Australia's National
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Low emissions pathways for Queensland agrifood

Final report prepared for the Queensland Department of Agriculture and Fisheries

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Citation

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Important disclaimer

Prepared for the Queensland Department of Agriculture and Fisheries on behalf of CSIRO's Towards Net Zero Mission.

Executive summary

Overview

This report, commissioned by Queensland Department of Agriculture and Fisheries, identifies coordinated policy, research and development, and industry action to progress tenable options and catalyse new pathways of greenhouse gas (GHG) reduction for Queensland agrifood. The report is written and actions are identified for government and industry bodies. It is not a report designed as extension for producers and farmers but identifies the criticality of the existing material from trusted voices such as farmers' federations and industry advocacy groups that can be extended to provide comprehensive sources of information for those on the ground to access.

A transition to a low emissions agriculture will require development of novel technologies and practices. But this will not be enough, and transition will require their widescale adoption across agriculture and food sectors and this needs market and governance innovation to generate economic incentive for practice change. Aligning government, industry and society interests increases the chances of success and of overcoming self-reinforcing elements in the agricultural sector that can impede change. There are opportunities that arise from early testing and implementation of actions to lower agriculture emissions. These include increased influence over the development of future standards and regulations, influence argued from a position of practical and contextual experience, and, secondly, progression of low emissions technologies to a scalable stage should mechanisms such as carbon border adjustment mechanisms be implemented in a manner that impacts Queensland agrifood exports.

The activities outlined in this report were derived from simultaneously convened government, industry, and civil society groups in a series of online forums, in addition to more traditional literature review processes. This increases the chance of these impeding issues being exposed and supportive actions for industry and government being identified. A governance process involving members from academia, government, and industry was engaged and consulted at all stages. Views expressed by community and industry advocacy groups are reported, and while they may be contested, they represent views that must be negotiated to achieve support for the low emissions transition.

The report ends suggesting a governance structure across the innovation, industry and government sector that could drive the transition, with the aim of indicating the key elements that need to be in place. It acknowledges that despite the proposed architecture the configuration of these elements needs to be organised in a manner consistent with industry and government needs and constraints. Ensuring the presence of the elements within the governance process is the important thing. It recognises that elements of this governance already exist and that there will be a particular 'Queensland-way' that innovation system players will construct.

The workshops and reviews identified five pathways for low emissions agriculture. In each of these pathways a range of activities are identified and classified as either emerging, scaling or consolidating. These are described below. No activity is at the consolidating phase, with all either emerging or scaling.

For the purposes of this report, Low Emissions Pathways are bundles of actions government and industry can take to reduce emissions across value chains or subsectors. To bound the work the Australian and New Zealand Standard Industrial Classification (2006) definition of agriculture was used and excludes forestry activities (though not here reforestation and afforestation), aquaculture and processing industries.

PHASE	CHARACTERISTIC
Emerging	The stage where new ideas are tested, often through investments in R&D, trialing at different scales and replication of these trials.
Scaling	If the emergence phase is successful, a practice or technology may be ready to enter a scaling phase. Adoption, diffusion and sometimes the disruption of pre-existing practices and technologies are the typical features of this phase.
Consolidation	A consolidation phase embeds the practice and technology as a normal part of business and market functioning.

Pathways and options for reducing GHG emissions in Queensland agrifood

In the tables below the most prospective activities and highest priority actions are identified for summary. Fuller lists and barriers and risks to activities are provided in relevant chapter sections.

1. Livestock sector emissions

Total feasible abatement[1] 4.5–8 MT $CO_2e\ yr^{-1}$

BEST BET ACTIVITIES	STAGE OF TECHNOLOGY OR ACTIVITY	ABATEMENT POTENTIAL 2030 (MT $CO_2e\ yr^{-1}$)	KEY ACTIONS TO BRING TO SCALE
Supplements in feedlots and dairy	Scaling	1–1.5	Support trials of technologies and build collaborations along value chains
			Promote infrastructure investment and regulatory support to allow early access to technologies for Queensland producers
			Provide up to date information on products and build trust and credentials of products with producers and consumers
Novel forages	Emerging	0.5	Improve prediction of realised methane reduction and productivity gains
			Promote adoption through extension services and provision of bioeconomic modelling data of financial, feed-base resilience and environmental benefits data
			Investigate support or financing of pasture regeneration with forage legumes as drought resilience measure and emissions reduction strategy
Supplements for grazing industry	Emerging (early stage)	2–5	Stimulate and invest in trials and measurement of outcomes from various encapsulation methods for supplements
			Build collaborations along value chains to test slow-release technologies as well as application of engineering/behavioural solutions to ensure herd isolation to identify feasibility
			Engage early with regulators and market around conditions required for crediting emissions reductions in extensive grazing systems (life cycle and system boundary issues)
Underpinning and common			Have a central point of information about technology, market opportunities and rules to assist producer engagement in opportunities and consider investment in public extension to support more rapid adoption of practices and trust in information provision
			Provide industry baseline calculators and management change scenario modelling to allow producers to explore opportunities within their enterprise contexts
			Engage in international policy developing around livestock GHG intensity and methane emissions and secure future export markets for Australian produce

1 The abatement figures given this report are feasible/attainable abatement and not technical potential abatement (after Eady et al. 2009). Attainable potential is the abatement achievable with concerted efforts in technical and management changes, policy adjustment and shifts in current land management priorities. It must be recognised that these estimates contain a combination of biological, technical, adoption and implementation uncertainty.

2. Cropping and horticulture

Total feasible abatement 1.2 MT $CO_2e\ yr^{-1}$

BEST BET ACTIVITIES	STAGE OF TECHNOLOGY OR ACTIVITY	ABATEMENT POTENTIAL 2030 (MT $CO_2e\ yr^{-1}$)	KEY ACTIONS TO BRING TO SCALE
Green fertiliser	Emerging	0.5–1	Support emerging industrial hydrogen transitions and encourage inclusion and partnership for green fertiliser production and offtake agreements
			Look at opportunities for renovation of water treatment plants and the like for micro hydrogen generation to accelerate uptake of hydrogen
			Look to engage in emerging green fertiliser developments and build forward demand and offtake agreement to derisk capital investment
Enhanced emission nitrogen fertilisers (EEFN) and optimal N practices	Scaling	0.1	Stimulate R&D and real-world demonstration projects of EEFN products and build corpus of knowledge of where the products are most successful
			Build enterprise level nitrogen emissions baselines and guidance and extension around the utility of emerging technologies in decreasing emissions
			Look at how best management practice can be rewarded in environmental markets and underpin with M&E systems that look at broader system benefits from on farm actions
Crop insurance products	Emerging	0.01	Build coalitions around crop insurance and look at mechanisms to scale up adoption
Common and underpinning			Build underpinning digital infrastructure (soils, climate layers) to support decision support tools
			Continually benchmark Australian crop and horticulture products and lobby for international lifecycle assessment protocols and standards that are appropriate for Australian producers
			Industry and government to articulate a vision for hydrogen support to the agriculture sector with collective action to accelerate opportunities for deployment into agricultural vehicles and the development of green fertiliser

3. Offsets

Total feasible abatement 19 MT $CO_2e\ yr^{-1}$

BEST BET ACTIVITIES	STAGE OF TECHNOLOGY OR ACTIVITY	ABATEMENT POTENTIAL 2030 (MT $CO_2e\ yr^{-1}$)	KEY ACTIONS TO BRING TO SCALE
Re-establish native forest cover	Scaling	2.5–14	Look to build rangelands methods that are cost effective to capture significant opportunity and co-benefit alignment
			Invest in risk assessment due to climate change and develop robust guidelines for resilient forest cover (fire management; thinning etc)
			Build strong evidence of benefits and disbenefits of woody vegetation on farm to support primary enterprise decision making
Establishing new forests	Scaling	0.3–1.5	Invest in understanding the implications of land-use change, especially on runoff and fire impacts
			Provide information and training on site by species by silviculture to decrease risk in reforestation/afforestation in a changing climate
			Create awareness and pathways for on farm forestry to support a broader range of benefits and income spreading options; examine regulations, energy ratings and land valuation principals that may be acting as disincentives to farm forestry
			Continue to drive investment into engineered wood products and biochar options to increase demand for farm forestry
Increase soil carbon	Scaling	0.1–1	Provide knowledge on risks and uncertainty in soil carbon farming and provide trusted point of reference and context to relevant assessment tools that can demonstrate plausible sequestration and reversal risks
			Support data collection and research into low-cost measurement and next generation model:data fusion approaches for soil carbon prediction and crediting to drive down compliance costs
			Explore financing approach to overcoming barriers to entry including supporting baselining and assessments
			Link soil carbon offset markets to natural capital assessments and other environmental markets (benefit stacking) to support wider market opportunities and improved economic viability of on farm actions
Underpinning and common			Foresighting and information gathering that shapes how agriculture should respond to future carbon markets that may require agriculture to use its own offsets for market access
			Monitoring and evaluation to document co-benefits and to expose emerging risks associated with scaling of projects; use information to adjust risk reversal buffers and permeance period discount
			Develop tailored region-specific outreach programs for the agriculture sector to overcome knowledge as a barrier to entry; support codes of practice to build trust between service providers and producers; build platforms for farmers to share experiences and learning about offset projects

4. On farm energy

Total feasible abatement 0.15 MT $CO_2e\ yr^{-1}$

BEST BET ACTIVITIES	STAGE OF TECHNOLOGY OR ACTIVITY	ABATEMENT POTENTIAL 2030 (MT $CO_2e\ yr^{-1}$)	KEY ACTIONS TO BRING TO SCALE
Enable fringe grid innovation in power generation, sharing and use	Emerging	0.01–0.05	Ensure agricultural interests/transitions and considerations are effectively considered at different levels of policy and investment related to decentralisation of power generation and use, through active involvement in working groups
			Build cross-industry networks that enable (for example) forward contracts, supply surety and consistent operating conditions around new generation/ supply options.
			Map areas where there are potential systems co-benefits from different forms of energy infrastructure developments (e.g. thermal solar/ammonia/mine rehabilitation)
Support early trialling and adoption of alternative options for agricultural machinery	Emerging	0.01–0.05	Consider when incentives and other policy instruments affect uptake of emerging fuels
			Build a coherent approach to information sharing and clearing houses for understanding fuel options and pathways, including rigorous trial information, to prevent misinformation and information asymmetry challenges
			Define niches and protected spaces where emerging fuels can be safely trialled in an agrifood context to enable rapid adoption and scaling of successful fuels (e.g. associated with regional demonstrators)
Expand energy audit program	Scaling	0.01–0.05	Extend programs such as Energy Savers Plus
			Consider low interest loan schemes to facilitate more rapid and greater uptake of energy efficiency interventions
			Consider procurement policies for government agencies of agricultural products based on GHG credentials of businesses
			Extend best practice standards to drive rapid uptake of energy and GHG audits and interventions
Common and underpinning			Use opportunities when renovating aging infrastructure to support low emissions agriculture (hydrogen production from wastewater plants etc)
			Support for industrial clusters – especially in the case of agriculture creating opportunities for spillovers from industrial and mining sector transitions into agriculture

5. Regional demonstrators

Low emission regional demonstrator creates new opportunities for cross sectorial integration of multiple low GHG options within a region creating additional value that goes beyond those possible with single abatement opportunities. Regional demonstrators need to be aligned to different regional strengths and opportunities, and the triggering points for action. Key to delivering the benefits, particularly cross sectoral opportunities, will be coordination, leadership and governance to provide the structural support for coordinated action. Potential demonstrator regions and examples of supporting action are below.

EXAMPLE DEMONSTRATOR	INITIATING POINT	PRIMARY GOALS/ ASPIRATIONS OF INSTIGATORS	POSSIBLE BROADER AGRICULTURE SPILL OVERS	SUPPORTING ACTIONS THAT CAN ACCELERATE AGRICULTURAL BENEFIT
Barcaldine	Community and civil community leaders initiated and developed a joint venture with local councils RAPAD (Remote Area Planning and Development Board)	Taking advantage of a possible REZ to revitalise the region, in particular agri-business	Hydrogen urea plant, prickly acacia biomass to biochar for potential steelmaking and agricultural use, large scale glass houses for protected horticulture	Benchmarking and tech-economic assessments; investment for new industries; digital frameworks for accounting and credentialling of products; innovation incubators and market support
Gladstone	Incumbent industry leaders and Climate Leaders Coalition (CLC) A potential hydrogen hub will provide opportunities	Driven by gas export industries who aim to reduce market exposure CLC drive to support just transition in a low carbon future	Access to a large supply of green energy and potentially green urea could drive diversification of agribusiness Offsetting and insetting opportunities as the Gladstone industrial hub decarbonises	Creating the incentive and support for agriculture to gain benefits from industrial transition including concessional funding for supporting necessary infrastructure; dialogue of how activity can support long term economic resilience and regional development
Lockyer Valley	Potentially government procurement through a climate positive 2032 Olympics	A low emissions horticulture and agribusiness sector in the Lockyer Valley	Access to markets (beyond the Olympics)	Increase access to renewable energy (for irrigation) and green fuel, provide coordinating and digital infrastructure to regional carbon reporting, grants for conversion of diesel machinery to ammonia fuel, region scale nature-based offsetting; regional branding

Recommendations and next steps

The report proposes a model for coordinated action to take the next steps and prioritise action. This needs to be negotiated among stakeholders from government, industry, and community.

The model for coordinated action proposed draws together the five pathways detailed above and embeds them within a wider distributed governance framework, supported by national technical networks across research and industry and an innovation hub/incubator that supports market scaling and creates opportunities for conversations such as raised earlier on offsets. This model rests on cross-industry and government leadership to catalyse an enabling environment and comprises three key interacting elements:

1 Working Groups

For each pathway Working Groups would drive sectoral and regional change through the pathways described in previous sections. Technological change is fundamental to this model and is the focus of the Pathways Working Groups and Regional Working Groups.

2 Governance Group

Rapidity and efficacy of emergence and scaling will need to be catalysed by a proactive and well-coordinated approach to governance. A high level, overarching Governance Group would coordinate across scales and drive state-wide prioritisation and investment in R&D and industry development as well as overseeing the development and embedding of strategies, and advice across State Government agencies and coordination with other jurisdictions. This group would thus drive key x-scale priorities and outcomes.

3 Innovation facilitation

An innovation incubator is included here as a function rather than necessarily a formal organisation. It could be a formal organisation or informal network but is essential about developing better connections between national technical capability across research and industry to identify and address specific challenges. This function would have the flexibility to draw on national as well as state, regional and local technical capability to experiment, innovate and drive market outcomes. A useful model of formal organisation for this function is a hub that operates as a ‘boundary organisation’ with accountability to industry, research, and government, and that has the in-house technical capability to assess and direct innovations priorities systematically and sequentially. Such an organisation may be able to be developed to work across multiple sectors on GHG-related transitions.

While this report identifies a variety of priority areas for action, it acknowledges that there is a great deal of capacity, knowledge, and know-how within the Queensland agrifood sector that should be harnessed to envision, develop, and implement approaches to emissions reduction, and, in doing so, ensure the sector is well placed to flourish in 21st Century GHG constrained markets. Ultimately, catalysing the shifts discussed in this report will happen through ingenuity, perseverance, coordination, and collaboration among diverse people across the private and public sector. While the recommendations have been made in this report, the way they are put together will be unique to Queensland and the network of people businesses and groups that make it happen.

Contents

Introduction

Action to reduce greenhouse gas (GHG) emissions is gaining momentum internationally and ambitious targets are being articulated at the international, national and corporate level. More than 80% of the global gross domestic product is now covered by a national net zero target. All States in Australia have net zero by 2050 targets. Pathways for attainment of these targets, however, are not clear. Despite the energy sector in Australia being deep into low emissions transition, and while energy production and energy use comprise most of Australia's emissions (81% in the September 2020 National Greenhouse Gas Inventory), Australia's transition to net zero requires progress in the harder to abate sectors of industrial processing and agriculture.

Agriculture in Australia is a significant source of emissions and is highly trade exposed. National and international moves to reduce GHG emissions present both a challenge and opportunity for the agriculture sector. Existing mechanisms such as the European Commission's revised mandated target on greenhouse gas savings for biofuel feedstocks entering the European Union (EU) show how greenhouse gas intensity of products can limit market access, and mechanisms such as the EU's Carbon Border Adjustment mechanism, while not yet targeting agriculture products, show the potential of future non-tariff trade barriers to agriculture product access to export markets. The sector has been proactive in Australia by setting industry targets and moving towards action and commissioning research and development. Peak agriculture bodies and Research and Development Corporations (RDCs) like the National Farmers Federation (NFF) and Meat and Livestock Australia (MLA) have set aggressive targets. Indeed, recent reports (Farmers for Climate Action) suggest that significant reduction could occur if existing and emerging practices were scaled across the sector.

But this isn't occurring. Significant inroads have been made in the development of technological options, however, reductions in GHG intensity of production remains elusive. By way of example many of the ERF methods developed have so far led to little on the ground abatement. The NFF in a submission to the Climate Change Authority review of the Emissions Reduction Fund (NFF submission to CCA ERF review) noted participation was limited, among other things, by: low carbon prices; policy and price uncertainty; lack of trust in information providers; scale of participation barriers; risk of loss due to climate and weather disasters and a general lack of awareness. As this suggests, a transition to low emissions agriculture will require development of new technologies and practices, but it will also require their adoption across agriculture and food sectors. For this to occur, market and governance innovation is required to ensure changes can be made to reduce the GHG intensity of production and that the benefits of these changes do not lead to negative social, economic and environmental outcomes. It is not just the challenge of the agriculture sector's contribution to national and international targets, but also understanding the implications on the prosperity of individual sub-sectors in a world that may well see market access constrained by greenhouse gas efficiency of production (that is greenhouse gas production per unit product). A key concept is that a transition to low emissions agriculture is not just a technology or economic activity but also a social transition and as such, must occur within the context of society's and the sector's parallel objectives, and that these may, particularly within the context of a diffuse and long-term threat such as climate change, take a higher priority. Aligning government, industry and society interests increases the chances of success and of overcoming self-reinforcing elements in the agricultural sector that can impede change (Conti et al. 2021). Achieving significant change requires multiple changes to occur on the same temporal scale (i.e. in policies, technologies, implementation capability).

The activities reported in this report have simultaneously convened government, industry, and civil society groups in a series of linked input processes (online and in discussion forums) as well as established a governance process from academia, government, and industry to look for commonly held feasible pathways to reduce emissions and ways to create alignment between other interests and the low emissions transition.

Transitioning to a greenhouse gas constrained world

While technological and practice change will be critical, and we see them emerging, they will not happen with the necessary rapidity to meet changing market expectations without strong and coordinated government and industry leadership, supported by R&D and significant attention to grassroots innovation across the agrifood sector.

A useful way to think about this change is to consider a trade barrier related to the GHG credentials of a product being imposed at an unknown point in the future. If a product does not meet the trade protocols that market will be lost. At scale, the loss of markets becomes a crisis for producers. The timing of appearance of these trade barriers is not easy to predict, but the occurrence itself is easily foreseeable. More importantly, the ability of the producer to meet the requirements of the barrier will not only require a lead time for a specific firm but will require coordination across an innovation system for a sustained period. Putting this concretely a carbon border tax imposed on livestock export will require full life cycle assessment of livestock production at the export unit level; for example, this might be wagyu beef to east Asian premium markets. For this to be done technologies that reduce GHG must be verified, an assessment framework against which GHG emissions will be assessed must be codified, and the data informatics and product tracing infrastructure to enable traded commodity credentialing must be in place and trusted across the supply chain.

Table 1 Phases in technology or practice adaption and scaling identified in this report.

PHASE	CHARACTERISTIC
Emerging	The stage where new ideas are tested, often through investments in R&D, trialing at different scales and replication of these trials.
Scaling	If the emergence phase is successful, a practice or technology may be ready to enter a scaling phase. Adoption, diffusion and sometimes the disruption of pre-existing practices and technologies are the typical features of this phase.
Consolidation	A consolidation phase embeds the practice and technology as a normal part of business and market functioning.

Coordination across these multiple changes can be considered to occur in three phases, emerging, scaling and consolidation (Table 1). Each of these overlapping phases can take years. But as we have seen with the rapid development and roll-out of mRNA vaccines for COVID-19 (e.g. Pfizer-BioNTech and Moderna COVID-19 vaccines), they can also be fast-tracked through conscientious and coordinated effort across government and industry (e.g. Sandmann and Jit 2021).

The report will look at action by industry and government that may accelerate the emergence and scaling of low emissions technologies, markets and supporting frameworks for agriculture.

In looking at ways to accelerate the emergence and scaling of low emissions technology we draw on international experience, especially as synthesised by Victor et al. 2019. In Table 2 we look at some broad principles for promoting cooperation among agriculture sector system actors. Table 3 looks at key actions by industry and government that can accelerate low emissions transitions. When synchronised these actions can create a reinforcing feedback that helps scale emerging technologies (Figure 1). However, as Conti et al. (2021) show, failure to synchronise key factors such as technological choices, attitudes, supporting infrastructure, institutions and politics and research and development priorities can impede directional change and reinforce existing modes of production. The transition to low emissions agriculture will not be driven by academia, industry or government alone but requires the connected action of all, with support of civil society. Without such coordination and support, innovation, adoption and transition will be slower. This is clear, for example in the findings of the NFF mentioned earlier that uncertainty on future policy has impeded adoption of carbon farming practices.

The other key consideration is that different technologies and practices can be at varying stages along this continuum. The challenge, then, is how do these technologies that are scaling and those that are emerging come together to form net zero emissions pathways for sub-sectors of agriculture and how do these get knitted together for a whole of sector transition. The emergence and scaling of technologies may be inter-dependent on other technologies to create systems within which they work, or alternatively may be locked out because other parts of the system compromised of markets, regulations and the action of incumbent interest 'lock them out' and stop them scaling (see Conti et al. 2021). Individual practices, approaches or technologies (we will call them niches) need to be integrated into systems of use or regimes to achieve scaling.

For example, realising the value of livestock methane reduction technology could be enhanced by the development of carbon trading markets or environmental markets overcoming barriers to entry, and these may only effectively operate if there is a range of other abatement opportunities to create scale to support such markets.

We focus on how regimes or systems of use can be developed by simultaneously progressing co-dependent technologies and practices. In this report we call these pathways; we specifically look at interdependencies between niches and how these can be coordinated into regimes.

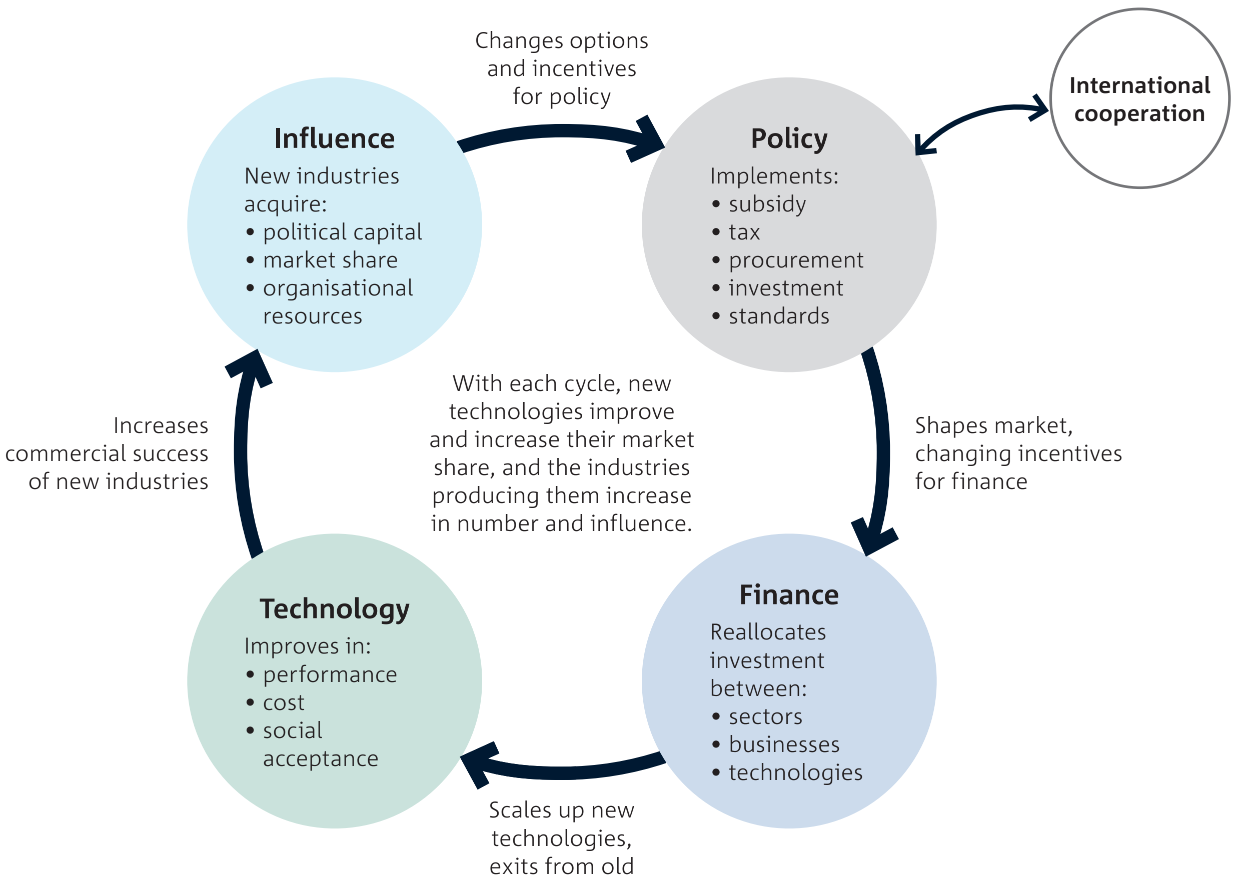


Figure 1 Reinforcing feedback in the scaling of new technologies and the acceleration of transitions (adapted from Figure 5, Victor et al. 2019).

Table 2 Summary of process occurring and principles for progressing through the phases of transition used in this report (after Table 1, Victor et al. 2019).

PHASE OF TRANSITION	PROCESSES IN PLAY	PRINCIPLES FOR EFFECTIVE COOPERATION AND COORDINATION	EXAMPLES WITHIN AGRICULTURE
Emerging	New and novel technologies and practices developed and piloted with early adopters and being piloted for individual benefit rather than broader systems change; partnerships and collaborations are transactional and focused on experimenting with a technology or practice within a contained system	• Break problem/opportunity down in manageable pieces that are aligned with how industries and policies are organised • Ensure there are processes to review the lessons from experiments and figure out what's working (and not) • Coordinate action among a critical mass of willing innovation actors to establish niches and provide credible assurance to encourage risk taking • Focus on bringing interests of key actors into alignment	Livestock industry emissions mitigation
Scaling	Multiple reinforcing feedbacks supporting growth of new technology market share	• Coordinate action to scale up niches into larger market shares – work in small groups: coalitions of first movers • Focus on markets where agreement is easier • Focus on joint actions that with experience and diffusion can plausibly lead to reconfiguration of interest	Development of greenhouse gas offsets industry
Consolidation	Complementary changes in institutions (policy and informal norms), infrastructure, business models, mainstreaming	• Set standards: monitor and verify compliance • Establish credible incentives to participation • Create detailed, reciprocal agreements around known solutions that address barriers and create efficiency in common infrastructure	Incorporation of renewable energy into network grids

Definition of agriculture for the purposes of the report

The term 'agriculture' refers to both the growing and cultivation of horticultural and other crops (excluding forestry), and the controlled breeding, raising, or farming of animals.

This excludes:

- Aquacultural activities include the controlled breeding, raising or farming of fish, molluscs and crustaceans.
- Forestry and logging activities include growing, maintaining and harvesting forests, as well as gathering forest products.
- Processing/Non-production processes, e.g. abattoirs, dairy refrigeration, freight of goods unless conducted on-site.

The Australian and New Zealand Standard Industrial Classification (ANZSIC), 2006.

Table 3 Prioritised policy and industry actions based on different phases of low emission agriculture transition (substantially modified after Table 2, Victor et al. 2019). Codes against actions are used later in the report.

PHASE OF TRANSITION	GOVERNMENT AND POLICY MAKERS	INDUSTRY AND INDUSTRY REPRESENTATIVE BODIES
Emerging	**GE1:** Stimulate R&D and real-world demonstration projects **GE2:** Prioritise actions that could deliver multiple public and private benefits **GE3:** Stimulate knowledge sharing between projects/niches; public funding for knowledge exchange mechanisms, building incubators and supporting early movers; providing information-based advisory tools **GE4:** Nurture the building of transformative coalitions **GE5:** Public procurement to create early application niches, including building public markets that deliver multiple benefits (e.g. Land Restoration Fund) **GE6:** Articulate vision and mission; Develop a regional economic development strategy that has low-emissions agriculture at the centre, focusing on specific, diverse industries for accelerated growth and retention **GE7:** Measurement of compliance costs for new low emissions industries and investigating where process burdens can be reduced **GE8:** Use opportunities when renovating aging infrastructure to support low emissions agriculture (hydrogen production from wastewater plants etc)	**IE1:** Dialogue with community and government to co-create future pathways **IE2:** Build collaborations with other firms and representative bodies to articulate strong future state vision for sector and share knowledge of practices **IE3:** Foresighting and forecasting potential disruptions to markets and industry profitability and finding ways to maximise positive impacts of future changes **IE4:** Have up to date information and extension services for technological options and emerging regulations, build awareness and capability in membership **IE5:** Drive investment to support experimentation, especially where technology and practice change appropriate to transition aligns to existing goal **IE6:** Engage in building credible baselines to assess contribution and assess policy and interventions **IE7:** Building trusted credentialling of products to support claims
Scaling	**GS1:** Taxes and regulations to alter the economic playing field **GS2:** Purchase subsidies, favourable prices setting, public procurement to shape firm investment **GS3:** Engage in international policy dialogue to support the needs of domestic industry especially in trade markets **GS4:** Public infrastructure investments **GS5:** Training programs and workforce reskilling to support transition **GS6:** M&E systems that document benefits of new actions, especially properly accounting for co-benefits **GS7:** Support for industrial clusters – especially in the case of agriculture creating opportunities for spill overs from industrial and mining sector transitions into agriculture **GS8:** Facilitate access to financing and attract co-financing for low emissions agriculture **GS9:** Recognise that agricultural transition to low emissions will require coordinated policies in the ministries responsible for agriculture, energy, economic development and environment	**IS1:** Build multi-level cross value chain partnerships and coordination committees and working groups to assist in efficient transitions and better distribute benefits and costs **IS2:** Work with other emerging innovators to lobby for common and necessary infrastructure **IS3:** Geographic or territorial branding programs to support early movers and create centres of aggregation **IS4:** Build niche markets around differentiated products **IS5:** Advocating for policy and support to enable transitions, especially considering how transitions will impact current employees or stakeholders, undertake skills mapping to inform employment training programs
Consolidation	**GC1:** Anchor new system/regime with regulations and standards **GC2:** Mitigate negative socio-economic effects with "just transition" policies (e.g compensation, retraining, position of new industries into affected regions) **GC3:** Catalyse broad coalitions in the new industrial configuration that support environmental and social goals	**IC1:** Share best practice and monitor performance and build business ESG goals **IC2:** Create opportunities for deep community engagement

Queensland Agriculture emissions profile

In 2019 Queensland's United Nations Framework Convention on Climate Change (UNFCCC) reportable emissions were 164.5 Mt CO_2e of which 21. Mt CO_2e were from Agriculture and another 16.3 Mt CO_2e were from land use and land use change and forestry (State Greenhouse Gas Inventory). Of the agricultural emissions 75% was due to methane emissions from enteric fermentation and of this 97% was due to beef cattle. Manure management contributed another 12% (Figure 3). If the objective was to reduce total 'scope 1' emissions (for definition see Figure 2) from agriculture the heavy lifting will have to occur in the livestock industry. However, in some activities, horticulture and cropping especially, scope 2 emissions from energy use can be a significant proportion of emissions. Further in cropping, scope 3 emissions from fertiliser can account for over 50% of aggregate scope 1, 2 and 3 emissions (after Sevenster et al. 2021). If the purpose of lowering agriculture's greenhouse gas emissions is to ensure the continued prosperity of agriculture and ensure that all sectors can access high value export markets and defend social license, measures of greenhouse gas intensity of products (tonnes of greenhouse gas per tonne of product) will be important, and this may include scope 2 and 3 emissions.

If the concern of the low emissions sponsorship by the Queensland Department of Agriculture and Fisheries is not just to pick those actions that have the biggest influence on agriculture's aggregate emissions, but to drive the prosperity of all of the sector in a greenhouse gas constrained trading environment, then low emissions pathways are required for all subsectors.

The trend in emissions from agriculture has been flat to slightly rising since 1990 (five-year average 1990–94 inclusive of 19.7 Mt CO_2e /yr cf period 2014–18 of 20.5 Mt CO_2e /yr). There is no discernible trend in the category data. Agriculture emissions have been offset by a sharp drop in the period by the land use, land use change and forestry (LULUCF) category which has fallen from 109 Mt CO_2e yr^{-1} in 1990 to 22.8 Mt CO_2e yr^{-1} in 2018. Much of the drop in emissions from this sector was in the early 90's and emissions from this sector have been approximately unchanged from the last 5 years.

SCOPE	EMISSION TYPE	DEFINITION
Scope 1	Direct	GHG emissions directly from operations that are owned or controlled by the reporting company
Scope 2	Indirect	Indirect GHG emissions from the generation of purchased or acquired electricity, steam, heating, or cooling consumed by the reporting company
Scope 3	Indirect	All indirect emissions (not included in scope 2) that occur in the value chain of the reporting company, including both upstream and downstream emissions

Figure 2 Definition of Scope 1, 2 and 3 emissions.

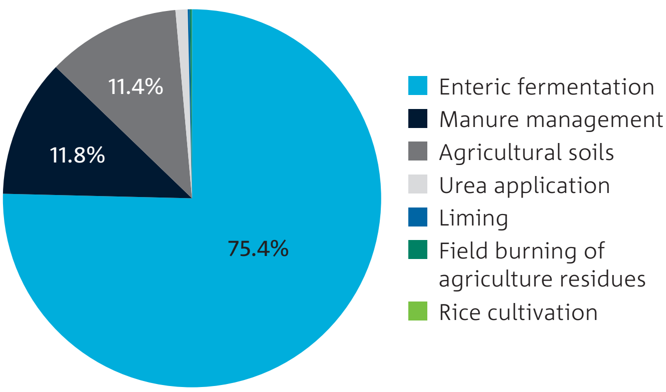


Figure 3 Proportion of Queensland's agriculture emissions by category 2018 (from Queensland State of the Environment).

Trends in emissions from the combined land use and agriculture sector suggest that agriculture cannot rely on reductions in LULUCF to reduce aggregate land sector emissions under a business-as-usual case. New approaches or scaling of existing techniques is required.

Summary of approach

Under the guidance of the project steering committee, comprising leaders from Queensland's agricultural sector and relevant State Government agencies, the project was conducted in four stages to develop a set of goals and then plan the work to build pathways for achievement.

In summary, these four stages moved from: 1) a preliminary synthesis of existing technical assessment of GHG mitigation options for the Queensland agrifood sector; 2) use of a crowd sourcing platform to surface novel ideas and options for reducing emissions; 3) Analysis; 4) Exposure of these and discussion of the actions for their enactment with policy and industry slice groups.

Preliminary desktop synthesis

The project commenced with a synthesis of the development and technical assessment of options to reduce GHG emissions for Australian agriculture, relevant to Queensland carried out by Climate-KIC. The Climate-KIC review has informed analyses in stages 2 and 3 below. The report largely drew from meta-analyses to produce tables of potential abatement, barriers to adoption and potential co-benefits associated with previously identified technology adoption or practice change. Some approaches have been formalised as methods under the Commonwealth's Emissions Reduction Fund (ERF), providing options for farmers and agribusiness to generate Australian Carbon Credit Units (ACCUs). Other options have been evaluated in terms of costs of abatement, still others are in preliminary research stages. The intention of this part of the work is to act as a supplement to what was raised in the crowdsourcing step.

Crowdsourcing of options

Crowdsourcing platforms are online tools for generating ideas, coalitions, reframing existing problems, mobilising action and identifying solutions to sustainability problems. To build and assess low emissions pathways for Queensland agriculture the project selected an existing crowdsourcing tool Crowdicity[2], for use. Crowdicity is a peer-to-peer platform that is built to capture ideas and insights from an external crowd, allowing individuals to share original ideas as well as build on, improve, challenge and vote on the ideas of other participants. The platform included a series of webpages designed by CSIRO researchers, that detailed the challenges statement co-developed with the project steering committee (see box), rules, privacy and ethics statements, frequently asked questions (FAQs) and other background information. On the website, participants could upload ideas about how to reduce greenhouse gasses (including links, additional documents, etc), and comment, vote and participate in conversations with regional, academic, policymaking and/or industry peers (Figure 4).

Challenge Statement designed by Steering Committee for Open Innovation Challenge

Low Emissions Pathways for Queensland Agriculture

To support a robust, competitive, and sustainable Queensland agrifood and fibre sector in a greenhouse-gas constrained world, the Queensland Department of Agriculture and Fisheries is partnering with industry, community and research bodies to define key low emissions pathways. Pathways are bundles of actions that will work in value chains or entire sectors to reduce emissions. These include new ways of doing things, novel technologies, market mechanisms, or actions to overcome barriers to practice change. Established, as well as early-stage ideas are welcomed. We want to hear from as many people as possible to source fresh ideas and perspectives to drive short- or long-term change that secures Queensland agriculture's future.

2 Crowdicity is an idea collaboration platform. crowdicity.com

OPEN INNOVATION CHALLENGE

An open innovation search for ideas and organisations to develop low emissions pathways* for Queensland Agrifood

*Pathways can include or bundled strategies and actions which can be applied to value chain

INPUT

The challenge purpose, context and background evidence

OUTPUT

Five to eight, high-potential, low emissions pathways, or pathway elements ready for progression

Key ingredients and process

Challenge statement
CSIRO, QDAF to create, and endorse, a suitable challenge

Open innovation campaign
An open innovation call to action, to appropriate parties, seeking ideas and/or capability to develop low emissions pathways

6 weeks

Online feedback
Open innovation crowd invited to provide feedback and constructive inputs to ideas

ActiRatification and prioritisation
A representative panel reviews and prioritises all submitted ideas and down selects 5-8 for invitation to the innovation workshop

Innovation workshop
Invited pathways developed to identify potential deal breakers, enablers and the resources required to make the project a reality

Details

- An online call to action to identify potential pathways and those organisations willing to help develop them
- Followed by a face-to-face workshop to develop and validate a prioritised shortlist of initial pathways

Important resources

- Innovation Challenge purpose, conduct and background evidence
- Crowdicity ideas management platform

Activity delivery team

- CSIRO Agriculture and Food business unit project leads
- CSIRO Innovation facilitators

Figure 4 Steps in the open innovation challenge.

The open innovation campaign platform was open for ideas and comments for a total of six weeks. Ideas submitted to the platform would then be ratified and prioritised by a CSIRO panel of experts that considered the connectivity and feasibility of ideas in reaching a low or zero emissions future for Queensland agriculture. Prioritised pathways arising from this process would then feed into the planned "Innovation Workshop," where a second round of invited participants would discuss the relevant opportunities, risks and benefits of the 5–8 pathways identified for consideration.

While the platform was open CSIRO researchers leveraged communication tools within the Crowdicity platform, and QDAF sent out weekly emails to the original email list. These approaches were designed to generate interest and amplify discussions, questions, or conversations happening on the platform.

Selection, recruitment, and engagement of participants. The QDAF steering committee and QDAF staff identified a priority set of participants and invited stakeholders. These included individuals and organisations from the following categories:

- Leaders from key agricultural sectors including extensive cropping, livestock, intensive cropping, perennial horticulture and processing.
- Those representing critical supply chain functions including agricultural inputs, on-farm, transportation/logistics, food manufacturers, wholesalers, exporters, retailers.
- Other key stakeholders including researchers, government and policy agencies, farmer and industry coordination groups, civil society groups.

Approximately 150 people were emailed Crowdicity platform invitations. Each invitee received subsequent invitations and reminders throughout the duration of the Crowdicity Open Innovation platform process. One week after the platform opened, CSIRO and QDAF staff made a joint decision to open the platform to a wider pool of participants. As a result, CSIRO researchers identified the social media accounts of approximately 20 regionally relevant organisations and sent links and personalised invitations encouraging participation on the site. Key participant statistics include:

- 145 registered participants
- 38 separate ideas submitted
- 259 votes
- 149 comments.

Original ideas included problem articulation as well as solution identification or conceptualisation. Solutions ranged from ideas about technology development, modification, or extension, stakeholder engagement and value chain collaborations, research and development opportunities and options for scaling and commercialisation.

Analysis of options and pathways

After closing the crowdsourcing platform, the CSIRO team analysed the outputs of the platform, the ClimateKIC report and other relevant reports and documentation related to options. These were used to develop bundles of options to achieve specific objects, or pathways. Pathways were then stress-tested and added to through workshops that engaged government, industry and civil society. The three stages of this analysis are outlined below:

a. **Developing pathways:** ideas and comments from the Crowdicity platform were summarised and then clustered to identify broad objectives at a sectoral or regional level. All options that contributed to achieving each of these objectives were initially listed underneath each objective. Activities were identified that pointed to different phases of transition (Table 1) for each of the options, providing a clearer sense of the technical or system readiness of different options. Voting was deemed too sporadic to provide any meaningful guide to the value of ideas (i.e. a couple of people voted a lot and most not at all). The ClimateKIC review was used to highlight key gaps, technologies and issues that had not been surfaced through the Crowdicity process. Finally, the analysis of pathways revealed a clear need for a higher-level governance pathway to enable the other pathways. This pathway focused on high-level coordination across government, industry, and R&D to define priorities, build or underpin market confidence and ensure critical infrastructure, policy, data and informatics, and other systems are in place to support the verification and tracing on which carbon markets rely.

b. **Evaluating options using criteria:** The criteria for evaluating options, co-developed with the project Steering Committee, was used as a basis for analysis of each option, which resulted in the heatmaps in the following section. These analyses were based on a mixed approach including drawing from recent scientific literature to establish readiness and mitigation potential of technological options, and expert analysis across categories for which information and analyses were variable. The ratings for GHG abatement potential for each option were added to the draft pathways to provide a visual indication of areas where investment and action could lead to substantial outcomes. For more details on criteria and methods of analysis see Appendix 1.

Stress-testing and refinement of options and pathways through workshops

A series of workshops were held with government, industry, civil society organisations and individuals to stress test pathways and better understand the current on-ground environment for driving GHG reduction across sectors and regions. Due to Covid-related restrictions, the original plan to have one large in-person workshop with breakout groups focused on different pathways was replaced by multiple online workshops. The first of these largely comprised Queensland Government staff and project Steering Committee members. This workshop, with 35 participants, reviewed the five draft-regional/sectoral pathways in a series of breakout groups. Each breakout addressed a series of questions to stress-test them relating to: the objective; any missing elements; the participants needed to achieve the objective; the risks and uncertainties; current related activities; and the next steps that should be taken to enact them. A workshop with the project Steering Committee was used to ground-truth and discuss the governance pathway, and develop invite lists for smaller, targeted industry workshops, each focused on a specific regional/sectoral pathway.

Invited participants to this last set of 1.5-hour workshops were sent a brief info pack prior to the workshop that highlighted the aim of the project, the key options being considered in the relevant pathway, and the aim of the workshop discussion. Overall 57 participants attended, many as organisational representative (e.g representing bodies such as AgForce or the National Farmers Federation, or industry bodies such as Mort&Co and Sugar Research Australia). Participants were led through the following questions:

- What are the potential risks and opportunities of the technologies and practices so far identified, including barriers to adoption and bringing them to scale?
- What activities (policy change, investment, capability building, extension etc) present the best opportunities for your sector to meet changing market demands around greenhouse gas emissions, in a timely fashion?
- Are there any technologies and practices that we may have missed that have significant potential?

In total, the seven workshops included over 92 participants, many of them representing large constituencies, and covered a wide range of aspects and considerations ranging from: coordination across different levels of government and industry, practicality of on-ground change; entrepreneurial and investment opportunities, trade-offs and risks; changing regional, community and consumer values; implementation challenges associated with logistics, incentives and market-based mechanisms, and; policy and other institutional enablers and constraints.

Final synthesis of findings

Finally, synthesis of the above was done to revise the pathways maps and develop the analysis and recommendations in the following sections. The overarching framework used in this report to help identify actions relevant to options at different phases (emergence, scaling and consolidation, see Tables 1 and 2) was used to more specifically identify key actions that are likely to be critical to achieving pathway objectives. These actions will have to be further considered and developed by groups who have carriage of the enactment of these pathways. As such the pathways presented in the next section provide guidance on key directions, opportunities and barriers, rather than a route map which can be followed precisely.

Pathways and options for reducing GHG emissions in Queensland Agrifood[3]

Low Emissions Pathways (for this report) are bundles of actions that will work in value chains or entire subsectors to reduce emissions.

Clustering from the open innovation process

The Crowdicity process identified areas where there is currently energy and activity to drive transitions to low GHG futures. Clustering the 38 ideas from action areas into a preliminary set of pathways created five clusters of activity that are the focus of most of this section of the report:

1. Livestock sector emissions, with a strong focus on enteric fermentation
2. Cropping and horticulture emissions
3. On-farm energy and efficiency
4. Regional demonstrators
5. Offsets and sequestration

Each of these clusters of activities was used to develop a first pass pathway by examining how the ideas were presented, the sorts of interventions suggested, who should be involved and the timeframes being suggested. While some ideas were clearly specific projects, business ideas or attempts to attract investment or funding for new or ongoing initiatives, many ideas were well articulated with clear linkages between research, technology development, policy interventions, industry action and coordination and other elements outlined in Table 2 and Table 3. These clustered ideas (Figure 5, also Appendix 2) highlight strong interest in offsets, livestock emissions and regional demonstrators with fewer ideas focused on on-farm energy and efficiency and cropping and horticulture.

3 While this section makes some reference to the literature around individual abatement technologies and action it is not a review. It draws from the review conducted by Climate-KIC (Appendix 5) with some additional referencing where needed to explain recommendations.

Offsets

- Strategic information for carbon farming
- Restoring riparian zones
- Nature-based solutions to carbon capture and storage
- Soil carbon measures
- Landscape scale CCS
- Ag waste, aggregators and soil carbon
- Advanced pyrolysis
- Biochar as offsetting and energy option

Livestock emissions

- Forage legumes for methane reduction
- GHG footprint measurement technologies
- Feed additives for cattle
- Seaweed additives to cattle feed
- Delivery technology for methane reduction in extensive systems
- Kangaroo protein and livelihoods
- Multispecies extensive grazing

Regional demonstrators

- Collaborative buying
- Industry-led networks
- Collaborative frameworks
- Food, soil health awareness
- Sectoral planning and coordination
- A net zero region
- Landscape planning
- Circular economy incubators

On-farm energy and efficiency

- Seeds for biofuels
- Hydrogen to fuel farms
- Drone technology for precision applications
- Speeding adoption of low emissions tech
- Green hydrogen

Cropping and horticulture

- Life-cycle assessment applications
- Digital agriculture and precision farming
- Crop rotations and types

Figure 5 The five clusters of ideas from the Crowdicity process that were used to identify initial pathways.

Cross-cutting considerations arising from industry led conversations

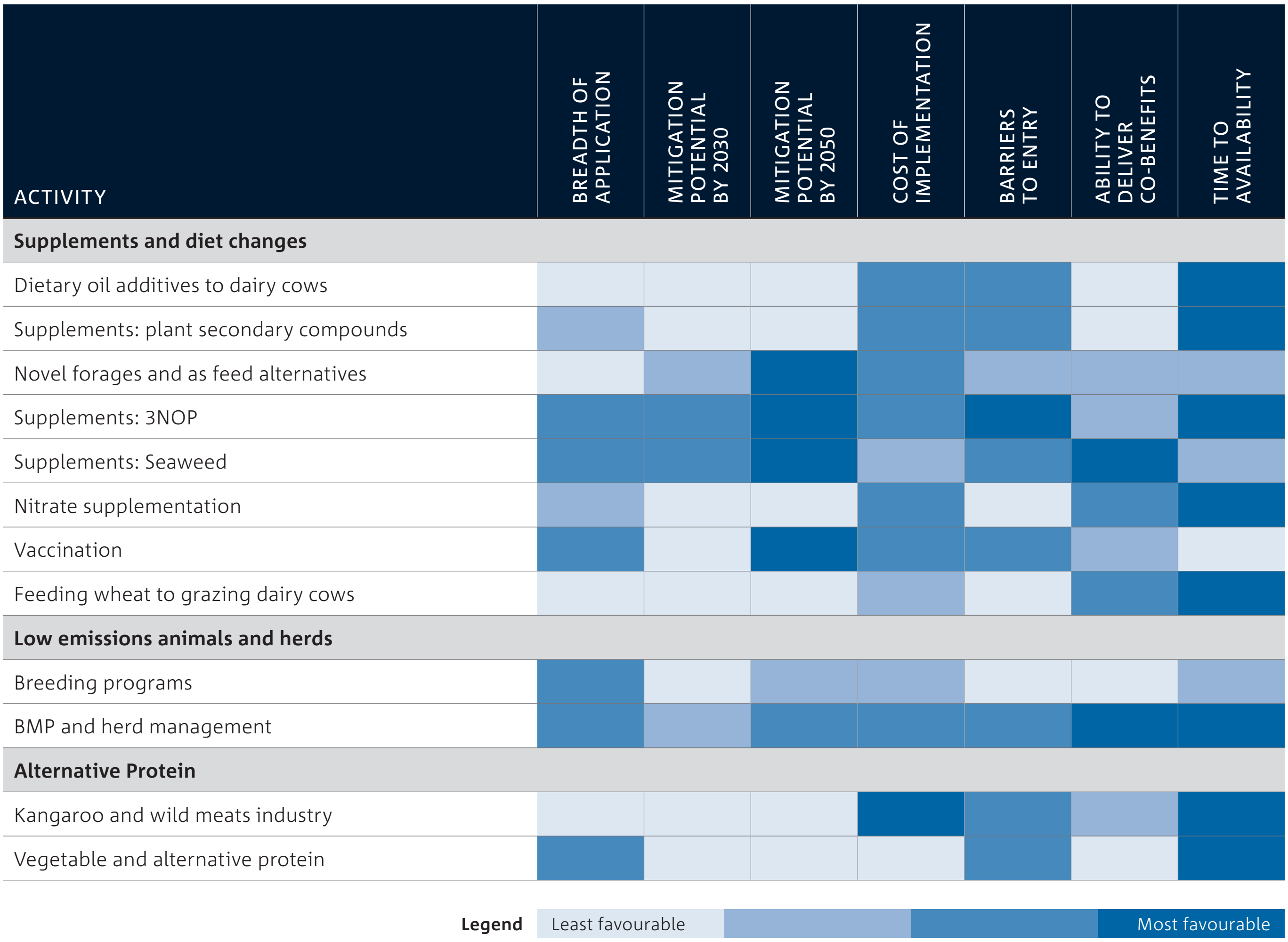
Several cross-cutting considerations were drawn from both the Crowdicity process and government and industry workshops. Many of which were consistently raised by participants across sectors and regions and are important framings in the building of legitimate and feasible pathways. They indicate key and common barriers and consideration and were used to shape priority actions. These are:

- **Setting goals and targets.** Setting goals and targets is critical to driving coordinated change. It is not the role of this project to define timebound and measurable targets. Instead, this development of targets should be done at an early stage by those responsible for enacting pathways to develop such targets. For this reason, objectives of the pathways are generic, and tables are provided to give an indication of potential abatement ranges of different options.
- **To get to a whole of economy or whole of sector net zero emissions status (or any other goal) not all gases need to be reduced to zero:** The livestock sector as a whole, for example has reduced the net emissions from lands and production systems utilised by the sector through increased land based sequestration offsetting emissions from animals which have also declined to a lesser extent through mitigation approaches based on management practices and breeding.
- **It is not just GHG reduction.** While each pathway highlighted GHG abatement potential, the magnitude of this potential is far from the only consideration for investment and innovation. Many products and therefore sectors will need to meet changing market demands for reductions in GHG intensity. One cattle producer, referring to the risk of potential future trade barriers based on greenhouse gas emissions intensity of product said, "I am fearful about market access". While enteric fermentation remains an important area of attention, there are significant risks for other commodities and products if they do not receive similar attention.
- **The sector may need the credits for its own market access.** Many agricultural opportunities for GHG sequestration and associated off-setting have been promoted as means for farm businesses to develop new income streams through offset markets. This opportunity needs to be carefully managed at farm, regional and industry scales as it poses a risk that agricultural products can be dissociated from GHG credentials if these are on-sold. That is, it is likely that short term returns from the sale of carbon credits will create long term risks for access to premium or specific international markets. One Northern Integrated cattle producer said. "we need to be clearer with what we are doing with our ACCUs…if we sell, we are passing on our benefit. They may cost a lot more later." Another producer said, "Industry will need those credits for themselves long term, not currently understanding the situation."
- **There is low trust in aggregators and poor understanding of markets.** The rapid emergence of markets and changing regulatory requirements around offsets is creating confusion and suspicion among farmers. Aggregators – who buy and resell carbon credits – have a variable reputation, limiting their ability to facilitate smooth adoption of opportunities, and participants at several workshops highlighted the need for improved regulation and oversight of aggregators. One cattle producer said, "There needs to be regulation around aggregators – they're getting a clear run and targeting some producers that are vulnerable and might tie these people to projects they can't get out of. We need regulation around information and make it easier for producers to understand. Messaging from aggregators makes it sound easy and risk free. Producers might not be thinking of the long-term ramifications".

- **Capacity to engage across the sector is highly variable.** There is significant variation in the degree to which enterprises can engage with GHG abatement or offsetting opportunities. Across pathways, participants highlighted that these emerging markets differentially advantage larger players, often in GHG intensive sectors, and especially where products are ultimately targeted to niche or premium markets. This may well contribute to further consolidation of large enterprises and the exit of smaller ones, especially as tariffs and other GHG associated export markets emerge. One horticulturist said "this is about both a cost and time barrier, if you are to go into carbon farming it is a lot of paperwork and this is a barrier too".
- **Sectors vary in prioritisation of GHG abatement.** The red meat sector has taken a relatively proactive stance, as has cotton. Other cropping industries appear to be more challenged by the transition with socio-cultural, infrastructure and R&D orientations creating path-dependencies that policy and market drivers for GHG reduction have not significantly shifted.
- **GHG abatement needs to be aligned to other production drivers and social and community needs.** Across areas participants highlighted emerging and future opportunities associated with natural capital accounting should be better integrated with GHG offsets. One livestock producer said "we need to think about the whole system" because this is how sequestration aligns with production drivers. A horticulturalist said they were prioritizing climate resilience because they "could get a better deal on insurance products if they lowered their risk' and was interested in how carbon markets could support on the ground actions. An agronomist in SE Queensland said, "how do you stop carbon markets getting disconnected from land management objectives." A finance sector participant said, "banks want to reduce portfolio risk and work on protecting natural capital valuation."
- **There is a need for access to credible and easy to use frameworks and analytics and decision support tools.** Across markets the need for robust scientific credentials for methods, accountability of measurement and verification, and the capacity to trace products and qualities along value chain are essential to the credibility of data in the system. Embedding these in decision support tools for producers can assist in evaluation of options.
- **Interoperability of systems and accounting is required:** Farm enterprises may produce a range of products and there needs to be a way to assign greenhouse gas footprints and reductions to the whole enterprise. In the words of a peak organisation leader "producers want to attribute systems on their farms to an industry initiative in comparison to each product (red meat, vs cotton, vs grain)".
- **Sovereign uncertainty is undermining industry action and participation in schemes.** Clear and stable policy to define market function needs to be consistent, ideally at an international level, but certainly across states and Federal Governments. One livestock producer for example said, "there is a lot of watching and waiting" and that they had a client who was "in denial that methane had to be counted. This is fine in Australia, but the global markets won't accept this".
- **Adoption will not happen with out a strong economic incentive.** A clear message from producers and industry representative bodies is that technologies and practice changes must be profitable or at worst cost neutral if they are to be adopted.

Livestock sector emissions

Table 4 Heat map of livestock emissions options against criteria (Appendix 1). The darker the colour the more favourable the activity ranks against the criteria (dark blue best, pale blue worst).



Technologies and methods to reduce methane from cattle could be the single largest contributor to emissions reduction in the Queensland agrifood sector (not withstanding vegetation and soil sequestration opportunities to create net emissions reduction). Discussions in the livestock industry workshop with producers highlighted that the leading beef producers are moving to develop and capitalise on opportunities to produce carbon neutral beef, especially through feed additives, improved mix of pasture species and vegetation offsets. Meat and Livestock Australia (MLA) have been proactive in setting a target of GHG neutrality by 2030 (the CN30 goal).

As part of this, MLA have set an interim goal of a 10% improvement in livestock productivity and 50% reduction in enteric methane emissions in 1.25 million cattle and 3.5 million sheep by 2025. Dairy Australia has the target of reducing their emissions intensity across the dairy supply chain by 30% by 2030. Meanwhile large retailers are increasingly signing up to science-based targets for beef, domestically and internationally. Industry leadership on vision and direction is strong.

Feed additives are still *emerging* but showing significant potential. Additives for containment systems are on the cusp of scaling, while for extensive systems they are in very early-stage emergence. Significant investment and technology development roadmaps are being developed for these technologies. Some still require testing and operationalisation, and the most prospective options still require progress through various regulatory pathways (APVMA, consideration of environmental impact, formal greenhouse gas reduction credit process for ERF or voluntary standards). Because most involve some additional cost or change of operational procedures, there is an important trialing process for producers to clarify the cost benefit in their contexts. The potential for these technologies will be realised first for containment producers (e.g. feedlotters) and for where animals can be fed a daily supplement (dairies and close to barn animals). This is a small proportion of the emissions from Queensland's livestock herd. From Table 4 (and consistent with the Technology Investment Roadmap) 3NOP (Bovaer) and *Asparagopsis* (red-brown anti-methanogenic seaweed) are the most prospective and scalable current supplement options. More work is required on product stabilisation and delivery systems for both products to develop reliable and verifiable GHG reductions through blocks and loose licks in extensive systems. An important element of uptake for these technologies in the absence strong subsidy or incentives will be the ability to demonstrate at least no decline in productivity or feed efficiency and hopefully substantiation of early evidence of productivity and profitability gains. These technologies are the target of the Federal Government programs and MLA CN30 Emissions Avoidance Plan with research funding directed at: 1) assessing feed additives including anti-methanogenic compounds in natural and marine and terrestrial bioactives; 2) Designing supplement delivery systems for feedlots and grazing. Commercial entities involved in marketing these technologies and early adopter industry partners are engaging in commercial trials to validate claims and understand operational implications of incorporation into enterprises. A further opportunity is to look at the use of these compounds in early rumen programming and then isolation of herds to maintain the low methane rumen biota. This may be another important way that these supplements can start to create an impact on grazing herds and may be assisted by grazing containment through actions such as virtual fencing. Although a possibility, review suggests that isolation and maintenance of changed rumen biota is not practically achievable for the foreseeable future given evidence of the rapidity of regression of biota (Goopy 2019).

Surfaced in the Crowdicity activity and reviewed in the scientific literature (see Black et al. 2021) are two other options relevant to supplements. A range of other supplements are available however scalability is low due either to adverse effects on animal health implications or productivity at doses necessary to induce significant effects, or for a range of Australian shrubs (e.g. *Eremophilia, Biserrula*) and plant compounds because of extraction costs and long development pathways though some potential exists from introducing into pastures or as inter-row cropping to provide feed during seasonal feed gaps. Some potential exists from the use of tropical legumes as plantation forage or feed supplements with both *Leucaena* and *Desmanthus* being identified in the Technology Investment Roadmap. They have both the potential to be included in silage for contained animals and incorporated into grazing systems. Inclusion of these legumes shows both moderate anti-methanogenic effect as well as some productivity gains. Collectively there is a bundle of options emerging in the supplement space that can tackle firstly the contained or near to barn situations that can later be scaled to grazing situations through technological advances (encapsulation etc) or with early animal rumen-biota modification.

Breeding options, both directed at either lower methane production for the same feed intake or lower methane with lower feed intake at the same growth rate are similarly ***emerging*** and have some promise though heritability for methane emission is low. While long lasting once achieved, the rate of change through breeding will be limited by the rate at which genes can be passed through national herds and for beef and sheep herds this is at 0.2–0.4% per year (though possibly higher for dairy if there is a shift in breeding trait weight which would come at the expense of genetic gains in production traits) (Black et al. 2021). For such a directed breeding program low-cost screening of sires for methane production would be required, and realistically this is only possible through genomic selection.

As with many agricultural systems the application of best management practice can reduce inefficiencies and in doing so reduce the greenhouse gas intensity of production, and in doing so, if area of production or number of animals is not increased lead to a reduction in emissions. Even if leakage of such gains occurs through increased scale of operations such changes improve greenhouse gas intensity of products and can improve market access or positioning. **The beef management method, a form of best management practice, is *emerging*** and being adopted by large producers with good systems, available capital and capacity. There is a good convergence of potential productivity gains (around 20%) and herd methane reduction (approx. 5%) to drive uptake however the method requires good and historical records and imposes a level of complexity that can create barriers for smaller businesses. While aggregators can play a key role, low trust can create resistance to adoption, and there is a clear role for trusted industry advocates. Widespread scaling will require industry capacity building and adoption and upskilling of records management skills and access to capital for infrastructure improvements.

Alternative protein industries are *emerging* and are providing alternatives to animal protein for some consumer segments, as well as helping meet rising global protein demand. New industries include V2 foods (v2food.com) producing plant-based mince products and Edenbrew producing animal free dairy from fermentation technology. While the global vegetable based protein market is expected to grow significantly, possibly from $29 billion in 2020 to around $162 billion by 2030 according to Bloomberg Intelligence, the global demand for animal-based protein is almost certain to remain high. Although shifts in diets domestically are evidenced by declining red meat per capita in Australia (down from 29 kg/capita/yr in 2018–19 to 24.2 kg/capita/yr in 2021–22 *ABARES agriculture commodities report March 2021*) this has done nothing to change the stable trend in Australian beef production (MLA industry projections 2021 show the number of head of cattle in 2021 to be approximately the same as 2016). It is possible that longer term global trends in diets may impact demand, for example if the EAT-Lancet diets were adopted (Willet et al. 2019), however, with an expected 70% growth in global protein production by 2050 required to meet human needs, a strong demand will continue for animal-based protein. It is unlikely within policy timelines that the emergence of alternative protein industries will change the emission contributions from the livestock sector in Australia: changes in domestic diet mix will be more than compensated by growing export demand.

While these technical developments taken together create some emerging opportunities, participants at the industry workshop highlighted low rates of adoption, especially among smaller producers. These were associated with the level of complexity of market entry, lack of trust in aggregators and assessors, and uncertainty about policy change that underpins market functioning. There was a clear concern that emerging carbon markets are already starting to change the structure of the farm sector and their supporting communities under 'lock it up and leave' approaches. According to participants, the financial, transaction, opportunity, and other costs of accessing emerging GHG (offset and premium) markets are starting to differentially benefit larger corporate and private businesses in the sector, because of economies of scale and scope that allow them to develop, assess and adopt technologies and practices more rapidly. However, even managers of large cattle businesses reported that GHG markets represented challenges for their business, especially where the same business operates in multiple state jurisdictions with differing rules. Participants highlighted that cooperatives and other industry owned models such as AgCarE (developed by AgForce) have the potential to speed adoption and benefit more farmers, and suggested models from industries where cooperatives have a longer history, such as dairy, or countries where these models have been in place for longer (e.g. Spain). Another option for 'lifting all boats' is to have a central clearing house for information about technology, market opportunities and rules, and to consider investment in public extension to support more rapid adoption of practices that have public and private benefit and ameliorate sector-wide risks.

The abatement figures given this report are feasible/attainable abatement and not technical potential abatement (after Eady et al. 2009). Attainable potential is the abatement achievable with concerted efforts in technical and management changes, policy adjustment and shifts in current land management priorities. It must be recognised that these estimates contain a combination of biological, technical, adoption and implementation uncertainty.

Developing a pathway with the livestock sector

As discussed, a range of feasible activities are available to livestock and there is good investment by producers, emerging industries looking to provide solutions and government driving trials and demonstrations. If the current emerging activities can be scaled, 4.5Mt/yr of abatement is attainable by 2030 and a higher level technically possible (Figure 6). Much of this is driven by supplements, and attainment requires successfully applying these technologies to the extensive grazing sector. There is considerable R&D required if this is to occur, and uncertainty is high about the level of abatement possible.

With strongly emerging activities the role of government and industry as described in the 39 actions listed in Table 5 are directed at sharing knowledge and extension activities to create awareness and appetite for change, creating frameworks and tools for benefits and costs to be contextualised in enterprise situations, driving trials and demonstrations to meet both regulatory requirements and build trust to accelerate, and building an enabling environment for rapid scaling through smoothing regulatory requirements, negotiating credentialing and build/support infrastructure requirements and sector skills and capability building to enable adoption.

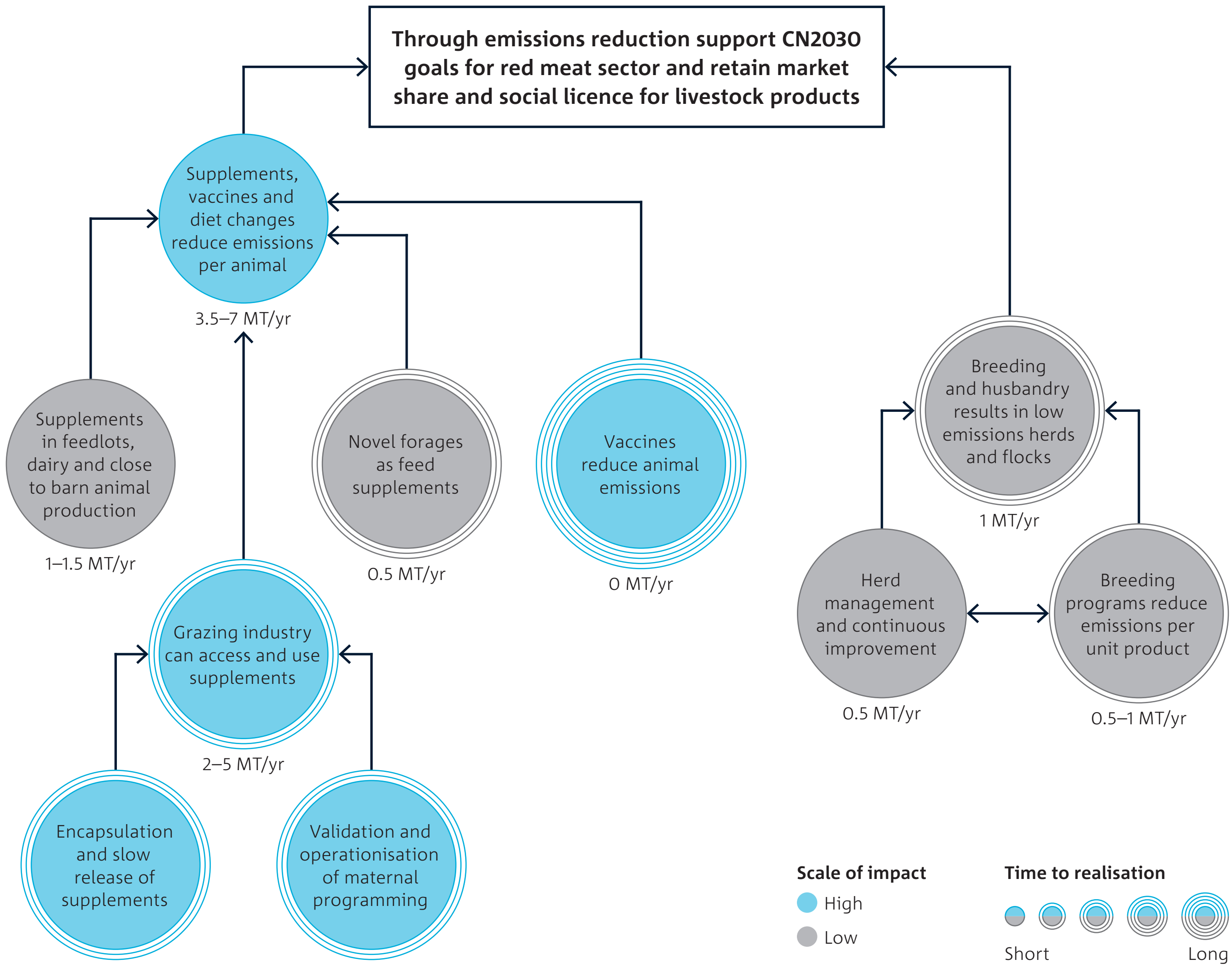


Figure 6 Pathway map for livestock emissions reduction. Numbers adjacent to activity are best case annual scope 1 emissions reduction by 2030 assuming successful acceleration of activity scaling. The actions identified in the blue enabler boxes are those that would accelerate or create the environment for scaling of all the activities. Scale of impact ranks high (blue) to low (grey); outlines indicate time to realisation.

Table 5 Livestock emissions actions and feasible abatement from Figure 6.

ACTIVITIES	FEASIBLE ABATEMENT	GOVERNMENT PRIORITY ACTIONS	INDUSTRY PRIORITY ACTIONS
Supplements, vaccines and diet changes reduce emissions per animal			
Activity 1: Supplements in feedlots, dairy and close to barn animal production	1–1.5 MT/yr	**GE2:** promote infrastructure for scaling of technologies including hatcheries for seaweed to ensure broader benefit accrues to the state from transition **GE7:** Advance regulatory barriers, provide land/sea access and invest in necessary trialling to reduce time to market of technologies and ensure Qld and early adopter to maximise capture of market premiums for producers **GE1:** support trials and demonstration of technologies (3NOP and seaweed and and novel technologies in Qld based operations	**IE2:** Build collaborations along value chains to test and validate technologies from producer to retailer to clarify QA and supply chain requisites and understand distribution of benefit and risk among nodes. **IE4/IE7:** Provide up to date information on emerging options and adoption pathways to producers; build trust and credential of products; test consumer acceptance of approach **IE5:** support trials and demonstration of technologies (3NOP and seaweed and I think novel technologies in Qld based operations: focus on saftey, and dose response in different contexts and formulations and dose intervals
Activity 2: Grazing industry can access and use supplements: Encapsulation and slow release of supplements and Validation and operationalisation of maternal programming	2–5 MT/yr	**GE3:** Stimulate knowledge sharing between projects and researchers to accelerate technology development **GE1:** invest in trials and measurement of outcomes from various encapsulation approaches as well as from maternal dosing and herd isolation **GE7:** Engage early with regulators and market around conditions required for crediting emissions reductions in extensive grazing systems	**IE5:** support trials and demonstration of new encapsulation technologies and trailing of maternal programming **IE2:** Build collaborations along value chains to test slow release technologies as well as application of engineering/behavioural solutions to ensure herd isolation. **IE4/IE7:** Provide up to date information on emerging options and adoption pathways to producers; build trust and credential of products; test consumer acceptance of approach
Activity 3: Novel forages as feed supplements	0.5 MT/yr	**GE3:** Stimulate knowledge sharing between projects and researchers to accelerate technology development, support information networks **GE7:** Fund build of enabling information architecture to enable formal capture of emissions reduction **GE7:** Investigate concessional loans, subsidies or financing of pasture regeneration with forage legumes as drought resilience measure and emissions reduction strategy	**IE7:** Build modelling framework that formalises the data and observations about forage legumes so realised methane reduction and productivity can be better predicted **IE4:** Promote adoption through extension services and provision of bioeconomic modelling data of financial, feedbase resilience and environmental benefits data. **IE1:** Support and potential establish co-research activities with emerging networks and action groups such as the the Lucaena network
Activity 4: Vaccines reduce animal emissions	0 MT/yr (not possible to forecast)	**GE3:** Stimulate knowledge sharing between projects and researchers to accelerate technology development; keep a watching brief on advancement.	**IE1/IE2:** Keep a watching brief on advancement. Engage in forward research planning as required; test consumer acceptance of approach

ACTIVITIES	FEASIBLE ABATEMENT	GOVERNMENT PRIORITY ACTIONS	INDUSTRY PRIORITY ACTIONS
Breeding and husbandry results in low emissions herds and flocks			
Activity 1: Herd management and continuous improvement	0.5 MT/yr	**GE2:** invest in sector digital infrastructure and management capacity to simultaneously drive improved land management outcomes and support smaller producers to adopt herd management methodology. **GE3:** invest with industry in defining and in extension services to support adoption of best practice management. **GE5:** look to align best practice livestock management with other public markets (e.g. LRF) to allow benefit stacking and overcome cost of implementation.	**IE4:** Build sector capacity through extension material and demonstrator days to implement 'herd management method' approaches as best management practice **IE6:** drive digital enablement of sector so that records required for enhanced management required for systems such as herd method are standard **IE5:** continue assessment of improvements and drive investment into improvement GHG intensity of products to drive further opportunities for aligning productivity x emissions reduction reward
Activity 2: Breeding programs reduce emissions per unit product	0.5–1 MT/yr	**GE3:** Stimulate knowledge sharing between projects and researchers to accelerate understanding of breeding potential	**IE5:** Continue to invest in building a reliable dataset of matched individual animal methane production and genetic profile to evaluate value/cost effectiveness of genomic selection **IE2:** Build collaborations and cooperatives to accelerate information acquisition and establish value of emissions to support inclusion of methane reduction traits in breeding values
Underpinning and common			
IE2: Build producer cooperatives among users to allow more rapid assessment and adoption of technologies			
GE3: Have a central point of information about technology. market opportunities and rules to assist producer engagement in opportunities and consider investment in public extension to support more rapid adoption of practices and trust in information provision			
GE3: Provide industry baseline calculators and management change scenario modelling to allow producers to explore opportunities within their enterprise contexts			
GS9: Recognise that Agricultural transition to low emissions will require coordinated policies in the ministries responsible for agriculture, energy, economic development and environment and environment, and look to leverage overlapping goals for credit stacking and regional development opportunities when scaling of technologies has infrastructure requirements; evaluate and where possible reduce regulatory barriers to emissions technology adoption and scaling			
GS3: Engage in international policy developing around livestock GHG intensity and methane emissions and secure future export markets for Australia produce			
IS3: As Australian beef drives down its emissions per unit product build enhance brand reputation already based on safe to add additional environmental credentials, and IE2 work along national and international supply chains to leverage this for market access and where possible price premium			

Cropping and horticulture

Cropping and horticulture industries in Queensland are diverse and vary widely, and, consequently, this project's ability to engage across this range was limited by time and resources. Nevertheless, it was clear that there are highly variable levels of progress; large, high value export crops such as cotton have done significantly more towards GHG abatement than smaller horticulture sectors and extensive bulk commodity sectors. Correspondingly, GHG accounting and abatement was viewed as unlikely to deliver price premiums for farmers and was only a current barrier to market entry in crops like cotton, where market barriers were being imposed by manufacturers or retailers. Many other industry participants saw the challenge of transition for this sector as largely typified by downside costs, with minimal benefits – "just adding another layer of stuff to do for farmers". In some sub-sectors participants also frequently highlighted barriers to engagement in carbon markets because of the scale of their industry, GHG abatement not yet being seen as a priority given the significant cost and time barriers for participation. They also highlighted increasing interest and concern to address GHG emissions driven by sustainability credentialling from buyers (e.g. retailers) and growing social license pressures.

Synergies and potential trade-offs between soil health and carbon were noted as areas needing greater understanding through applied science and on-farm trials, especially facilitated by improved and cheaper soil testing. Participants discussed the emerging potential in this area associated with precision agriculture and automation, which have potential synergies in improving productivity and reducing GHG intensity. However, there was some concern that people who have already made big changes (e.g. adopted zero-till, stubble retention and other 'best practices") will not benefit from carbon and natural capital markets (as they are existing practices and, therefore, do not provide additionality). Further, concerns were expressed that in complex mixed systems with diverse species and rotations, standardised methods were not going to apply, making accounting for GHG changes prohibitively complex and expensive.

Costs of shifting to more efficient irrigation systems, driven by renewables were a focus of discussion. Key differences between cropping and horticulture systems relate to the capital intensity of shifting locked-in production systems and the minimal associated returns. For example, much of the infrastructure supporting the sugar industry are "stuck on a course" – where irrigation schemes, high pressure pumps and old irrigation technology are aligned such that shifting one element requires shifting multiple components at once across many businesses. Such lock-ins were apparent but not as challenging for cotton growers, where the CRDC are currently investing in R&D to transition towards more efficient and solar systems.

More central to the challenges of the cropping and horticulture sectors than total emissions reduction is mitigating risks associated with externalities, such as nitrogen run-off into reef catchments, impacting social license, climate change vulnerability, and retaining market access in the face of greenhouse credentials of products extending to 'scope 2' and 'scope 3' GHG contributions.

In looking at pathways for low emissions in the cropping and horticulture sector it is important first to acknowledge the low contribution of emissions from this sector to agriculture's emission total, albeit a relatively high emitter per unit area especially for horticulture. At around 2.5 Mt CO_2-e/yr of 'scope 1' emissions it is not a significant contributor to the national challenge. A recent report on the grains industry (Sevenster et al. in press) showed in a national benchmark study that on-farm emissions ("scope 1") comprise around 60% of cropping emissions, dominated by the application of fertiliser and lime (26%) and denitrification of residual nitrogen (20%) and fuel use (11%). Off-farm emissions ("scope 3") are dominated by the embedded emissions in fertilisers (22%) and crop protection products (11%). A study on emissions from sugar farming defining the system through to processing (Rein 2010) shows emissions with a similar breakdown with scope 1 nitrogen fertiliser contributing 20%, crop chemicals (including lime) 20%, on farm energy use including irrigation 15% and cane burning 10%. Renouf and Wegener (2007) broke these down slightly differently with 59% of emissions being associated with soil nitrification/denitrification, 20% from electricity for irrigation, 9% for transport and machinery, and 5% from fertiliser and pesticide production and another 5% from bagasse burning.

More recent actions such as the SmartCane BMP (Connolly et al. 2018) have reduced emissions (up to 20% per unit product) from fertilisers (by up to 20%), pesticides (up to 48%) and fuel use (up to 20%) though the broad sources remain the same. The horticulture industry presents a very different profile with 70% of total emissions being fuel and electricity, 20% being fertiliser and soil emissions and around 10% from waste and refrigerant loss to the atmosphere. All sectors have opportunities to generate offsets through soil carbon and increased permanent vegetation on farms and this will be dealt with separately in the Offset section though the actual opportunity varies greatly: this section will deal with emissions reduction.

Recognising this broader challenge for the cropping and horticulture sector, the subsequent analysis focuses on emissions reduction strategies that drive down 'scope 1' emissions but also consider how reductions in indirect or 'scope 2' and 'scope 3' emissions can support improved GHG intensity of products. In this section we do not deal with offsets or on-farm energy use but focus on nitrous oxide (N_2O) emissions from on-farm fertiliser application and embedded emissions in fertiliser products and means by which precision agriculture can reduce on-farm traffic and by more precise delivery of chemical products reduce 'scope 3' emissions.

Approaches to **reducing emissions from fertiliser management are scaling** and in many cases they are embedded into industry best management practices and well supported by calculators. Simple approaches like the 4Rs (right fertilser source, right rate, right time and right place) are widely used for extension (e.g. Nutrient Stewardship). Canegrowers has the SIX EASY STEPS program to enable growers to calculate an appropriate rate of nitrogen fertiliser and this is tied into the Smartcane best management practice which allows farmer accreditation. For the grains sector tools such as Yield Prophet use calculations of ground water store and seasonal forecasts to predict whether there will be a return on investment from additional fertilisation. Horticulture has the Hort360 BMP program (https://www.hort360.com.au/). In the absence of strong GHG reduction incentives in some subsectors over fertilisation is a risk strategy to avoid growth and yield being limited by nitrogen in exceptionally good years when high profits can be made (that exceed inefficiencies from over fertilising in less good years); effectively actions to protect profitability across the whole climatic cycle. **Insurance products are emerging** as ways to reduce this risk for farmers: the opportunity for this exists because the risk of yield loss is overestimated by most farmers (Thorburn et al. 2020).

Enhanced efficiency fertilisers (EEF) are designed to improve nutrient use efficiency, minimising nutrient losses and comprise controlled release and fertiliser containing urease or nitrification inhibitors. In wheat for example, 40% of the nitrogen applied is assimilated with similar loss rates in flooded rice systems (Chen et al. 2008). Effectiveness of enhanced efficiency fertilisers appears to be variable with biogeography, with clear evidence of effectiveness in temperate climates but with some uncertainty of effectiveness in sub-tropical and tropical environments and this may impact on their use in Queensland (Rose et al. 2018) though other studies in corn (Dang et al. 2021) and sugar cane in glasshouse (Bell et al. 2014) show strong emissions reduction effects. This is consistent with meta-analyses that show the effectiveness of EEF has been variable (see summary review by Dang et al. 2021). While in principle reduction in environmental losses of N associated with fertiliser application should represent a win-win for agriculture, there is additionally some evidence that EEFs can lead to a reduction in crop yield, albeit while improving GHG efficiency of products. **Enhanced efficiency fertilisers are emerging** as an opportunity and could be cost effective, but need better diagnostic information on what situations will they be effective to really scale. Information on the impacts of soil type and application time in relation to rainfall events on the effectiveness of EEFs is required.

For the grains industry, adoption of rotations of different crops that are more profitable but reduce GHG emissions in the short term is realistic, if more information is available to growers on what these look like at a local level. Detailed analysis has been done for some regions (Hochman et al. 2021). Sevenster et al. (in press) show that for the grains industry up to a 40% reduction in the greenhouse gas intensity for scope 1 emissions only is possible through an optimum mix of rotations and perfect nitrogen requirement matching. Selecting the best combination of rotations improved emissions intensity by up to 4.5%. Use of **crop rotations for grains is widely used and scaling** and could be further enhanced with improved decision support and availability of bioeconomic modelling.

Green hydrogen and ammonia and consequently green N fertiliser are emerging technologies. Most planned production of green hydrogen and ammonia in Australia is expected to become (fully) operational around 2030. Estimates suggest that globally green ammonia could become cost-competitive in niche markets around 2030 (Fasihi et al. 2021) but more general cost competitiveness may take as long as 2050 to achieve (Advisian 2021). Sevenster et al. (in press) suggest that 100% adoption of green fertiliser would give a 11% reduction in GHG emissions as well as emissions intensity. They model the reduction in scope 3 emissions as 50% compared to present. Key to their development will be the inclusion of ammonia loop production facilities into hydrogen supply infrastructure. For further greenhouse gas advantage, a move away from urea as the preferred fertiliser to other forms such as calcium/ammonium nitrate and anhydrous ammonia, fertiliser forms that have the advantage of not having an embedded carbon molecule that gets released back to the atmosphere as the nitrogen is released from the fertiliser. A shift to domestic fertiliser production will have the advantage of reducing Australia's reliance on imported fertiliser which represents a risk to agricultural production and as has been shown in 2021 can expose agriculture to strong price rises when global supply chains and production is disrupted.

Current adoption of **controlled traffic farming is scaling** in Queensland at around 60% across the grains industry (ABARES 2021). Full implementation could deliver another 1% reduction in total emissions and around an additional 3% in emissions intensity improvement (calculated from Sevenster et al. 2021). In some sub-sectors such as horticulture traffic can comprise a higher proportion of emissions, up to 50% according to Page (2011), and these may be important to individual sector emissions intensity. Broader application of precision agriculture in the form of **robotics and precision chemical use is emerging** as an opportunity and will make trivial differences to greenhouse gas emissions but will reduce chemical use and reduce ecotoxicity loads. Digital connectivity in some rural areas is an impediment to controlled traffic farming and precision technology.

Table 6 Heat map of cropping and horticultural emissions options against criteria (Appendix 1). The darker the colour the more favourable the activity ranks against the criteria (dark blue best, pale blue worst).

ACTIVITY	BREADTH OF APPLICATION	MITIGATION POTENTIAL BY 2030	MITIGATION POTENTIAL BY 2050	COST OF IMPLEMENTATION	BARRIERS TO ENTRY	ABILITY TO DELIVER CO-BENEFITS	TIME TO AVAILABILITY
Cropping fertiliser – on farm							
Fertiliser management							
Enhanced efficiency fertilisers							
Development on nitrogen insurance							
Fertiliser – scope 3							
Green fertiliser							
Precision agriculture							
Crop rotations							

Legend Least favourable — Most favourable

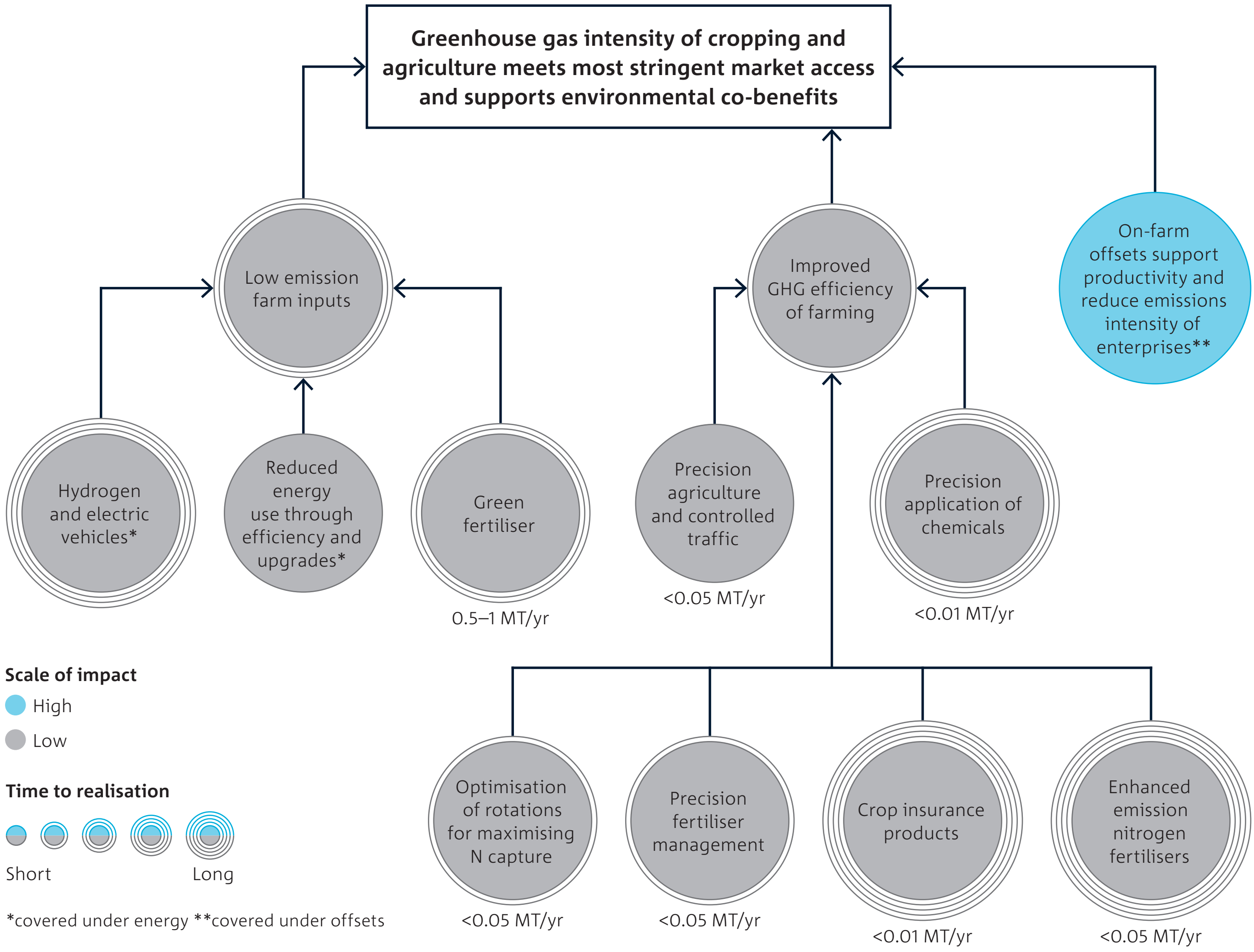


Figure 7 Pathway map for cropping and horticulture emissions reduction. Numbers adjacent to activity bubbles are best case annual scope 1,2, 3 emissions reduction by 2030 assuming successful acceleration of activity scaling. The actions identified in the blue enabler box are those that would accelerate or create the environment for scaling of all the activities. Scale of impact ranks high (blue) to low (grey); outlines indicate time to realisation. Offsets and on farm energy use are covered in other sections.

Table 7 Cropping emissions actions and feasible abatement from Figure 7.

ACTIVITIES	FEASIBLE ABATEMENT	GOVERNMENT PRIORITY ACTIONS	INDUSTRY PRIORITY ACTIONS
Low emission farm inputs			
Activity 1: Hydrogen and electric vehicles	Covered under Energy		
Activity 2: Reduced energy use through efficiency and upgrades	Covered under Energy		
Activity 3: Green fertiliser	0.5–1 MT/yr	**G2/GE4/GS7:** Support emerging industrial hydrogen transitions and encourage inclusion and partnership for green fertiliser production and offtake agreements (for example emerging NSW Hunter example) **GE8:** Look at opportunities for renovation of water treatment plants and the like for micro hydrogen generation to accelerate uptake of hydrogen **GE7:** Evaluate regulatory barriers to use of alternative forms of nitrogen that may be lower emissions or easier to produce from ammonia loop production facilities (e.g. homeland security constraints on ammonium nitrate)	**IE1:** Drive government/farming community/finance dialogue on accelerating green fertiliser **IE2:** Look to engage in emerging green fertiliser developments and build forward demand and offtake agreement to derisk capital investment **IE3:** prepare analysis of transition requires for alternative fertiliser forms
Improved GHG efficiency of farming			
Activity 1: Precision agriculture and controlled traffic	>0.05 MT/yr	For all Activities	For all Activities
Activity 2: Precision application of chemicals	>0.01 MT/yr	**GS5:** Support training and extension programs for adoption of best management practice	**S4:** Build niche markets around BMP certified products
Activity 3: Optimisation of rotations for maximising N capture	>0.05 MT/yr	**GS1:** Look at how best management practice can be reward in environmental markets	**IE6:** Build baselines around multi-criteria performance

ACTIVITIES	FEASIBLE ABATEMENT	GOVERNMENT PRIORITY ACTIONS	INDUSTRY PRIORITY ACTIONS
Activity 4: Precision fertiliser management	>0.05 MT/yr	**GS6:** build M&E systems that look at broader system benefits from on farm investments **GS2:** provide concessional loans mechanism to support capital purchase	**GS6:** build M&E systems that look at broader system benefits from on farm investments **GS2:** provide concessional loans mechanism to support capital purchase
Activity 5: Crop insurance products	>0.01 MT/yr	For all Activities	For all Activities
Activity 6: Enhanced emission nitrogen fertilisers	>0.05 MT/yr	**GE1:** Stimulate R&D and real-world demonstration projects of EEFN products and build corpus of knowledge of where the products are most successful **GE4:** Build coalitions around crop insurance and look at mechanisms to scale up adoption; provide public investment in risk assessment to underpin these products including key knowledge infrastructures in climate and crop models	**IE5:** Drive investment to support experimentation in use of EENF and crop insurance products **IE6:** Build enterprise level nitrogen emissions baselines and guidance and extension around the utility of emerging technologies in abating
On farm offsets support productivity and reduce emissions intensity of enterprises			
	Covered under Offsets		
Underpinning and common			
GS4: Build underpin digital infrastructure (soils, climate layers) to support decision support tools			
GS5: Investing in capability development to allow knowledge intensive farming			
GE2/GE6/IE1/GS8: Industry and government to articulate a vision for hydrogen support agriculture sector with collective action to accelerate opportunities for deployment into agricultural vehicles and the development of green fertiliser			
IS3/GS3: Continually benchmark Australian crop and horticulture products and lobby for international lifecycle assessment protocols and standards that are appropriate for Australian producers			

Offsets

Many studies have indicated that significant abatement potential exists within the Australian land sector (Eady et al. 2009, Polglase et al. 2013, Bryan et al. 2016, Gao and Bryan 2017). This is reflected by the part that offsets play in Australia's national emissions response. Identifying the true potential of offsets relies heavily on discriminating between the technically feasible abatement (abatement that is constrained by biological, edaphic, and climatic factors, as well as limitations imposed by the legal requirements of the methodologies) and the economically viable potential (what is viable given profitability of the current land use, project costs, and carbon price). Beyond this what is realised will be further constrained by socio-political concerns. While offsetting approaches and the market for them is established and the offsets area could well be considered as being in a ***scaling phase***, industry interviews showed that there are a variety of significant barriers to scaling, as well as opportunities and risks associated with offsets. Overcoming these will require building an appropriate incentive environment by uncovering alignment with co-benefits as well as through market mechanisms.

Participants described a variety of **barriers and challenges** to wider adoption and implementation of offsets:

- Uncertainty over the changing policy and market environment.
- Lack of a common understanding across the sector about options and reasons for carbon farming. One producer, for example, said that some farmers question "Why do people want to pay them to grow rubbish?".
- Lack of or poor baselines in many areas.
- Complexity of markets create barrier to entry. Although there are some good sources of information and relatively straightforward points of entry to ERF and Land Restoration Fund (LRF), many farmers find the array of different systems and approaches across carbon and other natural capital accounting very complex. This creates a barrier to wider engagement. It is also an opportunity for governments and research organisations to provide targeted information.
- Asymmetry of information availability on the costs, risks and benefits of offset actions were widely held as a concern.

A number of **opportunities** were revealed:

- Readily accessible tools that help farmers understand their baseline and reveal what abatement options are available for their enterprises.
- Linking carbon methodologies to natural capital accounting approaches and other environmental markets to encourage multiple, stacked benefits and deeper income streams.
- Identifying win-wins where offsetting can support core enterprise goals. Good examples exist such as the planting of shelter belts (Donaghy et al. 2009; McKeon et al. 2008; Mendham 2018).

Participants widely agreed that offsets present significant **risks** that may take years or even decades to be revealed, and so require particular care in design, implementation and monitoring. Key risks raised included:

- **Loss of agricultural land and production to carbon farming** land uses that require less capital, and labour-intensive management, potentially leading to hollowing out of rural communities.
- **Wider implications of carbon farming lands** on adjacent lands through pest, weed and fire issues.
- **Farmers may need their own on farm offsets** to reduce the greenhouse gas intensity of products for market access (or collectives may need to generate a pool that can be available).
- **Decoupling of farm carbon from integrated farm management** may lead to a loss of aggregated value creation.

Recent analysis (Roxburgh et al. unpublished) reveals that nationally at the current carbon price of \$15 t CO_2e^{-1} the major opportunities shown in Table 8 are significant. Many of the options increase markedly as carbon price (or benefit from stacked credits) increases. For this report we concentrate on establishing new forests and increasing soil carbon and include the others for context and for note.

Detailed analyses of these practices exist and we do not review them here but focus on actions by government and industry to achieve both abatement and co-benefits through their scaling. A detailed technical risk assessment of different methods under the ERF and an analysis of co-benefits that can drive uptake is provided in Roxburgh et al. 2020 (Table 8 and Figure 9).

Table 8 Offset potential and risk associated with various ERF method modelled at \$15 t CO_2e^{-1}. The ratio of national to Queensland abatements from Eady et al. 2009 are used to estimate potential abatement for Queensland.

APPROACH	ERF METHODS	NATIONAL ECONOMIC ABATEMENT AFTER ROXBURGH (UNPUBLISHED) MT CO_2e^{-1} yr^{-1}	POTENTIAL QUEENSLAND ABATEMENT (SCALED USING EADY ET AL. 2009)	RELATIVE RISK RATING FOUND BY ROXBURGH ET AL. 2020 TABLE S2 (LOW NUMBER IS LOW RISK)
Re-establishment of native forest cover	Human Induced Regeneration, Native Forest and Managed Regrowth	4.4–26	2.5–14	19
Protecting existing forests	Avoided Clearing of Native Regrowth	7.1	1.4	9
Establishing new forests	Plantation forestry, Farm Forestry, and Reforestation by Environmental Plantings	1.5–7.8	0.3–1.5	31
Increase soil carbon	Measurement of Soil Carbon Sequestration	0.6–4.8	0.1–1	39
Sequestration as part of savanna fire management		2.7 to 5	0.4–0.8	22

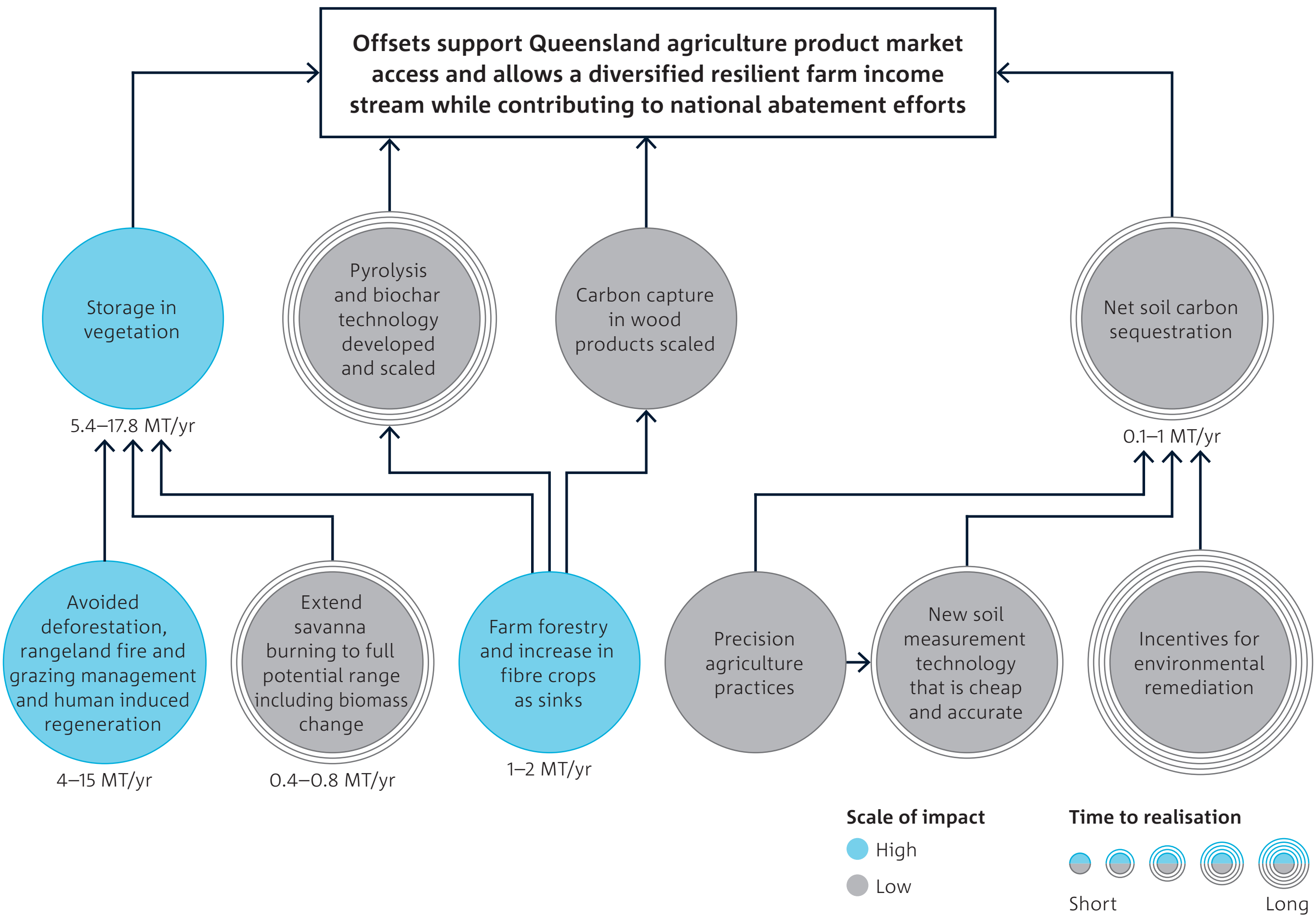


Figure 8 Pathway map for Offsets. Numbers adjacent to activity bubbles are guess sequestration assuming \$15 t CO_2e (see Table 9 for details). Scale of impact ranks high (blue) to low (grey); outlines indicate time to realisation.

Activity

CO-BENEFIT / DIS-BENEFIT	MEASUREMENT OF SOIL CARBON SEQUESTRATION IN AGRICULTURAL SYSTEMS	SAVANNA FIRE MANAGEMENT	HUMAN INDUCED REGENERATION	NATIVE FORESTS FROM MANAGED REGROWTH	REFORESTATION BY ENVIRONMENTAL OR MALLEE PLANTINGS	REFORESTATION AND AFFORESTATION	MEASUREMENT-BASED METHODS FOR NEW FARM FORESTRY PLANTATIONS	PLANTATION FORESTRY	AVOIDED DEFORESTATION	AVOIDED CLEARING OF NATIVE REGROWTH	BLUE CARBON
Farm productivity											
Improved crop/pasture yields & farm productivity	Strong co-benefit				Marginal/potential co-benefit	Marginal/potential co-benefit	Marginal/potential co-benefit				
Improved/diversified income streams	Strong co-benefit	Strong co-benefit	Strong co-benefit	Strong co-benefit	Strong co-benefit	Strong co-benefit	Strong co-benefit	Strong co-benefit	Strong co-benefit	Strong co-benefit	
Improved animal welfare (e.g. shelter, reduced stress)					Marginal/potential co-benefit	Marginal/potential co-benefit	Marginal/potential co-benefit				
Soil Health											
Improved soil health via increased SOC	Strong co-benefit										
Increased soil stability/reduced soil surface erosion	Strong co-benefit	Marginal/potential co-benefit	Marginal/potential co-benefit	Marginal/potential co-benefit	Strong co-benefit	Strong co-benefit	Strong co-benefit	Strong co-benefit	Strong co-benefit	Strong co-benefit	
Mediation of dry-land salinity				Marginal/potential co-benefit	Strong co-benefit	Marginal/potential co-benefit	Marginal/potential co-benefit		Marginal/potential co-benefit	Marginal/potential co-benefit	
Biodiversity/conservation											
Increased biodiversity & ecosystem function/resilience	Strong co-benefit	Strong co-benefit	Strong co-benefit	Strong co-benefit	Strong co-benefit	Strong co-benefit	Strong co-benefit	Marginal/potential co-benefit	Strong co-benefit	Strong co-benefit	Strong co-benefit
Reduced biodiversity e.g. mono-cultures/homogenisation								Marginal/potential dis-benefit			
Improved conservation outcomes	Marginal/potential co-benefit	Strong co-benefit	Strong co-benefit	Strong co-benefit	Strong co-benefit	Strong co-benefit	Strong co-benefit	Marginal/potential co-benefit	Strong co-benefit	Strong co-benefit	Strong co-benefit
Water quality/quantity											
Reduced nitrogen/phosphorus/pesticide leakage	Strong co-benefit			Marginal/potential co-benefit	Marginal/potential co-benefit	Marginal/potential co-benefit	Marginal/potential co-benefit	Marginal/potential co-benefit	Marginal/potential co-benefit	Marginal/potential co-benefit	
Reduced water yields				Marginal/potential dis-benefit	Marginal/potential dis-benefit	Marginal/potential dis-benefit	Marginal/potential dis-benefit	Marginal/potential dis-benefit	Marginal/potential dis-benefit	Marginal/potential dis-benefit	
Improved water quality	Marginal/potential co-benefit			Marginal/potential co-benefit	Marginal/potential co-benefit	Marginal/potential co-benefit	Marginal/potential co-benefit	Marginal/potential co-benefit	Marginal/potential co-benefit	Marginal/potential co-benefit	Marginal/potential co-benefit

Legend Marginal/potential dis-benefit | Marginal/potential co-benefit | Strong co-benefit

Figure 9 Matrix of co-benefits and dis-benefits associated with ERF methodologies (reproduced Table 19 from Roxburgh et al. 2020).

Activity

CO-BENEFIT / DIS-BENEFIT	MEASUREMENT OF SOIL CARBON SEQUESTRATION IN AGRICULTURAL SYSTEMS	SAVANNA FIRE MANAGEMENT	HUMAN INDUCED REGENERATION	NATIVE FORESTS FROM MANAGED REGROWTH	REFORESTATION BY ENVIRONMENTAL OR MALLEE PLANTINGS	REFORESTATION AND AFFORESTATION	MEASUREMENT-BASED METHODS FOR NEW FARM FORESTRY PLANTATIONS	PLANTATION FORESTRY	AVOIDED DEFORESTATION	AVOIDED CLEARING OF NATIVE REGROWTH	BLUE CARBON
Socio-economic											
Conflict/competition with other land uses				Marginal/potential dis-benefit	Marginal/potential dis-benefit	Marginal/potential dis-benefit	Marginal/potential dis-benefit	Marginal/potential dis-benefit	Marginal/potential dis-benefit	Marginal/potential dis-benefit	Marginal/potential dis-benefit
Emissions offsetting (e.g. bioenergy, product substitution						Marginal/potential co-benefit	Marginal/potential co-benefit	Strong co-benefit			
Reduced air pollution (e.g. particulates)		Strong co-benefit	Strong co-benefit								
Employment creation		Strong co-benefit	Strong co-benefit					Marginal/potential co-benefit			
Poverty alleviation		Strong co-benefit	Strong co-benefit								
Introduction of new/diversified products to market					Marginal/potential co-benefit	Marginal/potential co-benefit	Marginal/potential co-benefit	Marginal/potential co-benefit			
Promotion of new technical innovations	Marginal/potential dis-benefit	Marginal/potential dis-benefit	Marginal/potential dis-benefit								
Promotion/enhancement/expansion of an industry		Strong co-benefit	Strong co-benefit								
Harmonisations/improved efficiency of land use	Marginal/potential dis-benefit			Marginal/potential co-benefit	Marginal/potential co-benefit	Marginal/potential co-benefit	Marginal/potential co-benefit	Marginal/potential co-benefit	Marginal/potential co-benefit	Marginal/potential co-benefit	
Recognition/assimilation/respect of local/Indigenous knowledge		Strong co-benefit	Strong co-benefit								
Promotion of equity in access to land, decision-making, knowledge		Strong co-benefit	Strong co-benefit								
Increased community resilience		Strong co-benefit	Strong co-benefit								
Enhanced capacity for Indigenous communities to meet land stewardship		Strong co-benefit									
Improved or clarified land tenure/use rights for local communities		Marginal/potential dis-benefit	Marginal/potential dis-benefit								

Legend Marginal/potential dis-benefit | Marginal/potential co-benefit | Strong co-benefit

Table 9 Offset actions from Figure 8.

ACTIVITIES	FEASIBLE ABATEMENT	GOVERNMENT PRIORITY ACTIONS	INDUSTRY PRIORITY ACTIONS
Re-establishment of native forest cover	2.5–14 MT/yr	**GE1:** look to build rangelands methods that are cost effective to capture significant opportunity and cobenefit alignment **GS6/GE1:** invest in risk assessment due to climate change and develop robust guidelines for resilient forest cover (fire management; thinning etc) **GE2:** Work with regulators and markets to more flexible permeance period discount instruments that deliver payment for increased cover for periods of varying length to overcome constraints from permeance obligations (carbon renting)	**IE5:** Build strong evidence of benefits and disbenefits of woody vegetation on farm to support primary enterprise activities **IS3/IE4:** Industry and retailers could invest in insetting into their supply catchments to support natural capital values and reduce product GHG intensity and support their ESG agendas
Protecting existing forests	1.4 MT/yr	**GE5/GS2:** Examine where protecting forests clearly aligns to multiple values and look to build supporting markets **GS5:** Invest in transition pathways for workers and service industries if land use change implement	**IS5:** Advocating for policy and support to enable transitions, especially considering how change forest harvesting will impact current employees or stakeholders, undertake skills mapping to inform employment training programs
Establishing new forests	0.3–1.5 MT/yr	**GE2:** Review land valuation principals and encourage a broader valuation that include natural capital values associated with on farm woody vegetation **GS1:** Examine coherence between energy rating and full greenhouse life cycle assessment of use of timber in construction **GE2/GS9:** Continue to invest in understanding the implications of landuse change, especially on runoff and fire impacts	**IE5:** continue to drive investment into engineered wood products and biochar options to increase demand for farm forestry **IE1:** create awareness and pathways for on farm forestry to support a broader range of benefits and income spreading options **IE4:** provide information and training on site by species by silviculture to decrease risk in reforestation/afforestation in a changing climate
Increase soil carbon	0.1–1 MT/yr	**GS4:** Continue to support and invest in long term soil carbon measurement and soil attribute assessment as part of federated national programs **GS6:** Provide knowledge on risks and uncertainty in soil carbon farming and provide trusted point of reference and context relevant assessment tools that demonstrate plausible sequestration and reversal risks **GE7:** Support research into low cost measurement and next generation model:data fusion approaches to drive down compliance costs **GS2:** Explore financing approach to overcoming barriers to entry including supporting baselining and assessments	**IE5:** continue to support trialling and demonstrating of new approaches and equipment (including proximal sensing of soils) and build corpus of knowledge of on farm benefit to enrich extension activities **IS3/IE4:** Industry and retailers could invest in insetting into their supply catchments to support natural capital values and reduce product GHG intensity and support their ESG agendas **IE6/IE4:** Support formation of platforms in which information can be shared on soil carbon farming experience, returns, service providers, and that might allow pooling across property boundaries to reduce compliance costs per tonne of carbon
Sequestration as part of savanna fire management	0.4–0.8 MT/yr	**GE1/IE5:** Trials in the <1000m rainfall zone **GS6:** Climate modelling and fire frequency risk analysis; weed distributional analysis	**IC1:** share best practice and monitor performance of savanna burning programs to support broad based ESG goals including Indigenous economies

ACTIVITIES	FEASIBLE ABATEMENT	GOVERNMENT PRIORITY ACTIONS	INDUSTRY PRIORITY ACTIONS
Underpinning and common			
IS3: Support and accelerate branding of co-benefits associated with different offset methods to increase purchase prices and end-user value (as per savanna burning projects)			
IE3/GS3: Foresighting and information gathering that shapes how agriculture should respond to future carbon markets that may require agriculture to use own offsets for market access			
GS6: Monitoring and evaluation to document co-benefits and to expose emerging risks associated with scaling of project; use information to adjust risk reversal buffers and permeance period discount			
GS5/IS4: Develop tailored region specific outreach programs for the agriculture sector to overcome knowledge as barrier to entry; support codes of practice to build trust between service providers and producers; build platforms for farmers to share experiences and learning about offset projects			
IS2: Develop carbon offset portfolio tools to allow carbon industry to reduce risk from geographically clustered portfolios or construct portfolios with less risk based on counter-cyclic risks			
GE1/GS1: Consider concessional loans or other financial instruments to encourage project uptake where financial barrier to uptake exists or delayed cash-flows presents a barrier (e.g soil carbon)			
GE5/GS1: Look at mechanisms by which other environmental or regional funding actions can be aligned to carbon markets (as the LRF achieved) to increase returns to practice change by stacking co-benefits			
GS8/IS1/IS4: Link decarbonisation hubs and industrial and energy sector decarbonisation to agricultural sector offsetting (soil carbon, reforestation) that builds regional economies and resilience.			
IS4: Build and quantify offsetting practices (soil carbon, farm forestry) into best practice including M&E and credentialling to support claims			

On farm energy

On-farm energy use is a relatively small contributor to GHG emissions and agriculture is only a small player in a larger national transition that is typified by technical and regulatory complexity. It is beyond the scope of this study to fully detail recommendations around this larger energy transition. Nevertheless, participants in the Crowdicity process and workshops highlighted important considerations and priorities for the development of a clear pathway in this area and to ensure agriculture benefits early from transition. A fundamental message is that there are diverse opportunities that have co-benefits for agricultural productivity and profitability. These range from power use efficiency, GHG abatement and profit gains at a farm business level, through to improved alignments between investment in new infrastructure, rules, and innovative applications of emerging technologies, as well as scaling and consolidation of well-established renewable options through shifts in policy, protocols and infrastructure to enable peer-to-peer energy exchange and microgrids that support agricultural energy generation and use. It is also important to point out that much of the focus here is on scope 2 emissions. This means that emissions reductions associated with on-farm energy, beyond efficiency measures that simultaneously save on energy costs, will often be most applicable to producers of low GHG products.

For this report more industrially oriented options that need to be integrated with the agrifood sector activities for widescale adoption are considered as part of the regional demonstrator section, even though some of these may be relevant to large agribusinesses. The three options below are perhaps the most prospective areas for short-term intervention for on-farm energy:

- **Peer-to-peer, microgrids and smart metering:** Solar photovoltaic energy is in a scaling and consolidation phase, with widescale adoption hampered by large-scale technological and policy challenges of re-developing the network to support distributed and sporadic energy generation, including through development of viable storage options. Beyond the technological challenges, addressing grid reconfiguration and lock-ins will require cross-jurisdictional policy coordination at the highest levels, and is currently a stumbling block to the development of local and regional microgrids and peer-to-peer sharing arrangements. Building these might allow farmers to pool local energy generation to run high wattage pumps and other equipment at significantly reduced costs (ARENA and CEFC, no date).
- **Piloting alternative Fuels:** Alternative fuels include hydrogen, biofuels, and solar fuels and are currently in an emergence phase. Significant interest and opportunity for example exist for sugar mills to diversify, supporting local economies and including providing lower cost power back to supplying farmers however this will require policy and regulatory changes. Agrifood applications are likely to start as pilots where there is a co-benefit of fuel development or use, and where scale is sufficient to warrant investment. For example, byproducts of hydrogen production (oxygen and ozone) can offset the current high cost of production through application to waste such as municipal sewage. Similarly, large abattoirs may be able to recoup costs of biogas generation from waste streams and adoption can be accelerated if incentives or regulatory pressure come to bear. As participants pointed out, larger agribusinesses are better equipped to develop such innovative opportunities, both through access to capital and internal capacity for analysis and research, and their capacity to navigate regulatory and planning processes. These types of largescale pilots are covered under the regional demonstrators section.
- **Energy efficiency and precision agriculture options:** On-farm equipment, solar powered pumps, transport and machinery are areas where emerging technologies and options could scale rapidly, providing modest GHG abatement. Precision agriculture can save energy through applications, such as variable rate irrigation (VRI), which can reduce energy usage associated with pumping as well as N_2O emissions, while resulting in higher yields. There are already competitive options for the use of light electric vehicles and equipment on farm. Precision agricultural equipment also has the potential to create labour and fuel efficiencies. These can be considered as part of normal agricultural development, which can be aided by business level energy audits and lifecycle analysis, and industry and government supporting improved extension and service provision. Energy audit programs and Energy Efficiency Loans are available as industry programs and commercial products respectively. For intensive agriculture in Queensland significant savings and emissions can be realised, but these are highly case specific and can vary from increasing pump or tractor use efficiency (Chen et al. 2008). Numerous agricultural cases (see Qld Farmers Federation Case Studies) indicate that significant benefits can accrue through these programs.

In broad terms, on-farm energy transition is usefully viewed as a subset of a wider energy sector transition that is underway and likely to accelerate in the coming decade. Without effective awareness and coordination some of the rapid technological change and associated policy, infrastructure and other shifts could be disruptive for the agrifood sector.

A major opportunity exists for agriculture to create niches in which emerging technologies can be developed, ensuring these are developed in ways that are fit-for-purpose to support agriculture's transition to a low GHG future.

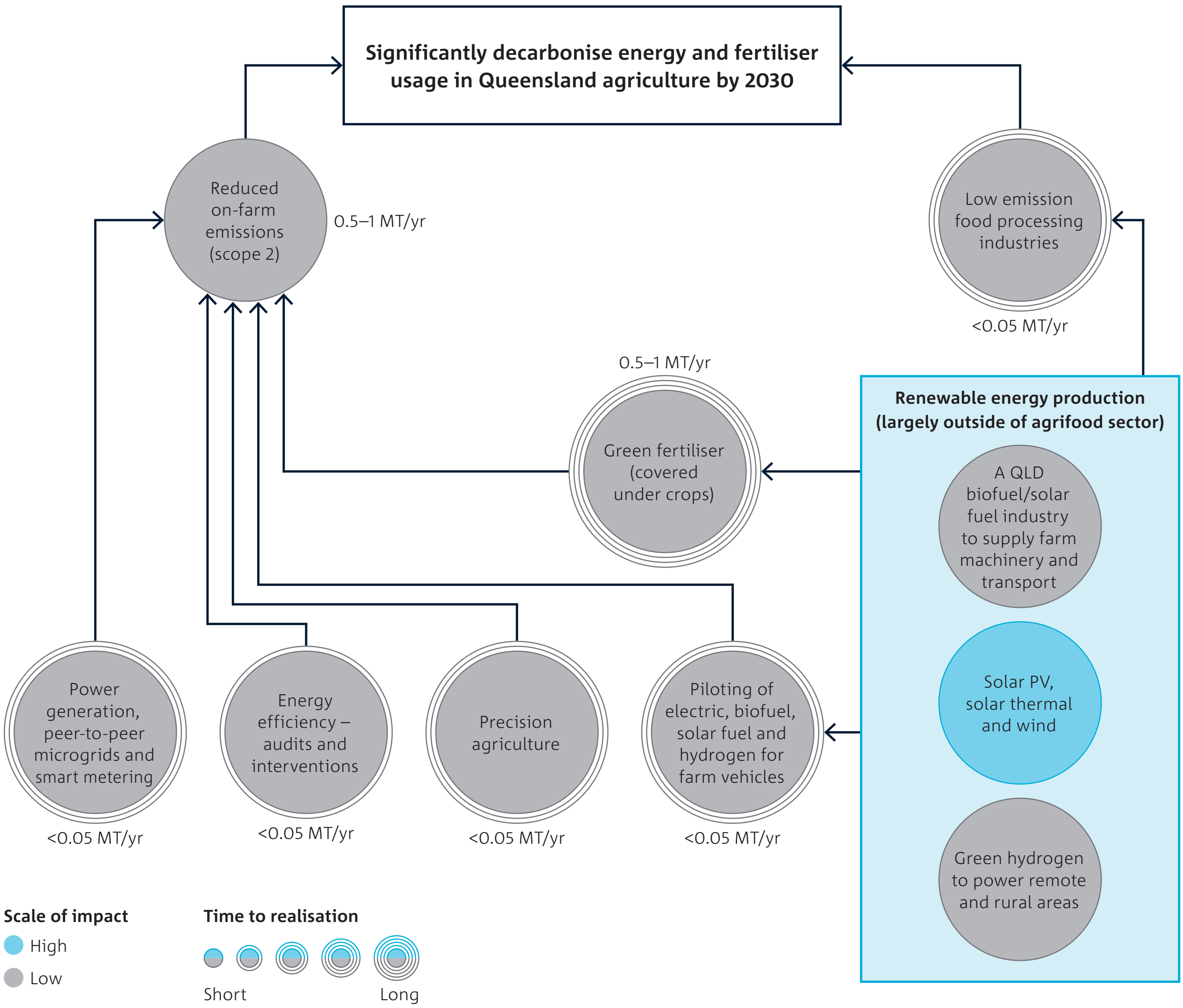


Figure 10 Pathway map for on-farm energy emissions reduction. Numbers adjacent to activity bubbles are best case annual scope 1, 2, 3 emissions reduction by 2030 assuming successful acceleration of activity scaling. Scale of impact ranks high (blue) to low (grey); outlines indicate time to realisation.

Table 10 On-farm energy actions and feasible abatement from Figure 10.

ACTIVITIES	FEASIBLE ABATEMENT	GOVERNMENT PRIORITY ACTIONS	INDUSTRY PRIORITY ACTIONS
Power generation, peer-to-peer microgrids and smart metering			
Activity 1: Enable fringe grid innovation in power generation, sharing and use	0.01–0.05 MT/yr	**GE2:** Ensure agricultural interests/ transitions and considerations are effectively considered at different levels of policy and investment related to decentralisation of power generation and use, through active involvement in working groups **GE8:** Map areas where there are potential systems co-benefits from different forms of energy infrastructure developments (e.g. thermal solar/ammonia/ mine rehabilitation) **GS4:** public investment in pilots and R&D that can bring these to scale/de-risk initiatives	**IE2:** Coordinate regional development activities to ensure opportunities are able to be capitalised on by agribusiness and farming communities **IE5:** Create investment partnerships, especially through new generation and energy exchange networks **IS1:** Build cross-industry networks that enable (for example) forward contracts, supply surety and consistent operating conditions around new generation/supply options
Piloting of electric, biofuel, solar fuel and hydrogen for farm vehicles			
Activity 1: Support early trialing and adoption of alternative options for agricultural machinery	0.01–0.05 MT/yr	As above (three action all relevant) **GS1:** Consider when and how rebates and subsidies affect uptake of emerging fuels and influence coordinated cross-jurisdictional approach	**IE1/IE4:** build coherent approach to information sharing and clearing houses for understanding fuel options and pathways, including rigorous trial information, to prevent misinformation and information asymmetry challenges **IE5:** Define niches and protected spaces where emerging fuels can be safely trialled in agrifood context to enable rapid adoption and scaling of successful fuels (e.g. associated with regional demonstrators)
Energy efficiency audits and interventions			
Activity 1: Expand energy audit program for medium to large agrifood businesses	0.01–0.05 MT/yr	**GS6:** Extend programs such as Energy Savers Plus Program Extension to monitor and evaluate GHG abatement options associated with energy savings **GS8:** Consider low interest loans schemes to facilitate more rapid and greater uptake of energy efficiency interventions **GS2:** Consider procurement policies for government agencies of agricultural products base on GHG credentials of businesses	**IC1:** Extend best practice standards to drive rapid uptake of energy and GHG audits and interventions **IE6:** At a sectoral level, develop energy and GHG efficiency goals and drive industry efficiency through programs that have mutual benefit in terms of business financial performance and GHG outcomes. **IC2:** promote regional and sectoral stories of energy efficiency schemes to increase business interest and uptake

ACTIVITIES	FEASIBLE ABATEMENT	GOVERNMENT PRIORITY ACTIONS	INDUSTRY PRIORITY ACTIONS
Precision agriculture			
Activity 1: Define priority R&D and pilot/demonstration projects which can use PA and other farm management approaches to significantly reduce energy intensity of sector	<0.01 MT/yr	**GE1:** Define priority options for investment in precision ag RD&E on the basis of cost savings for farmers and GHG abatements at sectoral level **GE3:** Stimulate knowledge sharing between projects and researchers to accelerate understanding drivers of adoption and adoptability of PA technologies that drive co-benefits	**IE5:** Continue to support R&D in PA, especially VRI, including research on segmented drivers of adoption and adoptability, and evaluation **IE6:** Develop capability to support water, energy, GHG baselining for sectors/industries to support best practice and whole of sector communications/marketing to consumers and investors
Underpinning and common			
GE2: Prioritise actions that could deliver multiple public and private benefits **GE3:** Stimulate knowledge sharing between projects/niches; public funding for knowledge exchange mechanisms, building incubators and supporting early movers; providing information-based advisory tools **GE8:** Use opportunities when renovating aging infrastructure to support low emissions agriculture (hydrogen production from wastewater plants etc) **GS7:** Support for industrial clusters – especially in the case of agriculture creating opportunities for spillovers from industrial and mining sector transitions into agriculture **IE5:** Drive investment to support experimentation, especially where technology and practice change appropriate to transition aligns to existing goals **IE6:** Engage in building credible baselines to assess contribution and assess policy and interventions			

Regional demonstrators

Demonstrator projects go beyond trialing individual options at a farm scale and are ***emerging*** as a way to help overcome fears associated with disruption caused by low emissions transitions and a way to show that additional social and economic value can be created. They can create cross sectorial integration of multiple low GHG options within a region creating additional value that goes beyond those possible with single abatement opportunities. Demonstrators can allow testing, and embedding into new business and social models, low emissions activities and technologies. Participants at the Demonstrator workshop mentioned options such as: new renewables industries and associated jobs; local micro-grids; hydrogen demonstrators; efficient machinery trials; biodiesel production, distribution and use networks; cooperatives and incentives to pool resources, aggregate offsets, or improve scale efficiency and coordination for farming businesses. A key message from workshop participants was that regional demonstrators need to be aligned to different regional strengths and opportunities. For example, in South-East Queensland, a food bowl region with strong eco- and food- tourism ties is emerging that could link consumer and community education with emerging approaches to holistic farm and regional land management for multiple sustainability outcomes, with targets set around key events such as the 2032 Olympics. In Barcaldine, an emerging renewable energy hub could facilitate new industrial development in the region, oriented by circular-economy principles. A hydrogen hub in Gladstone could become a nucleus for a range of agrifood transition elements, from fertiliser generation to low emissions intensity manufacturing. A common element of these regional demonstrators is that they provide opportunities to stack multiple activities and outcomes, creating positive feedbacks for economic development and GHG mitigation, building new hubs of activity that can attract financial, human and social capital.

Across these diverse forms of regional demonstrators, participants identified consistent underpinning enablers and challenges. Support and coordination across levels of government are integral to success. Evaluation of regulatory barriers are required where these inhibit establishment. This is especially so when catalysing entrepreneurial action and investment from the private sector, and especially from new and existing industries. Key individual leaders, whether in the private or public sector, play a critical role but need to be endorsed to do so by both government agencies and relevant groups within a community. This enables leaders to be legitimised and proactive in implementing an agreed vision which will often include multiple economic, social and environmental goals.

A key challenge is that demonstrators are rarely centrally planned and implemented. As one participant said: “No-one is accountable or responsible”. This means coordination, leadership and governance are the central challenge. Nevertheless, ensuring rules and processes imposed by different levels of government are effective but streamlined to deliver these multiple outcomes and do not unnecessarily restrict timelines or flows of capital into regions. Another challenge is building and attracting people with the right skills to coordinate across diverse groups, often in quite technical areas, yet with clear-eyed business focus and attention to making the financial/investment case around opportunities. Taken together, leadership, institutions and processes, flows of capital and common goals can align to create rapid change. This view from participants aligns with the emphasis of coordination of roles and enabling functions across government and industry in Tables 2 and 3. They also highlight that there are numerous existing local and regional initiatives that could be fast-tracked from emergence to scaling phases, each serving distinct demonstrator functions.

Opportunities for triggering points of action to catalyse transition may come from government (e.g. NSW Special Activation Precincts), industry (Gladstone with deep market exposure internationally) or community (Barcaldine with a local innovator to drive community desire). What is often missing is the enabling structural support to navigate the opportunities (and complexities) of cross sectorial decarbonisation in each region. Roadmaps rarely have the supporting structures to operationalise the required actions.

There is little precedent to draw upon to indicate what different governance and supporting mechanisms can be built into these different types of demonstrators, instigated in different places (community, industry, local government) that will improve their chance of success and increase the equity and inclusiveness of outcomes. Some explicit examples are given in Table 11 for a number of emerging Demonstators and in Table 12 we show more broadly the actions key government and industry can undertake to catalyse, accelerate and support transition.

Table 11 Some potential regional demonstrators already forming in Queensland.

EXAMPLE DEMONSTRATOR	INITIATING POINT	PRIMARY GOALS/ ASPIRATIONS OF INSTIGATORS	POSSIBLE BROADER AGRICULTURE SPILL OVERS	SUPPORTING ACTIONS THAT CAN ACCELERATE AGRICULTURAL BENEFIT
Barcaldine	Community and civil community leaders initiated and developed a joint venture with local councils – RAPAD (Remote Area Planning and Development Board)	Taking advantage of a possible REZ to revitalise the region, in particular agri business	Hydrogen urea plant, prickly acacia biomass to biochar for potential steelmaking and agricultural use, large scale glass houses for protected horticulture	Benchmarking and tech-economic assessments; investment for new industries; digital frameworks for accounting and credentialling of products; innovation incubators and market support
Gladstone	Incumbent industry leaders and Climate Leaders Coalition (CLC) A potential hydrogen hub will provide opportunities	Driven by gas export industries who aim to reduce market exposure CLC drive to support just transition in a low carbon future	Access to a large supply of green energy and potentially green urea could drive diversification of agribusiness Offsetting and insetting opportunities as the Gladstone industrial hub decarbonises	Creating the incentive and support for agriculture to gain benefits from industrial transition including concessional funding for supporting necessary infrastructure; dialogue of how activity can support long term economic resilience and regional development
Lockyer valley	Potentially government procurement through a climate positive 2032 Olympics	A low emissions horticulture and agribusiness sector in the Lockyer Valley	Access to markets (beyond the Olympics)	Increase access to renewable energy (for irrigation) and green fuel, provide coordinating and digital infrastructure to regional carbon reporting, grants for conversion of diesel machinery to ammonia fuel, region scale nature-based offsetting; regional branding

Table 12 Actions to catalyse and sustain regional demonstrators and decarbonisation node.

ACTIVITIES	GOVERNMENT PRIORITY ACTIONS	INDUSTRY PRIORITY ACTIONS
Industry and institution development		
Activity 1: Catalyse a low emissions region	**GE2:** Asses the potential of regions through a criteria of transition readiness to identify early adopters **GE3, GE4, GC3:** Work with developing nodes of decarbonisation action (be that communities or industry) and provide sponsorship and enabling support through small grants, digital infrastructure and supporting facilitation of co-designed pathways **GE6:** Regional economic development plan (in partnership with community and industry) that embeds circular economy principles within and across value chains, and cross sectoral activities	**IE1, IE2, IC2, IE4:** Connect with government, including local government, industry and community to drive the co-creation of credible pathways that span value chains that support regional decarbonisation (for example supporting green steel production with spill over benefits for Ag in hydrogen production and woody vegetation biochar production for industrial input) **IE5:** Drive investment and support the piloting and testing of new technologies that align with regional decarbonisation and other goals (such as sustainability) **IE3:** Model impacts of regional transition to identify barriers to adoption within industry (including outside of region implications)
Activity 2: Integrated Policy and planning to drive low GHG economic development	**GS1:** Allow flexibility in regulations to test and pilot new technology and co-location of industries to drive emissions reduction and resource sharing **GE2:** Incentive sharing of resources and the flow of new products and benefits to the region (e.g. hydrogen generation to support local fuel needs) **GC1:** Learnings from testing and piloting of new technology and resources sharing to inform changes in policy, regulation and standards: provide best practice guidance	**IE3, IS1:** Where decarbonisation nodes are developing, in partnership with government and local industry undertake material flows analyses and identify opportunities for resource sharing that reduces emissions **IS5:** With other innovators and community bodies, advocate for enabling policy and regulation to accelerate the transition of emerging decarbonisation nodes
Activity 3: Governance models, consolidated reporting and M&E	**GS7 (GC3):** Create (or support the creation of) supporting leadership governance to co-ordinate action in decarbonisation nodes to drive progress, broker shared vision and actions, and report on impact **GE7:** Provide enabling digital infrastructure to support consolidated reporting (either data standards for easy integration or digital platform) to reduce the cost of reporting **GS6:** An M&E system track emissions reduction, co-benefits metrics and impact of supporting infrastructure and innovation incubator	**IS1:** Actively participate in (or create) a governance model to co-ordinate action in the region to drive progress, shared vision and actions, and report on impact **IE6, IE7:** Build credible monitoring and measures of emissions and work with governing body to deliver regional level emissions reporting that protects commercial confidentiality while providing credible reports on emissions and co-benefits

ACTIVITIES	GOVERNMENT PRIORITY ACTIONS	INDUSTRY PRIORITY ACTIONS
Directed investment and infrastructure		
Activity 1: enabling infrastructure to support the transition	**GE8:** Use opportunities when upgrading aging infrastructure to support low emission technologies and provide opportunities for colocation of industry to embed circular economy principles **GS4:** Invest (and partner) in new enabling infrastructure such as low emissions transport hubs, digital infrastructure and regional energy generation in the fringe grid zones	**IS2, IS5:** With other innovators and community bodies, advocate for enabling infrastructure to support sharing of resources
Activity 2: Directed Investment for niche opportunities and supporting transition	**GE1, GE2:** Support the testing and piloting of new low emissions technologies that provide multiple benefits and structure grants program to scale according to need (e.g. more government invest for SMs) **GS2:** Use directed procurement to support developing decarbonisation nodes (for example 2032 Olympic food sourcing from regional decarbonisation hub) **GS1, GS8:** Incentivise acceleration of transition through access to low interest finance and tax incentives	**IS1, IS3, IS4:** Regional branding for the decarbonised nodes for differentiated products to reduce costs to individual businesses and improve access to green financing
Capability and participation increased		
Activity 1: Co-ordinated training and skills development to ensure access to new opportunities	**GC2:** Learnings from co-designed pathways to inform just transition policies to enable access to opportunities **GS5:** With Universities, Tafe and other training bodies develop courses to ameliorate skills gaps	**IS5:** Early identification of the impacts of transition on employees to inform government planning **IS5:** Undertake skills mapping to inform government and employer training programs
Communication, extension and incubation		
Activity 1: Knowledge building and innovation incubator	**GE3, GS6:** Provide a function to allow for market scanning, technoeconomic evaluation and provide incubation support for niche technologies	**IE2, IE4, IC1:** Sharing of best practice knowledge and public reporting to demonstrate emissions reduction and co-benefit
Activity 2: Public communication and extension	**GE3, GE6:** Marketing and online material, including a public dashboard to document benefits of actions and desired co-benefits (from M&E) and robust extension to support adoption and translation of research	
Underpinning and common		
GS9: There is a need for coordinated actions across all levels of government and the various departments to smooth the path and incentivise the transition. This will require clear roles around collaboration for each level of government to avoid duplication, for example the federal government may take responsibility for energy transformation grants and regulation for testing and piloting new technologies such as biodigesters to convert waste water from feedlots to fuel or fertiliser, state government to address state regulations, may provide the innovation incubator capability to commercialise and scale the technology and local government may provide co-location and access to underpinning infrastructure **GS3:** Engage in international policy dialogue to support needs of domestic industry especially in trade markets, some examples may include federal government ensuring Climate Active carbon neutral certification is consistent with internationally recognised standards that shape markets		

Overarching recommendations and next steps

Reducing and offsetting GHG emissions and developing from Queensland's agricultural sector is currently driven by emerging and anticipated market drivers, which are, in turn, driven by changing trade barriers and policies to avoid dangerous climate change, globally. Queensland's agricultural sector is exposed to trade barriers and these may form around the GHG intensity products. Importantly, this means that the challenge ahead is not only about reducing overall emissions (largely livestock emissions and generating offsets), but for Queensland's agrifood products to meet international market requirements or standards of emissions intensity.

OVERARCHING RECOMMENDATION 1

The focus needs to be on emissions intensity of products not just the net greenhouse gas contribution of the sector.

The State's agrifood sector has lead-time to reduce GHG from the sector. If this lead time is not used well then future market access remains uncertain. But the transition, as we have discussed, is not entirely of in the hands of agricultural producers. For example, some sectors such as cropping, require action on hydrogen generation capacity and the development of a green fertiliser industry to determine whether, or not, Australian producers lag systematic change in competitive countries. Agriculture needs a seat at tables where this coherent policy and action agenda is shaped. The outcome for Australian agriculture will be the result of policy decisions in multiple Ministries and the investment decision of capital investors into Australia.

OVERARCHING RECOMMENDATION 2

The sector has already been proactively engaging in lowering greenhouse gas emissions, sustaining and accelerating this engagement is important to capture the upside of a low emissions transition in agriculture.

Sovereign uncertainty, and a diffuse and fragmented view of agriculture's future as the world transitions to a global low emissions economy is a headwind to action. In the absence of a strong *existing* regulatory framework, public and private sectors will need to continue to work together in a coordinated way to sponsor and drive innovation pre-emptively. They will need to enable early development and trialling (emergence), and wider adoption and scaling of practices and technologies. Coordinated action should target niches where exporters, wholesalers or retailers are targeting the growing consumer and investor market for low GHG products, as well as into rapidly developing offset markets. Industry and government should work together to develop market and non-market based instruments that provide financial and other incentives for reducing GHG emissions.

OVERARCHING RECOMMENDATION 3

Industry and government should work together to develop market and non-market based instruments that provide financial and other incentives for reducing GHG emissions.

As discussed, offsets are a pinch point for the sector. The national dialogue, and focus on lowest cost low emissions transitions, has framed farm-generated offsets (soil carbon and reforestation-afforestation) as a useful bridging strategy pending the development and implementation of other technologies. Indeed, the Wilmot soil carbon credit sale shows that this strategy may well be transnational. However, primary producers must be well informed, capture their fair share of the rewards available from carbon markets and agriculture may also need to retain offsets to reduce product emissions intensity to maintain market access or avoid punitive tariffs into premium markets. This is a conversation that needs to be held across jurisdictions and involve both government, industry advocacy groups and producers. The forum for this to be a constructive and farsighted conversation is not apparent, even though there is considerable energy in the public and private sectors, as well as considerable public investment (i.e. the Land Restoration Fund, the Future Drought Fund) in moving to a low emissions future.

OVERARCHING RECOMMENDATION 4

There is an urgent need for clear vision and distributed information to producers on the risks and the rewards of land sector generated offsets particularly with regards to developing barriers to market access.

The model for coordinated action proposed here draws together the five pathways detailed above and embeds them within a wider distributed governance framework, supported by national technical networks across research and industry and an innovation hub/incubator that supports market scaling and creates opportunities for conversations such as raised earlier on offsets (Figure 10). This model rests on cross-industry and government leadership to catalyse an enabling environment and comprises three key interacting elements:

1. **Working Groups:** For each pathway Working Groups would drive sectoral and regional change through the pathways described in previous sections. Technological change is fundamental to this model and is the focus of the Pathways Working Groups (coloured diamonds) and Regional Working Groups (blue oblong).
2. **Governance Group:** rapidity and efficacy of emergence and scaling will need to be catalysed by a proactive and well-coordinated approach to governance. A high level, overarching Governance Group would coordinate across scales and drive state-wide prioritisation and investment in R&D and industry development (middle green oblong) as well as overseeing the development and embedding of strategies, and advice across State Government agencies and coordination with other jurisdictions (bottom green oblong). This group would thus drive key x-scale priorities and outcomes (bottom grey box).

3. **Innovation facilitation:** An innovation incubator is included here as a function rather than necessarily a formal organisation. It could be a formal organisation or informal network but is essential for developing better connections between national technical capability across research and industry to identify and address specific challenges. This function would have the flexibility to draw on national as well as state, regional and local technical capability to experiment, innovate and drive market outcomes. A useful model of formal organisation for this function is a hub that operates as a 'boundary organisation' with accountability to industry, research and government, and that has the in-house technical capability to assess and direct innovation priorities systematically and sequentially. Such an organisation may be able to be developed to work across multiple sectors on GHG-related transitions.

The model proposes connecting and signalling channels between the steering and orientation function of the industry and government governance role and the technology development networks. Crucially, the proposed approach to spanning industry and government relies on development of agreed targets and priority actions to advancing them and removing roadblocks. This would be the first steps of both working groups and the overarching governance group. Setting up science-based targets and strategic projects informed by the key recommendations for each pathway would provide a foundation for funding and investment in key areas. Critically important in this structure is to allow for ways that communities of interest can be formed in areas that span the scope of working groups and come together to influence directionality in research and policy that enables opportunities along supply chains or that integrate multiple greenhouse mitigation or sequestration opportunities. For example, a community of interest may develop around aviation fuels that may span working groups into energy and offsets. Others may exist around the use of carbon markets to support Great Barrier Reef protection works. This explicitly recognises the requirement for polycentric governance in society-wide transitions: they can be driven and legitimised from one overarching centre of governance but must be supported by the development of networks of overlapping interest and interleaving responsibility. Engaging industry participants beyond the innovators and early adopters will be a key issue for successful scaling up – potentially driven by clear value propositions around low-risk adoption of effective on-farm actions. Communities of interest and the working groups in association with the innovation facility have an important role in achieving scaling.

While this report identifies a variety of priority areas it acknowledges that there is a great deal of capacity, knowledge, and know-how within the Queensland agrifood sector that should be harnessed to envision, develop and implement approaches to emissions reduction, and, in doing so, ensure the sector is well placed to flourish in 21st Century GHG constrained markets. Ultimately, catalysing the shifts discussed in this report will happen through ingenuity, perseverance, coordination, and collaboration among diverse people across the private and public sector. While recommendations have been made in this report, the way they are put together will be unique to Queensland and the network of people, businesses and groups that make it happen.

OVERARCHING RECOMMENDATION 5

Key elements for governance of a low emissions transition for agriculture are identified. Some elements are in place but all elements are needed to accelerate adoption of low emissions practices that best deliver not just emissions reduction but agricultural prosperity and regional vibrancy. The actual configuration/ architecture needs to be agreed to by government and industry in relation to existing structures and constraints.

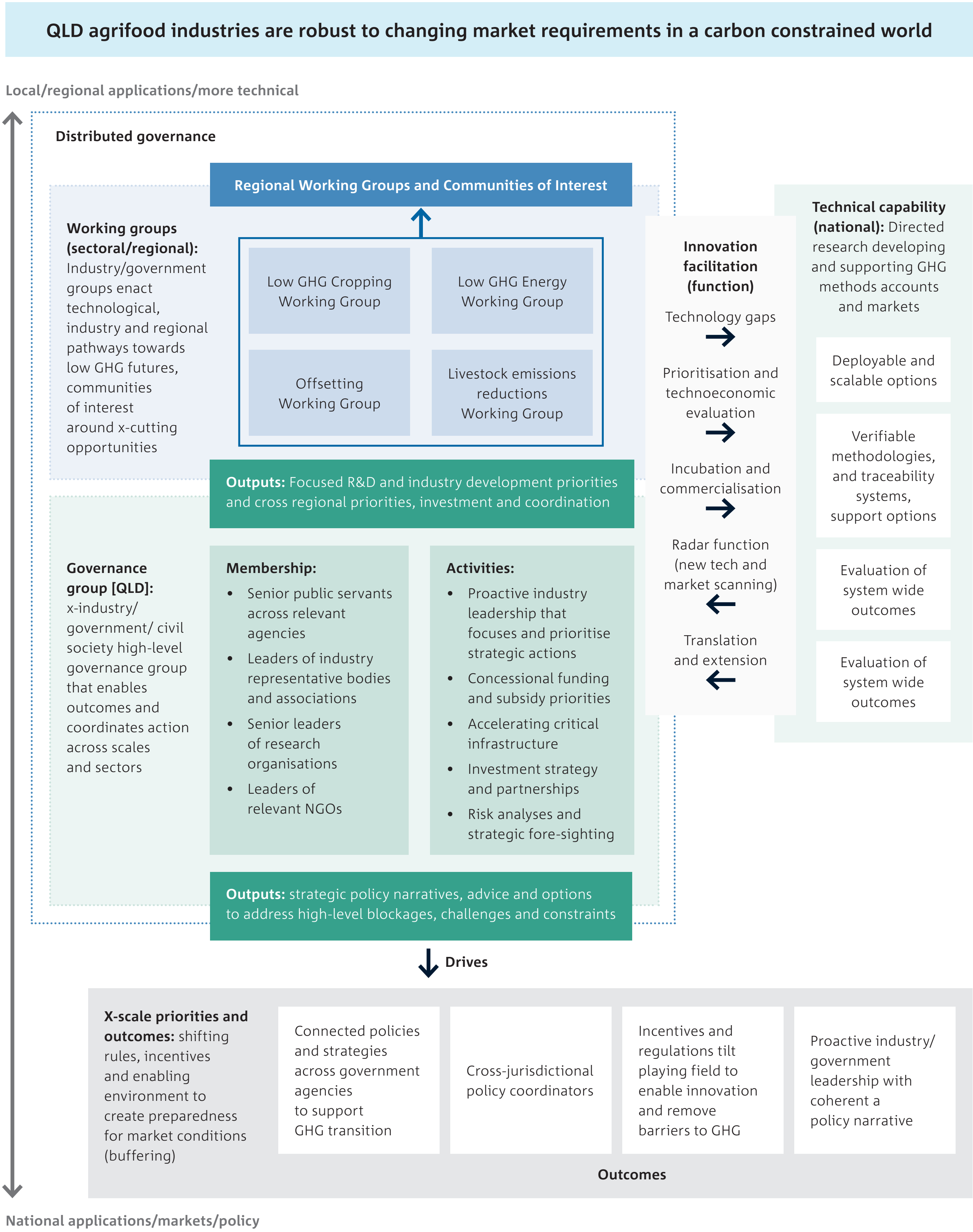


Figure 11 Proposed model for governance of x-industry and region enactment of pathways to reduce Queensland Agrifood emissions.

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Appendix 1: Evaluation criteria

Factors considered in evaluation criteria where composites of the categories under each heading

FACTOR		
Breadth of application	Number of sectors	One, several, many
	Number of regions	One, several, many
	Supply chain participant diversity	One, several, many
Scalability	Mitigation potential 2050	<0.1, 0.1–0.5, 0.5–<1 Mt, 1–5t, >5 Mt CO_2^{-2} yr^{-1}
	Mitigation potential 2030	<0.1, 0.1–0.5, 0.5–<1 Mt, 1–5t, >5 Mt CO_2^{-2} yr^{-1}
	Does it saturate or continue to deliver benefit indefinitely	Yes/no
Cost of implementation	Compatibility with existing management and/or ease of integration into existing systems	Drop in/minor adjustment/re-engineering or significant capability build
	Total investment required to get into practice	<$1 M, $1–10 M, $10–100 M, >$100 M
Barriers and Enables	Consistency with regulatory and policy framework	No change/minor change/significant institutional or regulatory change
	Negative consequences	None/would need active management to mitigate/show stopper without significant re-engineering
	Trialability: can farmers or supply chain participants experiment to gain confidence	Demonstrable and triable at small scale y/n
	Fundability/sponsorship	Interested parties evident and/or clear champions
	Alignment with government and industry priorities	Aligned with existing action plans or funding priorities
Co-benefit delivery	Economic/financial	None/low/moderate/high
	Social	None/low/moderate/high
	Cultural	None/low/moderate/high
	Natural	None/low/moderate/high
	Human	
	Physical	
Criteria – Maturity of technology	Metric – time to commercialisation	Unit – <1 yr, 1–5 yr, 5–10 yr, >10 yr

Appendix 2: Short titles, clusters and content from Crowdicity

Summaries and content reflect initial inputs and are not edited nor necessarily endorsed by authors or reviewers

SHORT TITLE	CLUSTER/ PATHWAY	NAME (FROM CROWDICITY)	SUMMARY (FROM CROWDICITY)
Life-cycle assessment applications	Cropping and horticulture	What's the easiest way to deliver a zero-carbon product for a range of the horticultural industries?	Carbon lifecycle assessments can be reviewed over a 2–3 year period to identify opportunities for reduction in carbon footprint along the chain, elements that will have to be offset and current offset mechanisms available at the lowest cost.
Digital agriculture and precision farming	Cropping and horticulture	Utilising Technology to Improve Productivity	My project would harness the latest digital technology to develop a measurable demonstration farm in a reef catchment to demonstrate the most efficient farming system possible. By collaborating with other industry players such as DAF, OGBR, a "standard" farm would be transformed into "state of the art" production system. All aspects of the farm would be geared towards maximising inputs and minimising emissions through efficiency gains.
Crop rotations and types	Cropping and horticulture	Industrial Cannabis Cropping – Improving Carbon Sequestration, Soil Sustainability through Rotational Cropping and New Regional Economic Development	Request to undertake cropping trials across Australia to demonstrate scientifically the value of industrial cannabis to not only increasing carbon capture but also potentially improve soil nutrition and create new broad hectare based industrial cannabis cropping and value adding industry across Australia. Estimated budget: $15 million + Time line 7 years (3–5 actual project) first two years to gain regulatory approvals and buy in from stakeholders across Regional Development, Agriculture, R&D and Funding bodies and private sector support.
GHG footprint measurement technologies	Livestock and enteric fermentation	Science Meats Software	Support respected herd management software companies to incorporate internationally recognised carbon footprint functionality into their existing dashboards via an expert working group over a period of 3–4 years. National rollout of fit-for-purpose workshops to run throughout the duration of the project.
Kangaroo protein and livelihoods	livestock and enteric fermentation	Hopping towards lower red meat emissions	Currently treated as pests, millions of kangaroos and emus represent a climate-friendly opportunity for growing regional income and employment, including for first nations peoples. The enormous animal welfare, economic, environmental and social costs associated with human-induced kangaroo and emu eruptions cannot continue. This mixed grazing enterprise concept, which is a major challenge in its own right, provides solutions for problems that have remained contentious and unresolved for decades.
Multispecies extensive grazing	Livestock and enteric fermentation	Soil Carbon and Multispecies Pastures in Extensive Grazing Systems	Enabling graziers in Northern Australia rangelands to increase productivity and resilience while verifying lowered emissions and accessing market-based emissions schemes through introducing economic establishment of multispecies pasture systems.
Feed additives for cattle	Livestock and enteric fermentation	New feed-based additives for cattle will lower GHG emissions in Queensland	Technologies that significantly reduce enteric methane emissions from ruminants need to be developed for most grazing operations to reach a carbon neutral position by 2030. For example, the company DSM has developed the compound, 3-nitrooxypropanol (3-NOP) which acts as a greenhouse gas (GHG) mitigant by inhibiting methane production in the rumen. Feed additives such as 3-NOP that reduce enteric methane emissions need to be delivered frequently (daily) and consistently to produce a sustained reduction in emissions that are verifiable for carbon credit accounting. Thus, new nutritional supplement formulations and delivery methods are required to provide them to grazing animals in a manner that reduces methane by a predictable amount.

SHORT TITLE	CLUSTER/ PATHWAY	NAME (FROM CROWDICITY)	SUMMARY (FROM CROWDICITY)
Seaweed additives to cattle feed	Livestock and enteric fermentation	Methane-busting seaweed supply chain built in Qld, for Qld	Asparagopsis is proven to reduce methane emissions in cattle by over 80%. Whilst Asparagopsis is abundant and native to Queensland, the barrier for Queensland in developing commercial-scale seaweed production is the absence of a hatchery to supply the seeded lines for sea-based farming. Queensland has an opportunity to establish seaweed operations in Queensland and accelerate seaweed availability to its cattle producers to directly reduce enteric methane emissions. An approximate $5–8 million investment in an Asparagopsis hatchery and processing facility in Queensland over two years will deliver a new aquaculture industry for the State, create new jobs and support a sustainable and carbon neutral beef industry in Queensland.
Delivery technology to for methane reduction in extensive systems	Livestock and enteric fermentation	Continuous delivery of methane-suppressing additives in extensively grazing cattle	There are feed additive technologies that supress enteric methane production in ruminants that are close to being commercially available in Australia. However due to the need for the animal to receive a consistent dose daily to be effective, their application in extensive grazing animals is limited. The development of a new delivery technology, such as degradable rumen bolus, that slowly releases the methane suppressing active within the rumen of individual animals will enable the expected methane reduction to be used for carbon credit accounting in extensive grazing enterprises.
Forage legumes for methane reduction	Livestock and enteric fermentation	Forage legumes to reduce the carbon footprint of the Queensland beef industry	In summary, there is already a wealth of activity directed at increasing adoption of these tropical legumes. This proposal is an overarching attempt to build on these existing activities by developing an impartial modelling framework that can quantify the qualitative information that abounds around Leucaena and Desmanthus. Primarily this is built on the collection of quality data on properties using the most up to date techniques available and feeding this data into an established modelling protocol specifically aimed at linking the economic and environmental benefits of tropical legumes in biophysical systems. Extension is always difficult, but we believe the combination of strong industry-led networks coupled with proven scientific method offers a new and prospective approach to increase adoption of these valuable forage resources for the Queensland beef industry.
Strategic information for carbon farming	Offsets	Optimising long-term value from carbon abatement in the agriculture sector	This project will provide essential information to landholders that will enable them to make more strategic decisions on optimising the long-term value from their carbon farming activities.
Restoring riparian zones	Offsets	Carbon sequestration from restoration of degraded riparian zones	Identification of partners and interested regions. Site selection of existing (old as possible) restoration projects in riparian zones. Field assessments. Testing of virtual fencing at a few case study properties. Field days. Data collation and analysis. Working with policy makers to implement, e.g. incorporate in existing ERF methods and include with Reef Credits or LRF etc.
Nature-based solutions to carbon capture and storage	Offsets	Nature based solutions in direct CCS	To be worked out in more detail. Would need support of communities. So perhaps need to start with social surveys by social scientists.

SHORT TITLE	CLUSTER/ PATHWAY	NAME (FROM CROWDICITY)	SUMMARY (FROM CROWDICITY)
Soil carbon measures	Offsets	The accurate measurement of carbon content in the soil	From our international contacts we believe that our technology for soil-based carbon measurement is unique. The CAS program solves the cost, productivity, scalability and measurement roadblocks and connects capital markets with farmers to stimulate the transition to regenerative agriculture and carbon farming. We will work with suppliers of agricultural goods and services to maximise carbon sequestration returns to participating farmers. With sufficient capital and the current development plans for Sept 21 to June 22 CAS anticipate to be operating commercially by the last half of 2022 in Australia and North America. We project that the returns to successful carbon farmers will become a significant component on their on farm income. Once a market and pricing and offtake agreements become established, the market opportunity will be huge. Take just Microsoft MSFT -0.5%, for example, which estimates that their annual carbon emissions impact is 16 million tons. At $100/ton, that would represent a $1.6 billion annual market opportunity for that potential buyer alone. Sure, hopefully a lot of that market opportunity is diverted into actual direct emissions-reducing activities in Microsoft's actual operations instead of into offsets. But still, imagine what this total market opportunity looks like across the top 1000 companies around the globe? And then the next 10,000 after them?
Landscape scale CCS	Offsets	Landscape based approaches and innovation for carbon capture and land restoration	Use of high level data sources and methods for landscape approaches to carbon farming, land rehabilitation and integrated (farm-based) water management. Support to seven pilot action areas covering a range of linked efforts that increase capacity of producers and growers, forms various communities of practice, enables collective actions and is built on local ownership and learn-by-doing principles. Capture of lessons, data, information and knowledge for sharing among the broader network on stakeholders over the whole Central Queensland region. Support for strategic development and operationalisation of a cluster & node network systems to support collaboration and targeted innovation
Farm forestry as sink	Offsets	Carbon capture in forests and wood products	Establish future forest resources through plantation forests, managed native forests, and mixed farming systems (Silvopasture, agroforestry) to enable replacement of high emission products such as concrete and steel in construction, and further wood encouragement policies at various levels of government, with industry partners.
Ag waste, aggregators and soil carbon	Offsets	Valorising ag-waste through smallholder aggregate closed loop carbon farming	This project seeks to increase Queensland's soil carbon sequestration by making carbon markets more accessible to small farmers (96% of farms) and scaling proven and commercialised Queensland-developed soil technologies that convert ag-waste into microbial rich soils. Facilitation by an aggregator would allow small farms access to the Land Restoration Fund as a single bidder. Carbon farming methods would be provided through Atlas Soils, further reducing the burden of farmers. Co-benefits to farmers include reduced waste levies and fertiliser costs, and income diversification from carbon credits and soil enhancer products.
Advanced pyrolysis	Offsets	Biochar and advanced pyrolysis: new supply chains	Build high value biochar supply chains using advanced pyrolysis approaches and with a sound diagnostic of how inputs and processes influence biochar attributes design biochars for high value end uses. Probably in the order of $1–5 million to develop pilot scale activity
Biochar as offsetting and energy option	Offsets	Bio-based value chains for marginal land	Negative emission biochar production for broad-scale application in industries such as construction, agriculture and road building. Using low productivity marginal land to bolster regional development, add value to existing farms and provide renewable energy to local communities.
EV farm machinery	On-farm energy and efficiency	EV farm machinery	How do we incentivise uptake of electric farm machinery?

SHORT TITLE	CLUSTER/ PATHWAY	NAME (FROM CROWDICITY)	SUMMARY (FROM CROWDICITY)
Seeds for biofuels	On-farm energy and efficiency	Seed 2 Diesel	Seed 2 Diesel is developing a technology pipeline at a demonstration facility that will process 4–5 t of seed, producing 1000–2000 Litres of Biodiesel, every 24 hours. This technology and equipment will be licensed to other facilities established as co-operatives, in other oilseed growing areas, to help address agriculture's >$3 billion fuel bill and fuel security, increasing the value of the crop to the grower.
Green hydrogen	On-farm energy and efficiency	Opportunities for Green Hydrogen in Queensland	The Queensland Hydrogen Industry Strategy outlies the government's commitment to delivering a sustainable hydrogen industry by 2030 to provide opportunities for domestic users, (with the potential to deliver significant economic, employment, energy security and environmental benefits), and develop new export markets. However, the Strategy strongly focuses on green hydrogen through electrolysis, produced by renewable energy, (namely solar and wind). Why are there not more commercially based opportunities in Queensland using plant feedstock/biomass gasification to create green hydrogen to meet domestic energy needs and for export at scale? What are the market constraints/limitations? Can they be minimised, or eliminated?
Hydrogen to fuel farms	On-farm energy and efficiency	Farming Systems fuelled by the Hydrogen Economy	Hydrogen as a source of fuel is purported to a significant opportunity for meeting the demands for energy in a renewable energy future. The use of anhydrous ammonia is considered a safe medium to harness the opportunity of hydrogen as a fuel source. The need for N fertiliser will remain in some industries. The use of on farm renewable energy to produce anhydrous could be used as fertiliser and a fuel source for machinery etc; both outcomes reducing emissions. While not a new idea. The concept will need expertise and innovation across the energy and farming sectors to implement, demonstrate value, and important deliver and service in a rural setting.
Drone technology for precision applications	On-farm energy and efficiency	Drone application-monitoring/ seeding/spraying	In summary utilise the linked drones (5) on a big scale to reduce water in chemical applications. Comparing traditional methods (tractors and planes) and work loads, time (day or night), resources and people during growing cycle. Resources-Trial area with a open minded operation willing to explore the drone possibilities for a growth cycle on a crop) preferably in the reef catchment area) of 200ha- purchase additional drones equipment to facilitate trial
Speeding adoption of low emissions tech	On-farm energy and efficiency	Increased uptake of known low emissions technologies	Greater uptake of known low emissions practices is needed to start the broader agriculture sector on the journey towards low emissions production. What is needed to help producers to overcome the barriers to adoption?
Collaborative buying	Regional demonstrators	Collaborative Buying Alliance for Agri-Food Manufacturers	In recent years a number of agrifood manufacturers have expressed individual interest in using green technology and investing in carbon in-setting in individual plants and across the supply chain. Large scale manufactures with ample capital and sufficient risk appetite have been lauded as early adopters, but for critical Qld industries like meat, carbon in-setting and alternative energy opportunities need to be more less expensive, more readily available, and more numerous so that a range of agri-businesses can have the chance to be part of a zero carbon future.
Industry-led networks	Regional demonstrators	Industry-led networks and clusters as change leaders	Peer-to-peer, business-business, interactions remain one of the most important channels for practice change, business outcomes, accelerated learning, building trust, and collective intelligence. Someone once used the phrase "coopetition". These groups could a key pathway to reduce emissions in response to markets and community expectations, or other drivers or incentives/disincentives, while delivering on the local needs, with local solution to local problems. Creating the right environment for these networks and clusters to flourish, and channelling the most recent and relevant information/evidence and support to them to meet their needs is critical.

SHORT TITLE	CLUSTER/ PATHWAY	NAME (FROM CROWDICITY)	SUMMARY (FROM CROWDICITY)
Collaborative frameworks	Regional demonstrators	Building a whole-of-agriculture collaborative framework on climate action	Building a framework for collaboration across sectors, interests and specialties to enable the sector to evolve and respond to multiple drivers simultaneously.
Food, soil health awareness	Regional demonstrators	Permaculture for sustainability, community and health	The need is urgent. The idea is relatively easy to execute, and is widely applicable even for unit-dwellers; and will be effective with CSIRO and community support. The general population is so removed from food production many children aren't aware carrots grow in the ground! Growing food locally is therapeutic for both people and the planet. My background is in delivering workshops, eLearning and sales. I wish to quit my income-generating activities to focus entirely on this permaculture initiative but would require financial assistance to do so. The outcomes are improved sustainability, better health and community development.
Sectoral planning and coordination	Regional demonstrators	A Sustainable Future for the Dairy Industry	This idea proposes a regional-level project that aims to transition dairy farmers from traditional inorganic farming to regenerative biologically based practices. Such training provided by farmers with a proven track record is able to be demonstrated. The project would adopt the principle of sustainable profitability. Farmers are exiting the industry due to low farm gate practices. They are also locked into traditional farming practices and simply need to be shown how to transition from chemical to biological agriculture. Sediment/Nutrient Runoff into waterways will also be addressed as this industry has proven to be a major contributor to this issue.
A net zero region	Regional demonstrators	A Net Zero region?	By tackling emissions reduction at the regional level, we look at the system as a whole and can optimise resource use across the system and identify decarbonisation pathways across value chains that support local businesses and jobs, diversify the economy, improve sustainability and build climate resilience. It will take some time for all industries in a region to fully decarbonise (if at all) but we can find novel ways to generate offsets within the region so benefits will flow back to the community.
Landscape planning	Regional demonstrators	Landscape-based approach to planning for agricultural lands in transition	This is a project that needs a multi-disciplinary team of dedicated people to champion the value of taking a landscape-based approach to managing and planning for agricultural lands (and other) in transition. This is a collaborative project. It would also require someone to document the progress and advancement of the social and ecological changes in the specific region in question.
Circular economy incubators	Regional demonstrators	Investigating the circular economy to reduce hort emissions	Horticulture faces the twin issues of food waste and reliance on plastic packaging to extend shelf-life. USQ is doing some really interesting things looking at using waste to create plastics so it would be fantastic to create a circular mechanism whereby food waste is used to create plastics that extend shelf-life to reduce food waste (and reliance on plastic).
Planning options		Plan a better future	We all make plans. No industry or community sector is immune to the impact of climate change and we need to include it whenever and wherever we make plans.
Targets aligned with Brisbane Olympics		Net Zero 2032	This is a complex space, and the number of activities and actors working with great ideas and good intentions is adding to the complexity (and perhaps duplicating effort rather than collaborating to reach a shared goal). So set a single big goal that is shared, memorable and everyone can work to in their own ways. As an aspirational starting point: net zero Queensland agriculture emissions by Brisbane Olympics 2032. Use science to see if it's possible. Build truly collaborative emissions and sequestration pathways to get there. And then report progress frequently, credibly and transparently.
Easy wins in energy		Capturing the easy wins	How do we prioritise and grab the low hanging fruit in the near term while we work on longer term solutions?
Marketing to build low GHG demand		Raising awareness	Develop a marketing campaign to address some of the simple solutions that can be applied now to start to build interest and momentum and a group of 'early adopters'

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