Stage 4 of the demand component by constraining the growth of each production pathway according to the modelled availability of applicable feedstocks. The feedstock constraint is represented by the orange segment in the figure above.

The theoretical maximum availabilities of feedstocks and proportions are varied across the scenarios. In the Broad Use and Targeted Deployment scenarios, it is assumed that the development of a large-scale bioenergy industry would improve commercial markets for feedstocks, leading to growth in feedstock availability.

In contrast, under the Business As Usual and Industry Stagnation scenarios, growth in feedstock availability is limited to historic trends.

There is limited existing literature that investigates the forecast economics and sustainability of bioenergy feedstocks in Australia. Estimating the impact of potential feedstock limitations is identified as an area for future investigation.

Scenarios

Although significant, Australia's bioenergy potential varies across the different markets. In particular, this potential is anticipated to be highest in hard-to-abate sectors. Four scenarios have been developed to test a range of possible futures, ranging from least to most optimistic about bioenergy uptake.

Industry Stagnation represents a loss of government and community support while Business As Usual represents a continuation of current levels of support.

Broad Use comprises increased government and community support coupled with strong technology cost reductions, and Targeted Deployment consists of concerted effort by industry and government on end-use markets that are hard to abate.

Each scenario has a different combination of settings for the key model levers as shown in Table 2.

Figure 1 – The four different modelled scenarios

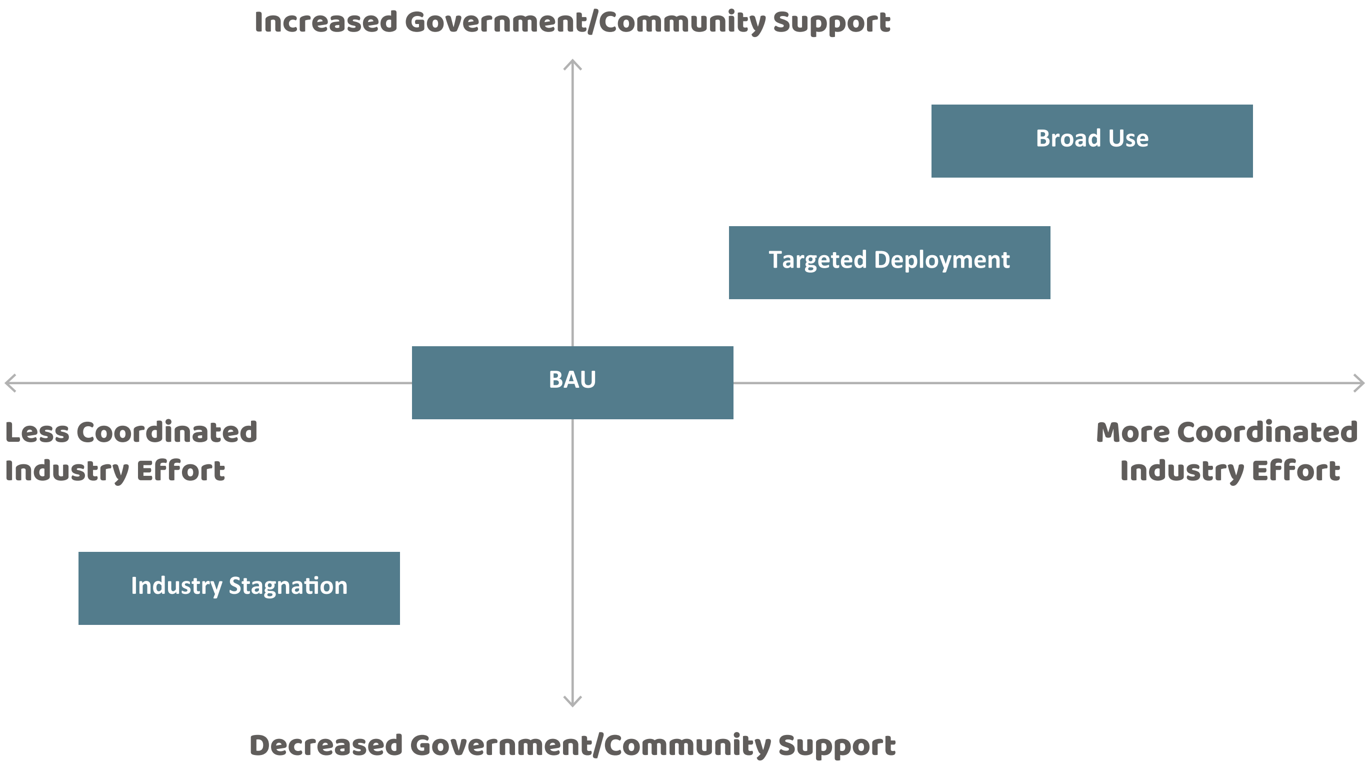


Table 2 – Comparison of levers across the different scenarios in the Bioenergy Model

Comparison of levers used in the modelling of the scenarios

Scenario	Improvement in learning rate	Cost of competing fuels	Cost of feedstock inputs	Demand driven by Gov't policy	Feedstock available to bioenergy
Targeted deployment	↑↑ (better)	↑ (better)	↓ (better)	↑↑ (better) Pipeline gas and aviation ↑ (better) Road transport petrol and diesel — (current) All other markets	↑↑ (better) Pipeline gas and aviation ↑ (better) Industrial heat — (current) All other markets
Broad use	↑↑ (better)	↑ (better)	↓ (better)	↑ (better)	↑ (better)
Business As Asual	— (current)	— (current)	— (current)	— (current)	— (current)
Industry stagnation	↓↓ (worse)	↓ (worse)	↑ (worse)	↓ (worse)	↓ (worse)

Current "Business As Usual" levels   Better than current "Business As Usual" levels   Worse than current "Business As Usual" levels

Economic modelling methodology

A shock to the economy in the form of a policy or program will have impacts that reverberate around the economy. These effects are often defined as 'second-round impacts' where agents (households, firms and the government) respond to changes in prices that result from the shock. Ultimately these responses cause crowding out or spill over into other regions and sectors as the economy adjusts to a new policy path. Estimating these impacts through economic-impact analysis is critical to understating how a project or policy might affect the broader economy.

Computable General Equilibrium (CGE) models are the best-practice method available for examining the impacts of a change in one part of the economy on the broader economy. Estimation of the economic impact of growth in Australian bioenergy output is estimated using Deloitte's in-house CGE model, DAE-RGEM (Deloitte Access Economics, Regional General Equilibrium Model). This section outlines the modelling approach and assumptions, including DAE-RGEM.

CGE modelling estimates how a policy or program would impact specific parts of a regional economy. It differs to other tools of economic analysis such as Cost Benefit Analysis (CBA) or Input Output modelling (IO). CBA for example estimates the 'net benefit' of a project or policy to society, by valuing as many of the associated costs and benefits of a proposal as feasible. IO modelling quantifies the economic contribution of a policy or program at a specific point in time.

CGE modelling compares a baseline scenario against specified policy scenarios. The policy scenarios used here are described in the previous section, while the baseline scenario is unique to the economic impact modelling presented here. The baseline assumes that there is no further development in the bioenergy sector amidst broader growth — that is consistent with long-term average historical rates — in the global and Australian economies. This baseline is different to the Business As Usual scenario that assumes the continuation of existing levels of bioenergy development across all pathways.

Each of the policy scenarios, including Business As Usual, is additional to the baseline and introduced to the model as shocks based on the demand modelling. The shock data includes Capital Expenditure (CAPEX), that is assumed to be supplied by investors external to the region, and Operational Expenditure (OPEX), including estimated feedstock purchases as well as other operational activities required to generate energy. As such, this modelling approach focusses on the economic impacts of specific development pathways in the bioenergy sector, rather than any underlying government policy framework.

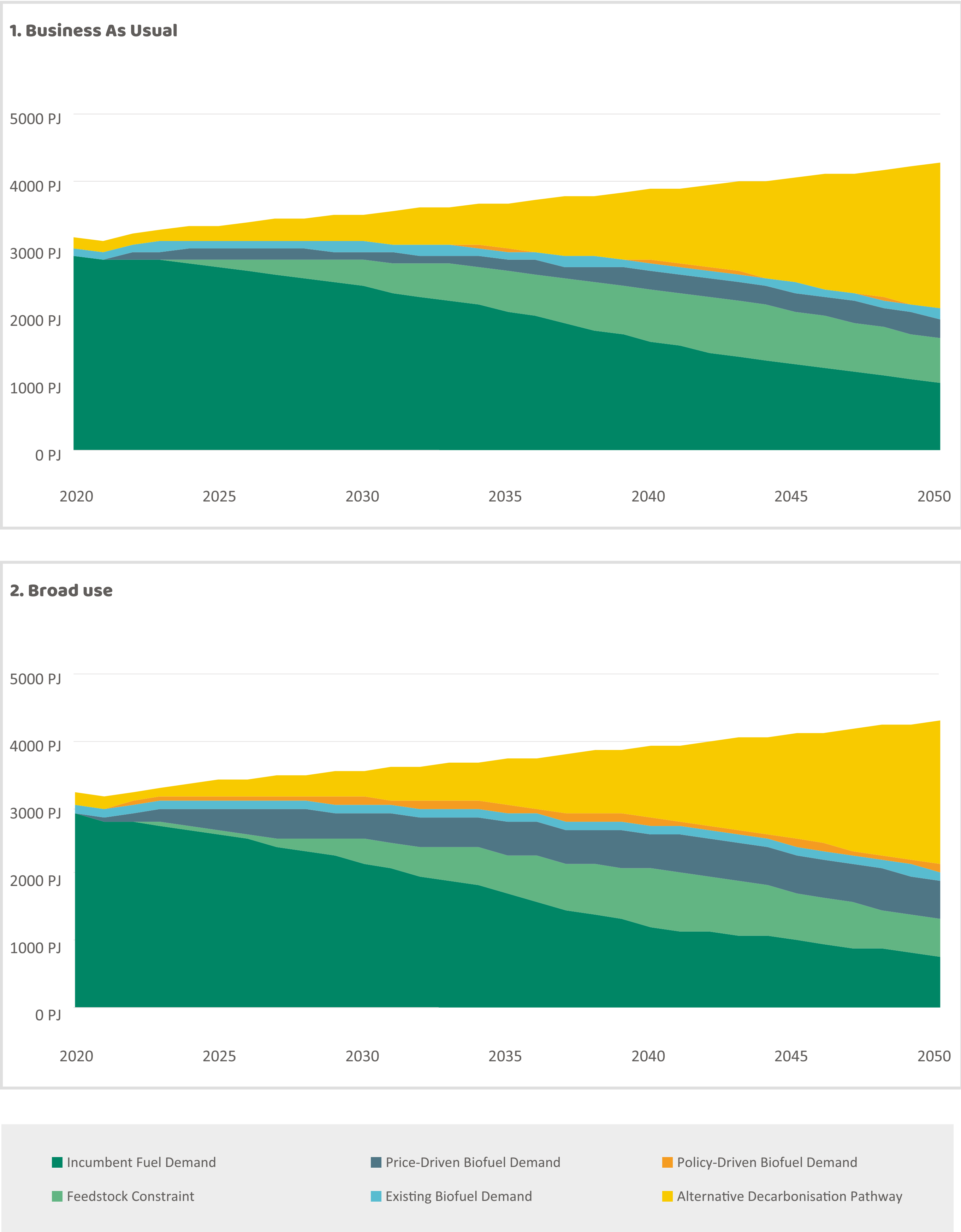
4. Demand modelling results

In this section the outcomes from the Bioenergy Model are detailed. The overall demand is first presented and then broken down by end-use market.

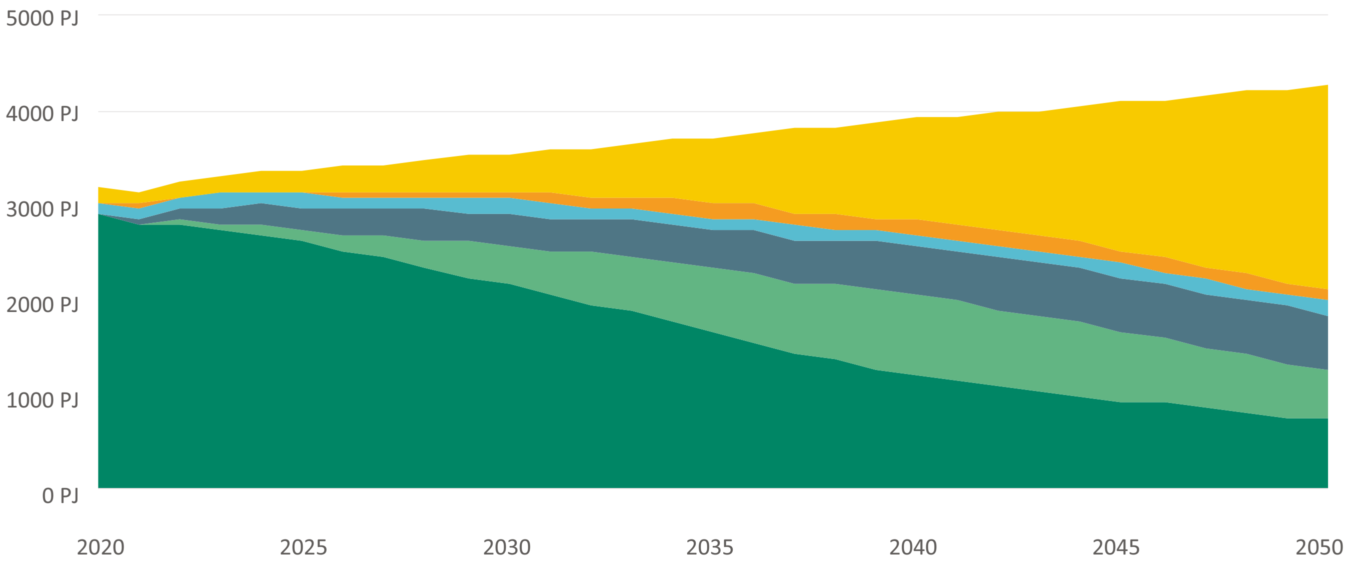
Overall demand

The total energy demand across the seven markets in the Bioenergy Model is shown in Figure 3, broken down by incumbent fuel, bioenergy and alternative low emissions technologies. The percentage breakdown is provided in Table 5.

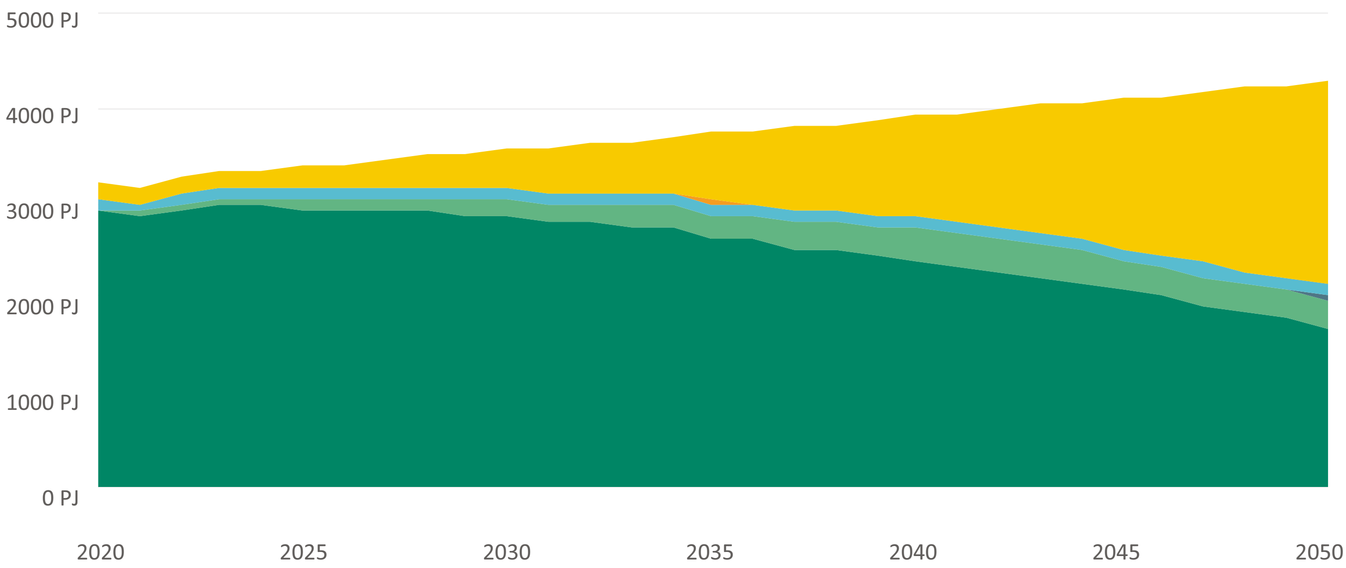
Figure 3 – Overall demand by scenario



3. Targeted deployment



4. Industry stagnation



Incumbent Fuel Demand
Price-Driven Biofuel Demand
Policy-Driven Biofuel Demand
Feedstock Constraint
Existing Biofuel Demand
Alternative Decarbonisation Pathway

Table 5 – Market share of different alternatives by scenario in 2050

	Scenarios			
	Business As Usual	Broad use	Targeted deployment	Industry stagnation
ALTERNATIVE LOW EMISSIONS PATHWAY	51%	51%	51%	51%
Existing Bioenergy Demand	3%	3%	3%	3%
Policy-Driven Bioenergy Demand	0%	1%	3%	0%
Price-Driven Bioenergy Demand	7%	15%	14%	0%
TOTAL BIOENERGY DEMAND	10%	19%	20%	3%
Feedstock Constraint	16%	13%	12%	7%
Incumbent Fuel Demand	23%	18%	17%	39%
TOTAL INCUMBENT FUEL DEMAND	39%	31%	29%	46%

Under all scenarios, growth of the bioenergy industry is constrained by feedstocks.

Bioenergy market share could increase by an additional 7 to 16 per cent in 2050 across the different scenarios if it were not for feedstock constraints. For this Roadmap, this highlights that there needs to be concerted effort by industry and government in understanding and directing sustainable feedstock use.

Bioenergy could meet 10 per cent of the total energy demand in 2050 under Business As Usual settings. This is an increase compared to today's 3 per cent. This share could double under Broad Use and Targeted Deployment scenarios.

For this Roadmap, this highlights what additional growth might be achieved under certain industry and government settings. In particular, realising the growth of the Business As Usual scenario relies on alleviating non-economic barriers that currently hinder further bioenergy uptake.

In the Broad Use scenario, bioenergy uptake grows quickly in the first 10 years relative to Targeted Deployment as the implementation of broad-based policy intervention, such as an increased focus on lowering emissions, catalyses low emissions industries, including bioenergy. It should be noted, however, that the bioenergy outcomes are less certain when being stimulated by broad-based policy initiatives when compared to more specific, targeted initiatives as represented by the Targeted Deployment scenario.

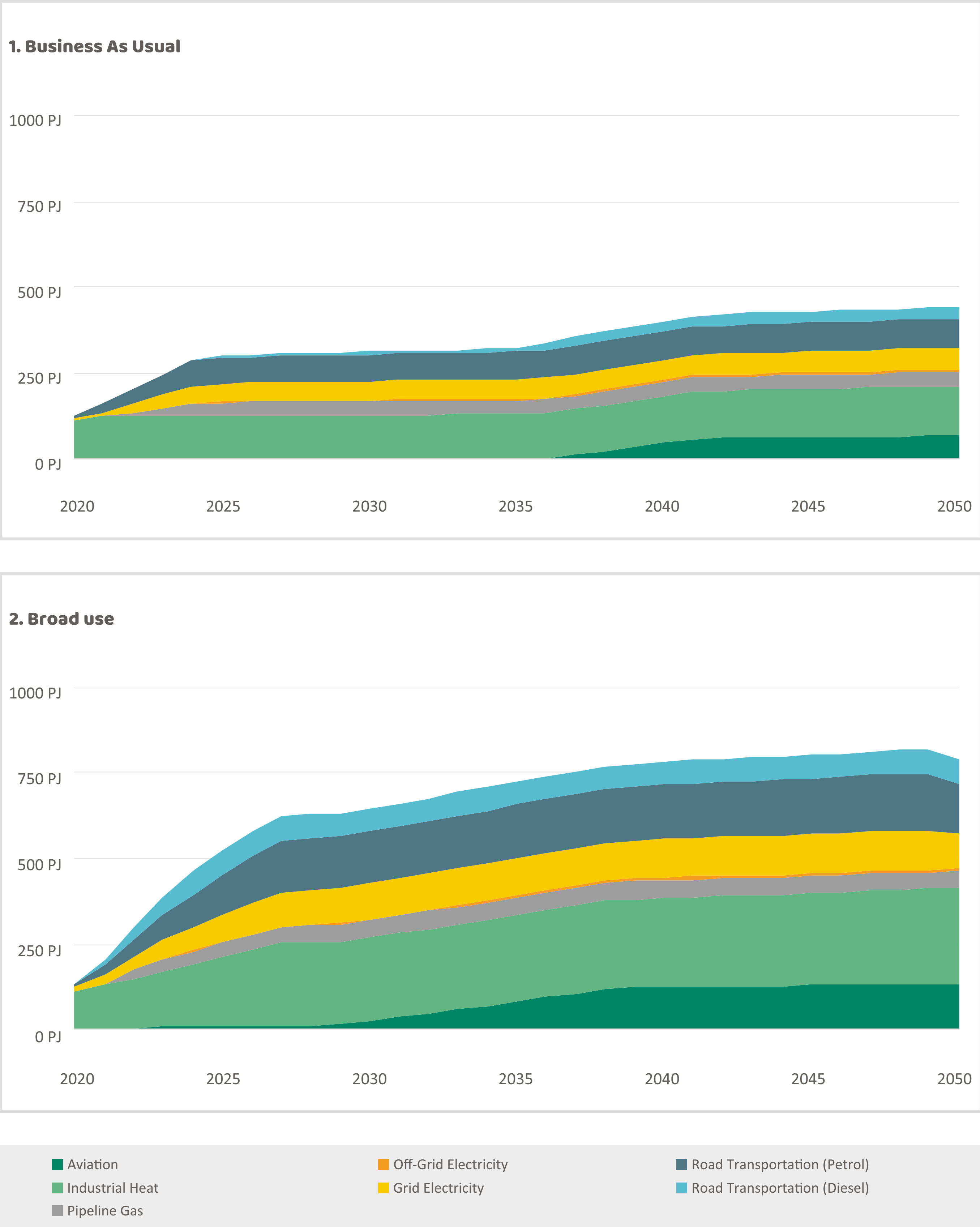
Under the Industry Stagnation scenario, bioenergy captures just 3 per cent of the total energy demand in 2050, i.e. the same share as today. For this Roadmap, this highlights the impact of retracted government and community support for the bioenergy industry.

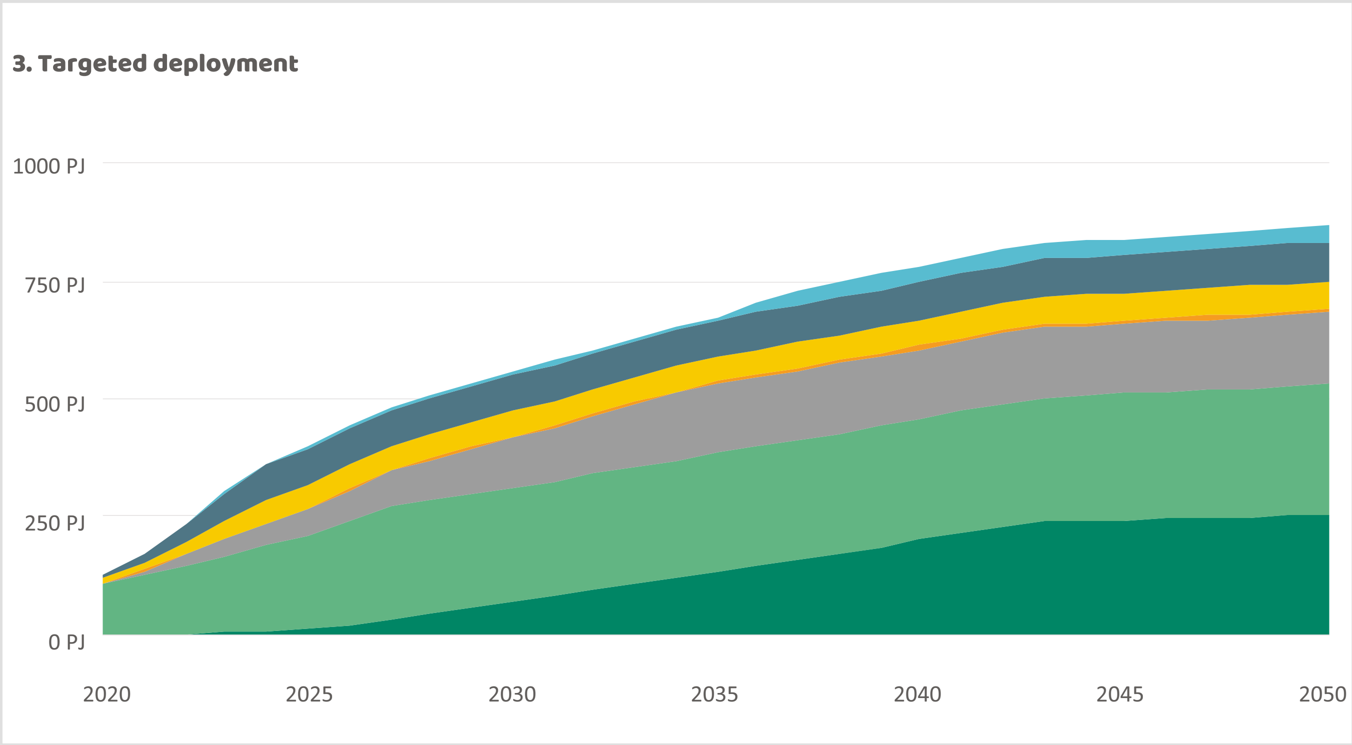
The highest market share in 2050 for bioenergy is achieved under the Targeted Deployment scenario, achieving 20 per cent compared to 19 per cent under the Broad Use scenario.

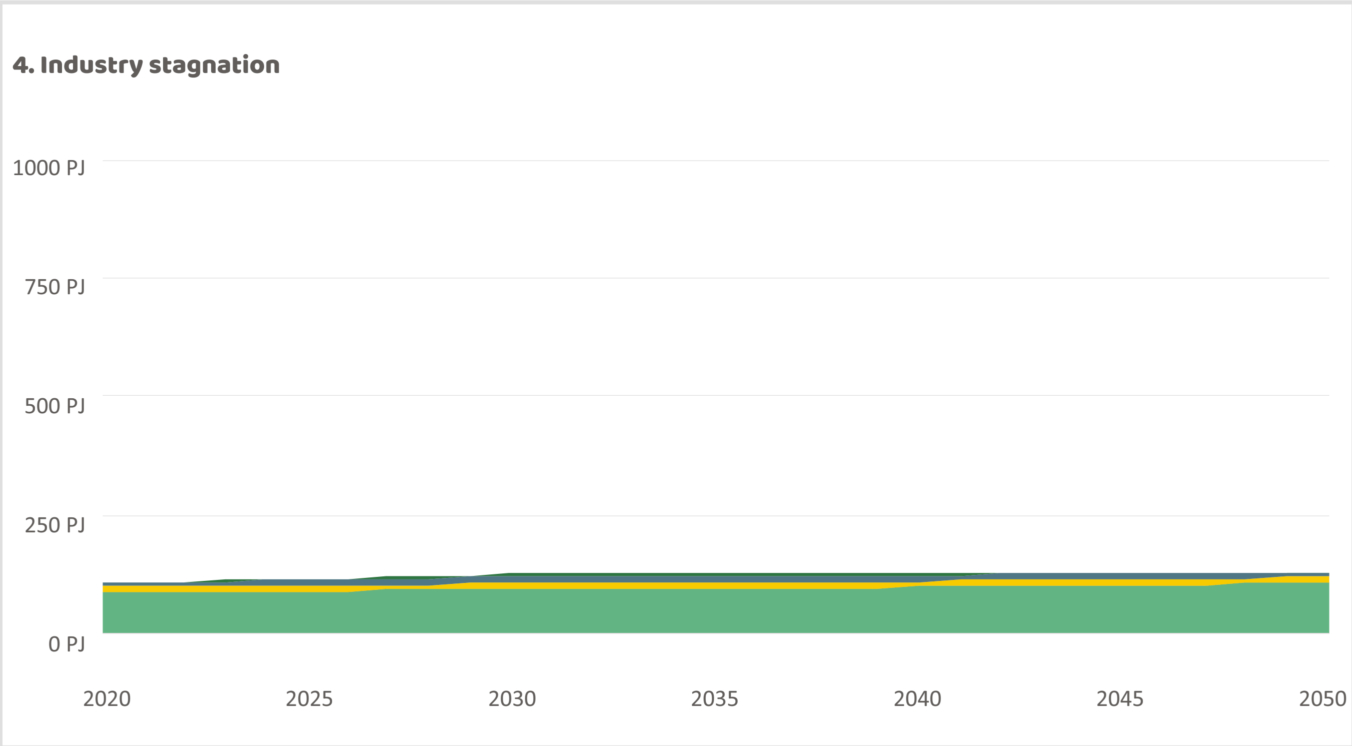
For this Roadmap, this highlights that there may be benefits in focused effort by government and industry on those sectors which are hard-to-abate and have limited low emissions alternatives, namely aviation and pipeline gas.

Bioenergy demand by end-use market

Figure 4 – Bioenergy demand by end-use market







Aviation
Industrial Heat
Pipeline Gas
Off-Grid Electricity
Grid Electricity
Road Transportation (Petrol)
Road Transportation (Diesel)

Table 6 – Total size of the bioenergy industry and breakdown by market in 2050

	Scenario			
	Business As Usual	**Broad use**	**Targeted deployment**	**Industry stagnation**
Total Bioenergy Demand	**444 PJ**	**784 PJ**	**871 PJ**	**132 PJ**
Aviation	15%	17%	29%	-
Grid Electricity	15%	13%	7%	10%
Industrial Heat	33%	36%	32%	82%
Off-Grid Electricity	1%	1%	1%	-
Pipeline Gas	9%	6%	17%	-
Road Transportation (Diesel)	8%	9%	4%	2%
Road Transportation (Petrol)	19%	19%	10%	6%

A broad effort by industry and government can, when compared to Business as Usual, roughly double bioenergy's role in 2050 for the markets of aviation, industrial heat, grid electricity and road transportation.

By 2050, Broad Use sees an increase in bioenergy demand:

- In the aviation market, from 66 (BAU) to 132 PJ (Broad Use)
- In the industrial heat market, from 145 (BAU) to 279 PJ (Broad Use)
- In the grid electricity market, from 65 (BAU) to 104PJ (Broad Use)
- In the road transportation (petrol) market, from 86 (BAU) to 146PJ (Broad Use)
- In the road transportation (diesel) market, from 34 (BAU) to 68PJ (Broad Use)

A focused effort by industry and government on the aviation and pipeline gas markets can drive significant gains.

By 2050, Targeted Deployment sees an increase in bioenergy demand:

- In the aviation market, from 66 (BAU) to 132 (Broad Use) and 255PJ (Targeted Deployment)
- In the pipeline gas market, from 42 (BAU) to 48 (Broad Use) to 151PJ (Targeted Deployment)

Across all scenarios, bioenergy for industrial heat grows immediately and becomes the largest market by petajoules.

It achieves 108PJ in 2020 under BAU, Broad Use and Targeted Deployment scenarios and only a little less under Industry Stagnation, at 91PJ. For all scenarios, bioenergy for industrial heat is the largest market by petajoules in 2050, achieving 145PJ under BAU, 279PJ under Broad Use and Target Deployment, and 109PJ under Industry Stagnation.

Whilst a broad effort by industry and government (as seen in Broad Use) achieves the fastest growth rate for bioenergy over the next decade, it is a focused effort (as seen in Targeted Deployment) that achieves the largest market share for bioenergy in 2050.

In 2030, bioenergy contributes more under Broad Use (745PJ) than under Targeted Deployment (559PJ). By 2050, this has reversed with bioenergy contributing more under Targeted Deployment (871PJ) than under Broad Use (784PJ). In a way, Broad Use could be seen to be playing the short game while Targeted Deployment plays the long game.

Figure 5 – Bioenergy demand by market in 2020, 2030, 2040 and 2050

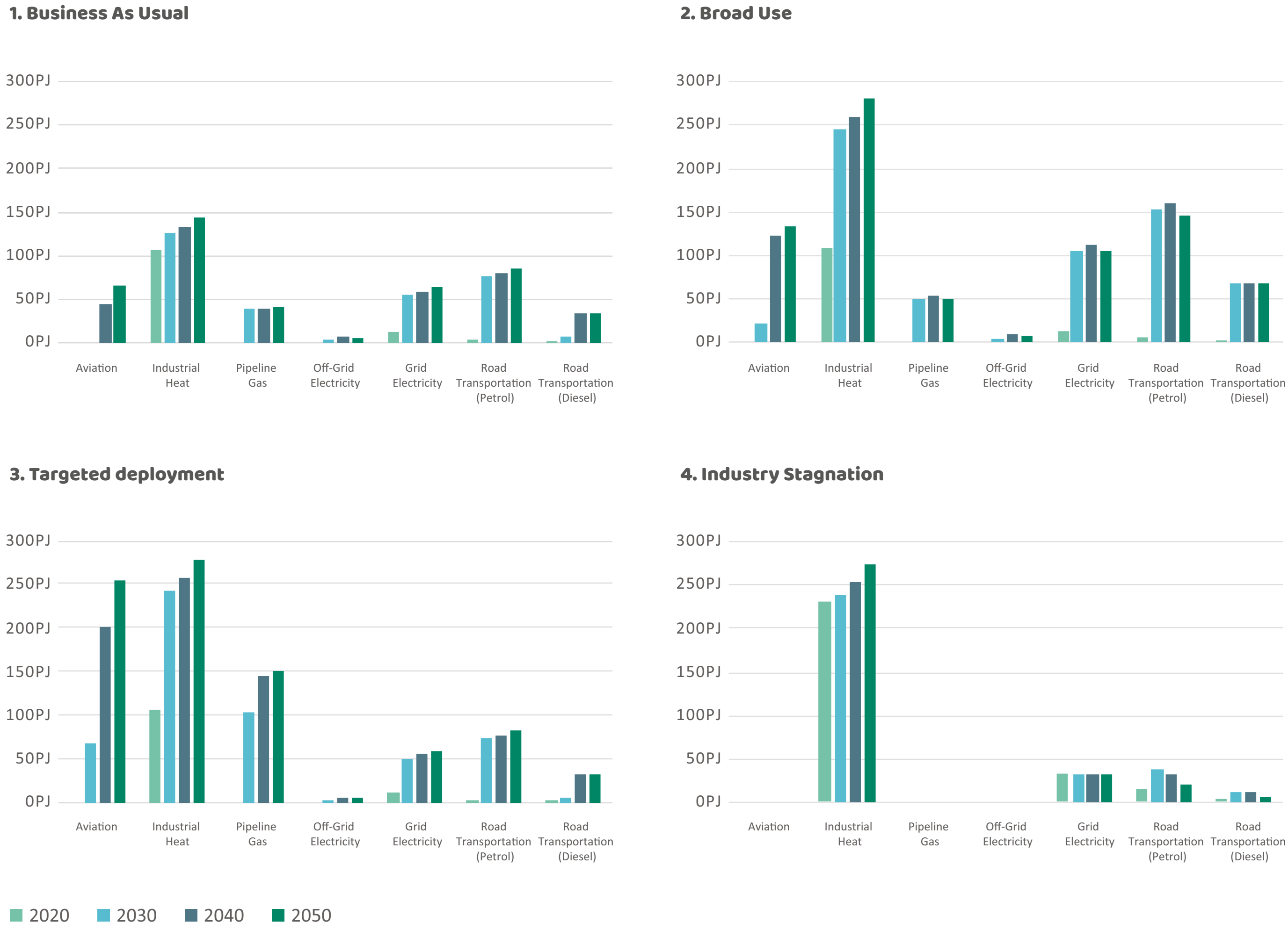


Table 7 presents specific insights into individual markets for bioenergy in Australia from the four scenarios.

Table 7 – Insights from the bioenergy model by market

Market	Summary
Industrial heat generation	**Bioenergy for industrial heat is cost-competitive today and may be able to take a significant market share.** In 2050, bioenergy's share of the industrial heat market is 17 per cent under BAU (145PJ), 33 per cent under Broad Use (279PJ), 33 per cent under Targeted Deployment (279PJ) and 13 per cent under Industry Stagnation (109PJ). Achieving the level of growth in reality will require: • increased access to sustainable feedstocks • increased awareness of bioenergy solutions amongst relevant industrial stakeholders (particularly waste-generating industries such as food and wood processing)
Grid and off-grid electricity	There is a need for firming technologies and bioenergy can play a role through cost-competitive provision of reliable and dispatchable electricity. In 2050, bioenergy's share of the grid electricity market is 9 per cent under BAU (65PJ), 15 per cent under Broad Use (104PJ), 9 per cent under Targeted Deployment (61PJ) and 2 per cent under Industry Stagnation (13PJ). In 2050, bioenergy's share of the off-grid electricity (diesel) market is 11 per cent under BAU (6PJ), 13 per cent under Broad Use (7PJ), 11 per cent under Targeted Deployment (6PJ) and 0 per cent under Industry Stagnation (0PJ). Whilst this is not one of the primary growth markets highlighted through the analysis in this Roadmap, further growth could be enabled by ensuring that bioenergy receives similar attention as other dispatchable solutions in schemes, encouraging them the provision of such solutions. Furthermore, as firming characteristics of renewables become more valued in the transition to a lower emissions intensity grid, there may be additional value streams that may be recognised and monetised.
Road transportation	**Biofuels contribute to emissions reduction in the road transportation markets in the short term. In the longer term, electrification will be the major contributor to emissions reduction in these markets, taking 5 per cent of the total market in 2030 and 75 per cent by 2050.** In 2050, bioenergy's share of the road transportation (diesel) market is 5 per cent under BAU (34PJ), 9 per cent under Broad Use (68PJ), 5 per cent under Targeted Deployment (34PJ) and 0.3 per cent under Industry Stagnation (2PJ). In 2050, bioenergy's share of the road transportation (petrol) market is 10 per cent under BAU (86PJ), 17 per cent under Broad Use (146PJ), 10 per cent under Targeted Deployment (84PJ) and 1 per cent under Industry Stagnation (8PJ). The potential for biofuels to contribute to the medium-term emissions reduction in transport will be enhanced through improving community education on the safe use of biofuels, addressing any inconsistencies across fuel types in financial incentives and, over time, as the vehicle emissions standards improve.
Aviation	**Biojet fuel is not cost-competitive today and its future market share is highly dependent on the level and timing of government and industry effort.** In 2050, bioenergy's share of the aviation market is 12 per cent under BAU (66PJ), 23 per cent under Broad Use (132PJ), 45 per cent under Targeted Deployment (255PJ) and 0 per cent under Industry Stagnation (0PJ). Biojet fuel consumption grows to a point at which it is constrained by feedstock availability, reaching that point in 2043 under Targeted Deployment, 2039 under Broad Use and 2042 under BAU. Further growth of biojet fuel consumption will be reliant on developing resource potential and demonstrating technologies able to leverage these resources at scale – i.e. beyond oil-derived fuels.
Gas grid injection	**The Bioenergy Model shows that biomethane from landfill gas is cost-effective to grow bioenergy's share of the pipeline gas market but hits resource constraints in 2023–2025. Biomethane from anaerobic digestion (AD) presents an opportunity to grow bioenergy's market share further but it is not cost-competitive today and therefore requires sustained policy support to bridge the cost gap between biomethane from AD and natural gas.** In 2050, bioenergy's share of the pipeline gas market is 9 per cent under BAU (42PJ), 10 per cent under Broad Use (48PJ), 33 per cent under Targeted Deployment (151PJ) and 0 per cent under Industry Stagnation (0PJ). In all scenarios, biomethane from landfill gas and biomethane from AD are more cost-competitive than forecast hydrogen prices – even at H2 under \$2/kg. This means that biomethane appears to be a low-cost candidate for emissions reduction in the pipeline gas market.

5. Economic modelling results

Impact on Economic Activity

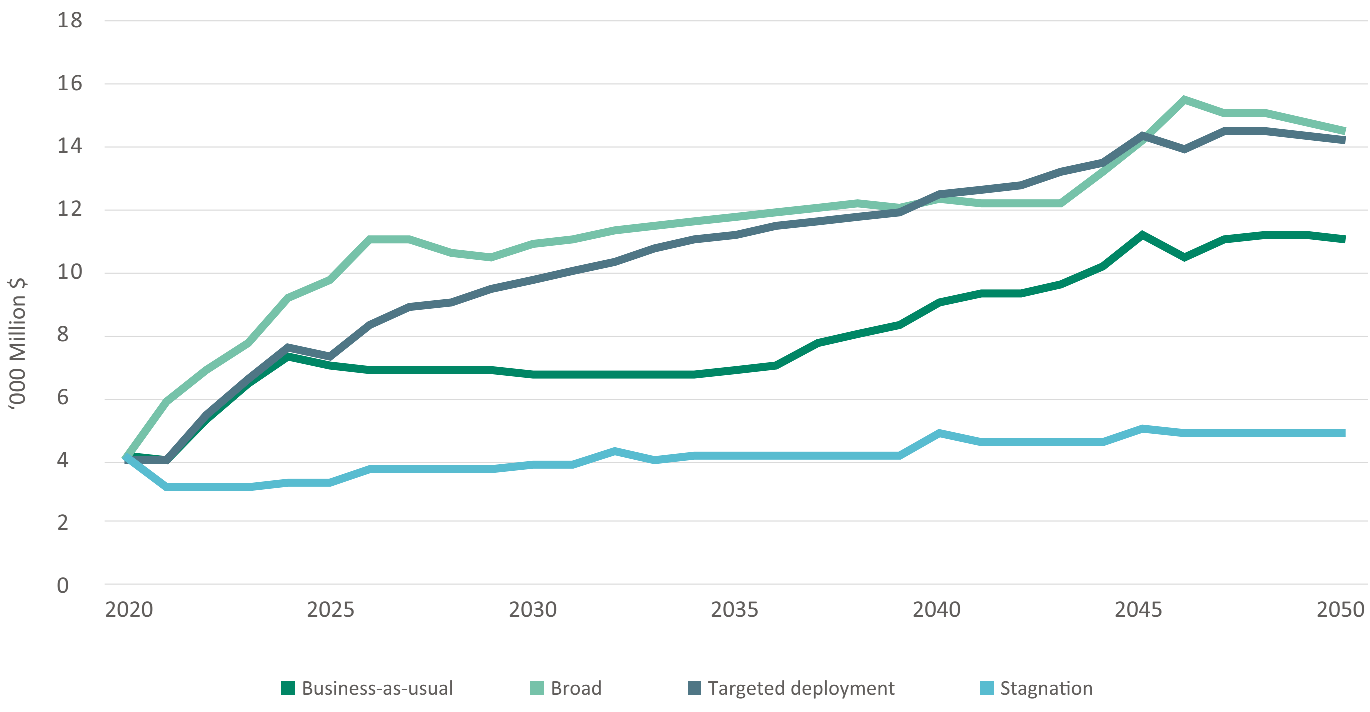
Developing Australia's bioenergy sector is estimated to have a significant impact on the domestic economy over the next 30 years. This growth is driven initially by the significant capital investment required in each of the bioenergy pathways, although expanding production of the bioenergy sector maintains this growth beyond the initial construction phases.

Between 2021 and 2050 the cumulative impact on Australian Gross domestic Product (GDP) is estimated to increase to around **$89 billion**[2] in the Business As Usual (BAU) scenario (compared to the baseline scenario). The **Broad Use** and **Targeted Deployment** scenarios see comparatively larger impacts on the Australian GDP, estimated at **$130 billion** and **$116 billion** respectively, reflecting in part the more advanced expansion of bioenergy sector under these scenarios.

The Industry Stagnation scenario sees the Australian economy grow relative to the baseline ($48 billion), but this impact is significantly reduced compared to other modelled scenarios.

Relative to the baseline, all scenarios see GDP impacts sustained well beyond the initial assumed construction and development phases. The sustained expansion in bioenergy production out to 2050 supports continued economic growth during this period, with capital replacement causing localised short-term peaks. In 2050 the BAU scenario is estimated to add an additional **$11 billion** (undiscounted) to the Australian GDP (above the baseline), considerably more than that added in 2025 ($7 billion). For the Targeted Deployment and Broad Use scenarios, the impact on GDP in 2050 is estimated at $15 billion and $14 billion respectively.

Figure 6 – Deviation in Australian gross domestic product from baseline scenario



Source: Deloitte Access Economics - Regional General Equilibrium Model

[2] Unless otherwise stated all dollar values are in present value terms, discounted at 7 per cent

No quantitative estimate of the proportion of the economic benefits that will be captured by regional economies has been made for this Roadmap. Economic assessments specifically focusing on regional economic development and regional job creation would need to be undertaken to appreaciate the significance of this sector for regional communities.

The direct benefits and jobs though from the bioenergy activity and feedstock using agricultural products are all likely to be in regional areas. Economic direct benefits from MSW, however, are likely to be in metropolitan areas along with many of the wider benefits to the economy. The Technology Investment Roadmap's First Low Emissions Technology Statement indicated over half of the jobs supported from the Technology Investment Roadmap would be in regional communities.

It may be possible that a higher proportion than this could be attributed to the bioenergy sector. However, this cannot be ascertained at this point in time, as this Roadmap's modelling focused on GDP and aggregate national job creation. It did not assess the distribution of jobs created between metropolitan and regional centres, for instance.

Employment Impacts

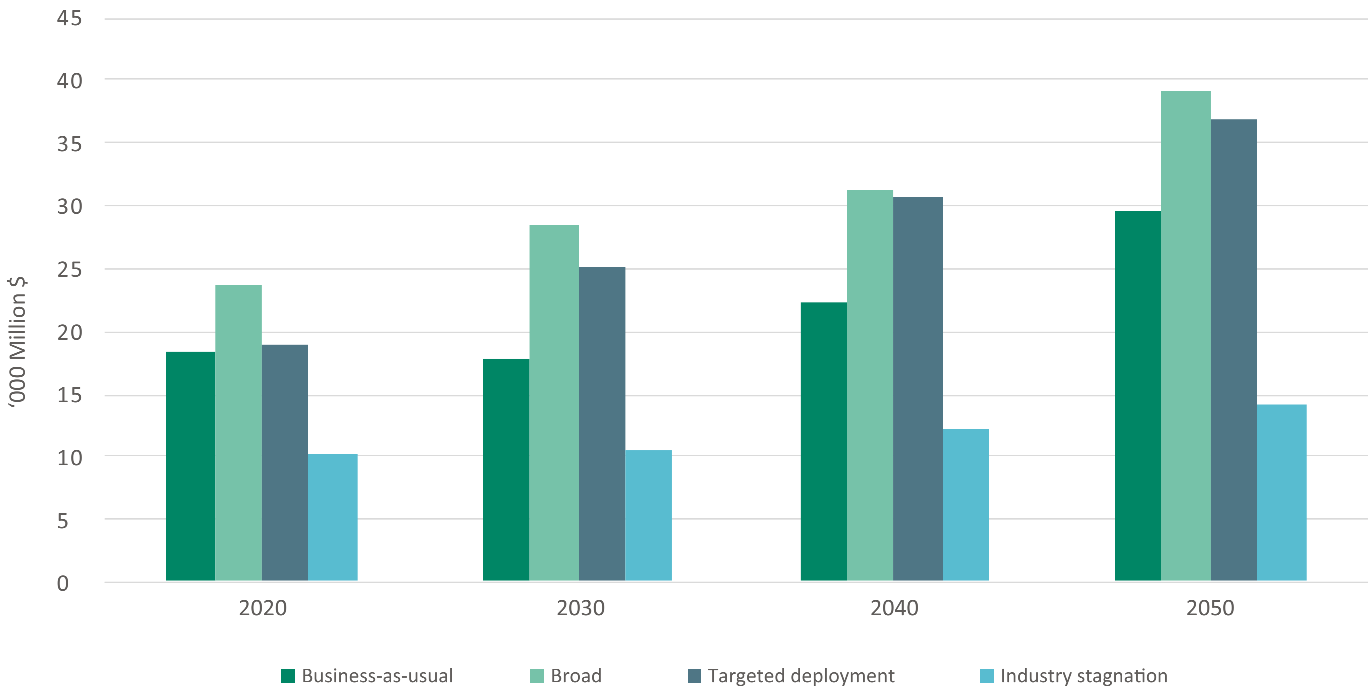
Developing the bioenergy industry is also estimated to have a significant impact on Australian employment. Much of this is anticipated to occur early in the modelling horizon as significant construction activity results from the required capital works. However, employment gains are projected to continue out to 2050 across all scenarios as the sustained expansion in the bioenergy sector leads to employment gains in that sector alongside gains elsewhere in the economy. This includes both regionally located feedstock supplying industries and the services sector.

Under the **BAU** scenario the expansion of the bioenergy sector is estimated to create on average around **22,380** Full Time Equivalent (FTE) jobs in Australia between 2021 and 2050. Estimated employment impacts are relatively higher for **Broad Use (31,300 FTEs on average)** and **Targeted Deployment (29,277 FTEs on average)** scenarios over the same period. For the **Industry Stagnation** scenario, employment impacts are relatively more modest **(around 11,800 FTEs on average)** but represent a significant deviation from the baseline.

As with the GDP, the impact on Australian employment grows out to 2050. In the 5 years to 2050, Australian employment is on average around 30,000 FTEs higher in the BAU scenario than the baseline. This compares with 18,000 FTEs in the 5 years to 2025.

The numbers above are average employment figures over the period and the specific forecasted additional jobs under the BAU scenario are 17,700 in 2030 and 28,100 in 2050. For the Broad Use there are 28,100 jobs in 2030. and 35,300 in 2050, and in the Targeted Deployment, there are 26,200 in 2030 and 35,300 in 2050.

Figure 7 – Impact to Australian employment, 5-year average



Source: Deloitte Access Economics - Regional General Equilibrium Model

Economic Impact on Australian industries

The modelled expansion in the bioenergy sector results in significant structural adjustment for the Australian economy. This occurs across all modelled scenarios, with positive impacts on both upstream and downstream industries.

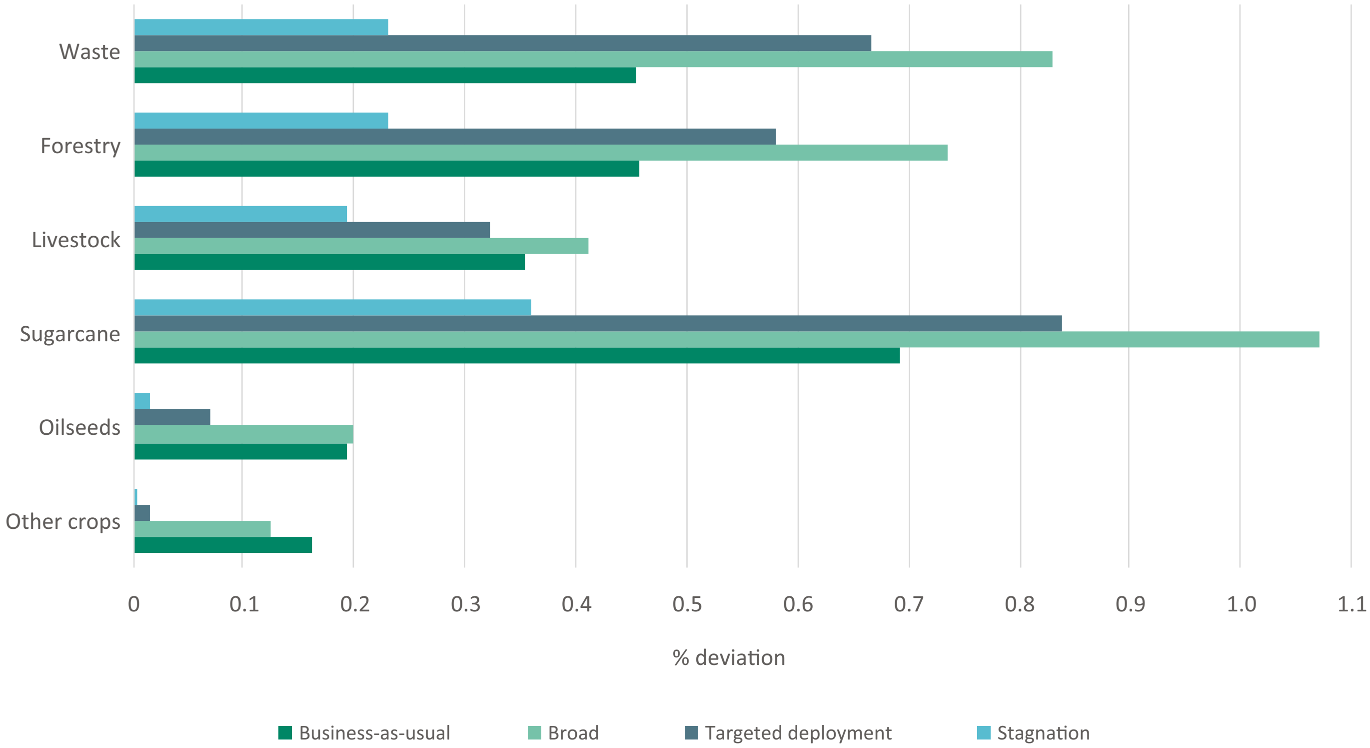
Industries upstream from the bioenergy sector benefit from greater additional demand for feedstock input. In the BAU scenario, the most significantly impacted of these industries is sugarcane, with industry output on average 0.7 per cent higher in the 10 years to 2035. Waste, livestock production and forestry also undergo significant increases (around 0.4 per cent on average), while increases for the oilseeds and other crops industries range between 0.1 per cent and 0.2 per cent.

Importantly, increases in output for upstream industries occur within a broader context of greater competition for productive input. The expansion of the bioenergy sector requires capital and labour to support greater output. As these resources are finite, existing industries face greater competition in attracting the resources they need to expand, which ultimately supports higher prices for capital and labour.

Across each of the scenarios, feedstock industries all expand relative to the baseline scenario. However, there are considerable differences across the individual scenarios as industries respond to the unique circumstances of each. The largest variance in deviation comes from the sugarcane sector, which sees rapid expansion under the Broad Use and Targeted deployment scenarios, while the output changes in these scenarios are relatively more constant for the oilseeds, other crops and livestock industries.

It is also important to note that the majority of the industries that supply bioenergy are principally located in regional parts of Australia. These feedstock industries include much agriculture and forestry, utilising both output and waste products. Stronger demand for output from these industries could potentially be expected to land in regional parts of Australia. Sugarcane, for example, is projected to see a 0.7 per cent increase in output between 2025 and 2035. This would deliver significant economic impacts on specific regions, including for example, Queensland's Mackay, Isaac and Whitsunday regions, which account for around a third of Australian sugarcane production.

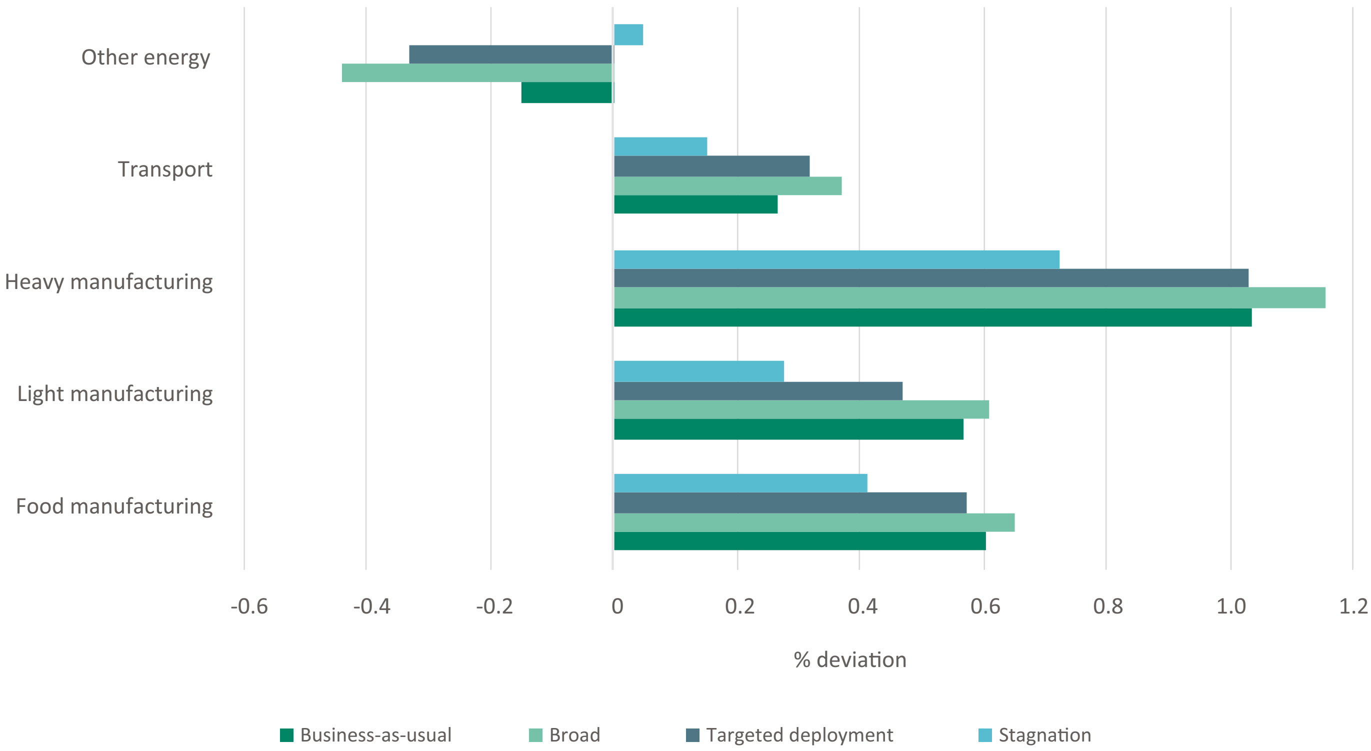
Figure 8 – Percentage change in sectoral output relative to the baseline upstream industries, average 10-year to 2035



Source: Deloitte Access Economics - Regional General Equilibrium Model

Amongst the industries downstream of bioenergy, most sectors see positive economic impacts. This includes most of manufacturing and transport. For these sectors, energy is a significant input to production and increased competition in Australian energy generation is projected to place considerable downward pressure on prices. This ultimately means reduced production costs for these industries, which drives expanded output. The manufacturing sector for example is estimated to be between 0.6 per cent and 1 per cent higher on average in the BAU scenario over the 10 years to 2035, while transport increases by 0.3 per cent.

Figure 9 – Sectoral results of output for other industries, 10-year average over the period 2025–2035



Source: Deloitte Access Economics - Regional General Equilibrium Model

Unlike the feedstock industries, downstream users of energy are located throughout Australia. It is therefore difficult to disaggregate the geographic spread of these impacts. Manufacturing and transport activity are primarily based in metropolitan areas, so it is likely that much of the aggregate impacts that result from the growth in bioenergy output would be located in Australia's capital cities. However, these sectors do make important contributions in regional Australia, including for example, food manufacturing. Energy-using sectors in Regional Australia would therefore be expected to benefit from an expansion in Australia's bioenergy sector.

Development of the bioenergy sector is also expected to result in slower growth for some sectors of the Australian economy. This 'crowding out' is projected to be mainly contained to the existing energy generation sector. In the BAU scenario, for example, the energy generation sector is projected to contract by around 0.4 per cent on average between 2025 and 2030.

Slower growth under the policy scenarios reflects both supply and demand factors. The existing energy generation sector faces reduced demand in its markets as bioenergy emerges as a viable alternative. The sector has limited capacity increase exports and therefore sees reduced demand occurring alongside a broader increase in the cost of production, as the bioenergy sector increases competition for productive input such as capital and labour.

6. Quantifying the benefits

Growing modern bioenergy industries results in four key benefits. The modelling conducted for this Roadmap has quantified what these benefits could be for Australia as shown in Table 7-9.

Table 8 – Quantifying potential bioenergy benefits for Australia

2030 Modelling Results								
Scenarios	Emissions		Economics		Liquid Fuel Security		Waste Recovery	
	Reductions (Mt-CO_2-e p.a.)	per cent of 2019 emisions	Additional GDP	Additional Jobs	ML p.a.	Additional days of 2019 Consumption Cover	Mt p.a.	per cent of 2019 landfill volumes
Business As Usual	31	6%	$7b	17,700	2,760	17	1.4	7%
Broad Use	59	11%	$11b	28,100	7,340	44	2.6	12%
Targeted Deployment	46	9%	$10b	26,200	4,513	27	1.3	6%
Industry Stagnation	13	2%	$4b	10,700	590	4	1.0	5%
2050 Modelling Results								
Business As Usual	41	8%	$11b	28,100	5,590	33	1.8	8%
Broad Use	70	13%	$15b	35,300	10,200	61	3.2	15%
Targeted Deployment	67	12%	$14b	35,300	10,551	63	1.6	7%
Industry Stagnation	12	2%	$5b	13,400	330	2	0.4	2%

The quantified benefits in Table 8 highlight:

- **Economy** – the bioenergy industry can deliver additional GDP (up to $15bn additional GDP in 2050) and jobs (up to 35,300 additional jobs in 2050)
- **Emissions reduction** – bioenergy can play a role in reducing emissions in the Australian economy (up to 13 per cent of 2019 emissions in 2050) and take significant market share in hard-to-abate sectors such as aviation
- **Liquid Fuel Security** – bioenergy can significantly improve the current situation of 18–23 days of consumption cover for liquid fuels (up to 63 additional days in 2050)
- **Waste Recovery** – the bioenergy industry can play a role in reducing waste to landfill (up to 15 per cent of 2019 landfill volumes in 2050), contributing towards the National Waste Policy Action Plan's objective of halving the amount of organic waste to landfill by 2030

The benefits from bioenergy could be substantial but the scale of the benefits varies across the modelled scenarios. To set the country on the path to one of the more beneficial scenarios, outcomes will require an integrated approach between industry and government.

The approach should consider actions that will need to be completed across varying timeframes to create strong foundations for growth, build the sector's breadth and capabilities, and then scale up the most prospective market opportunities.

Action themes should be built around the markets for which there are limited alternative emissions reduction solutions available, as well as those markets where bioenergy can play a complementary role to other low emissions solutions. The approach for these two themes will necessarily be different.

In addition, a focus on ensuring the availability and sustainability of feedstocks will be required as well as looking at wider ecosystem activities that will build an enabling environment for growth.

Image: Southern Oil

7. Acknowledgment and disclaimer

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Enea provides independent analysis and tangible future-driven advice through strategy, innovation and modelling services. Its team is united by shared values and is positively focused on addressing climate change, sustainable development and energy access.

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