SIEF TRANSPIRATIONAL IMPACT ASSESSMENT

June 2022

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Glossary

A&F	Agriculture and Food
APAC	Asia Pacific Countries
ASL	Average Staffing Level
BAU	Business as Usual
BCR	Benefit Cost Ratio
BD	Business Development
BM	Boron Molecular
BU	Business Unit
CAPEX	Capital Expenditures
CBA	Cost Benefit Analysis
CEO	Chief Executive Officer
COGS	Cost of Goods Sold
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CR	Commercial Readiness
CS	Consumer Surplus
DPIRD	Department of Primary Industries and Regional Development
DW	Discovery Workshop
EDP	Experimental Development Program
GHG	Greenhouse Gases
GS	Government Surplus
HSE	Health, Safety, and Environmental
IAF	Innovation Acceleration Fund
IP	Intellectual Property
LCA	Life Cycle Assessment
NPV	Net Present Value
Newco	New Company
OPEX	Operating Expenses
PMF	Plastic Mulch Film
POC	Proof of Concept
PS	Producer Surplus
PU	Polyurethane
PV	Present Value

PVL	Powerhouse Ventures Limited
R&D	Research & Development
RD&I	Research, Development, and Innovation
SIEF	Science and Industry Endowment Fund
SLO	Social Licence to Operate
SBPM	Sprayable Biodegradable Polymer Membrane
SBM	Sprayable Biodegradable Mulch
SBMT	SBM-TranspiratiONal
TBL	Triple Bottom Line
TRL	Technology Readiness Level
WA	Western Australia
WTP	Willingness to Pay
WUE	Water Use Efficiency

1 Executive summary

Global Challenge For more information, see Section 2	Feeding and clothing the world sustainably are pressing challenges in today's world. There is a need for solutions to feed a global population of 10 billion and meet an expected >50% increase in food demand by 2050.[1] It would require two planets to meet these demands unless there is access to higher efficiency options.[2]
The Science Challenge For more information, see Section 2	Petroleum based preformed Plastic Mulch Films (**PMFs**) are widely used in agriculture to reduce soil evaporation, suppress weeds, and maintain soil microenvironment to deliver enhanced productivity. However, plastic fragments from the use of PMFs have detrimental effects on the natural environment, as well as contribute to the global plastic waste problem. As an alternative, a biodegradable plastic mulch line has been available for nearly 20 years for use in agricultural applications but attracted limited market adoption mainly due to its low biodegradation in soils, high costs, lack of industry standards to validate its safety, and potential ecotoxicity caused by the breakdown of products.
The Response For more information, see Section 2	CSIRO developed commercially exploitable aqueous-based Sprayable Biodegradable Polymer Membrane Technology (**SBPM Technology**) from the Science and Industry Endowment Fund (**SIEF**) funded TranspiratiONal 1 and 2 initiatives.[3] This effort supported the advancement of the Technology Readiness Level (**TRL**) of the initial prototype water-based sprayable biodegradable membrane, which is now called **SBM-TranspiratiONal** . These 'spray and walk away' formulations applied to the soil surface help improve crop water productivity and control competing weed growth. Field trials to date have demonstrated the ability of the product to decrease plastic (PMF) waste, impede weed growth, reduce herbicide application requirements, and provide protection against water stress, thereby improving farm profitability. The membrane properties (e.g., thickness) and degradation can be tailored for crop-specific cycles. With the assistance of the soil microbiome, the sprayable biodegradable mulch (**SBM**) typically biodegrades naturally in 5-7 months into gases, water, biomass, and inorganic salts without leaving any environmental imprint. The polymer membrane also offers the ease of application using regular farm equipment such as handheld pump sprayers or large mechanised sprayers.
CSIRO's key Challenges addressed	Food Security and Quality Resilient and Valuable Environments Future Industries

[1] www.fao.org/fileadmin/templates/wsfs/docs/Issues_papers/HLEF2050_Global_Agriculture.pdf
[2] https://www.theworldcounts.com/challenges/planet-earth/state-of-the-planet/is-the-world-running-out-of-food/story
[3] As a part of SIEF Experimental Development Program.

<table>
<tr><td>Background IP

For more information, see Section 3</td><td>CSIRO began the development of aqueous-based SBPM technology in 2012. In 2014, the first patent, a ‘Sprayable Polymer Membrane for Agriculture’ was filed.

Later SIEF supported the following initiatives to advance the technology:

- TranspiratiONal 1: Active between 2016-2017

- TranspiratiONal 2: Active between 2017-2018</td></tr>
<tr><td>Current Scenario

For more information, see Section 3</td><td>Since the inception of the R&D in 2012 and post the SIEF supported projects, the technology has progressed to a TRL of 6-7. Currently, the core team is engaged in efforts to realise the creation of a new company (the Newco) – the SBM-TranspiratiONal (SBMT) spin-out – to act as a vehicle to deliver TBL impacts through the successful commercialisation of the SBPM technology.

At the time of writing this report, an Entrepreneur in Residence had been engaged, and Innovation Acceleration Fund (IAF) funding had been received. The team is actively seeking a suitable investor to effectively facilitate the spin-out of SBMT Newco.</td></tr>
<tr><td>Impact Assessment Approach

For more information, see Section 4</td><td>The assessment of the prospective impacts of sprayable biodegradable polymer membrane technology is conducted based on the potential SBMT spin-out pathway. A part of the overall estimated benefits are attributable to SIEF’s support. This evaluation is based on the impact hypothesis developed post-discussion with the core team. The assessment adopted CSIRO’s Impact Framework to identify the causal relationship of the initiative.

Although the project is yet to reach a point where it is possible to quantify the nature and magnitude of economic benefits, a body of evidence for future economic and social impacts is presented in the assessment. Tractuum provides a potential approach to quantify the prospective economic benefits, once more data becomes available in the next 18-24 months.</td></tr>
<tr><td>Prospective Impacts

For more information, see Table 2 and Sections 8 and 9</td><td>The successful development and scaled adoption of the SBPM technology through the SBMT spin-out pathway is envisioned to deliver future economic, social, and environmental benefits. These include (but are not limited to) yield benefits to farmers, export income, environmental conservation (land and aquatic), creation of jobs, collaborative networks, and new technology options created by R&D. Key TBL impacts:

Economic
- National Economic Performance
- New services, products, experiences, and market niches
- New Jobs
- Australia’s competitiveness

Environmental
- Land quality
- Aquatic environments

Social
- Food Security
- Health and wellbeing
- Innovation and human capital (creativity and invention)</td></tr>
</table>

Potential barriers to impact	- lack of economies of scale due to sub-optimal manufacturing processes - lack of access to required funding and support to launch the spin-out - lack of/weak drivers – regulatory intervention, investor/industry interest, etc. - lack of consumer preference to shift to a sprayable mulch system due to familiarity with conventional film-based approach; low cost, and ease of use, of alternate options - new, improved, and competitive biodegradable solutions that are reliable, cost-effective, easy to implement with adequate lifetime, provide better weed suppression, WUE, and erosion protection
Recommendations For more information visit Section 10	- a high-level CBA be performed once the TRL improves, and high-scale manufacturing viability is established (expected 18-24 months) - an impact planning workshop with internal and external stakeholders should be held to establish critical indicators for baselining, planning, monitoring, and reporting evidence-based impact - robust impact management from the outset would help assess whether the intervention is delivering the intended value to society in the target areas of assessment and highlight the need to make adjustments (feedback loop) where necessary - the R&D team provides a thought-through, clear, and coherent articulation of support requirements to the leadership team to drive this longer-term initiative
Confidence rating in impact assessment For more information, see Section 11	The SBPM R&D is aspirational, with the potential to reduce the environmental footprint of agricultural activities and improve the efficiency of agricultural operations on a sustainable basis through the SBMT spin-out commercialisation pathway. This ex-ante assessment represents an early-stage analysis, based on preliminary empirical data, and informal consultations with key stakeholders. At this early stage of technology development, and given the uncertainty associated with the launch of the spin-out, the projection of benefits is based on several assumptions. Some of the key benefits such as incremental yield gains from the application of SBM cannot be assessed until the technology is sufficiently advanced with a clear manufacturing pathway, and is commercially viable. The initiative is also subject to key risks. Due to the inherent ambiguity associated with the TRL development and adoption of SBM at this stage, the **confidence rating in this impact assessmentis rated very low** by Tractuum.
Business Unit(s) and Partners	CSIRO: Technical arm (CSIRO Agriculture & Food and Manufacturing BUs) Boron Molecular (BM): Industry arm Dr Shalen Kumar: Entrepreneur-in-Residence arm (Technology productisation)
Collaborators and sources to corroborate Impact	Trial Partners: Kagome/Green Cloud Nursery/Myrtle Park Farms Distribution Partners: Nufarm, tbpi
Further Information	SIEF Office, SIEF; Anne-Maree Dowd, CSIRO

3 Introduction

Industry challenge

What challenges are the drivers behind TranspiratiONal 1 and 2 initiatives?

Feeding and clothing a growing global population sustainably are pressing challenges in today's world. There is a need for solutions to feed a global population of 10 billion and meet an >50% increase in food demand by 2050.[4] It would require two planets to meet thesedemands unless there are higher efficiency options that can help achieve this goal using thesame land areas as currently cultivated, but with much less water, and fewer nutrients andagrochemicals.[5] The vagaries of climate change amidst increasing environmental degradationand pollution have further exacerbated this issue.

Addressing this challenge requires intensification of irrigated and dryland cropping systems so that more of the water that enters the soil is readily available to the crops, rather than lost through soil evaporation or deep drainage. Current technology offerings that reduce soil evaporation, suppress weeds, and maintain the soil microenvironment are dominated by petroleum-based preformed Plastic Mulch Films (**PMFs**). However, the product is proving to be a major source of pollution to soil and water systems, as well as contributing to the global plastic waste problem. Because PMFs fragment rather than biodegrade, there is potential for plastic fragments and associated toxins to accumulate in the environment and contaminate soil and water, thereby ultimately creating a significant agronomic, economic, and environmental burden.[6] There are also dominant technical and non-technical barriers associated with the improper collection, and low reuse and recycling of conventional agri-plastics that impede higher recycling and reuse rates.

To mitigate the adverse effects of PMFs, biodegradable plastic mulch is an alternate product line that claims the benefits of being able to be tilled into the soil after use and degraded by soil organisms. Although these products have been available for nearly 20 years,there has been limited market adoption mainly due to their low biodegradation in soils, high costs, lack of industry standards to validate their safety, and potential ecotoxicity from breakdown products (i.e., accumulation of plastic fragments and particulates in soils). In addition, the sprayable mulch solutions remain largely in the concept stage. The challenges associated with the current solutions are further discussed in Section 7.

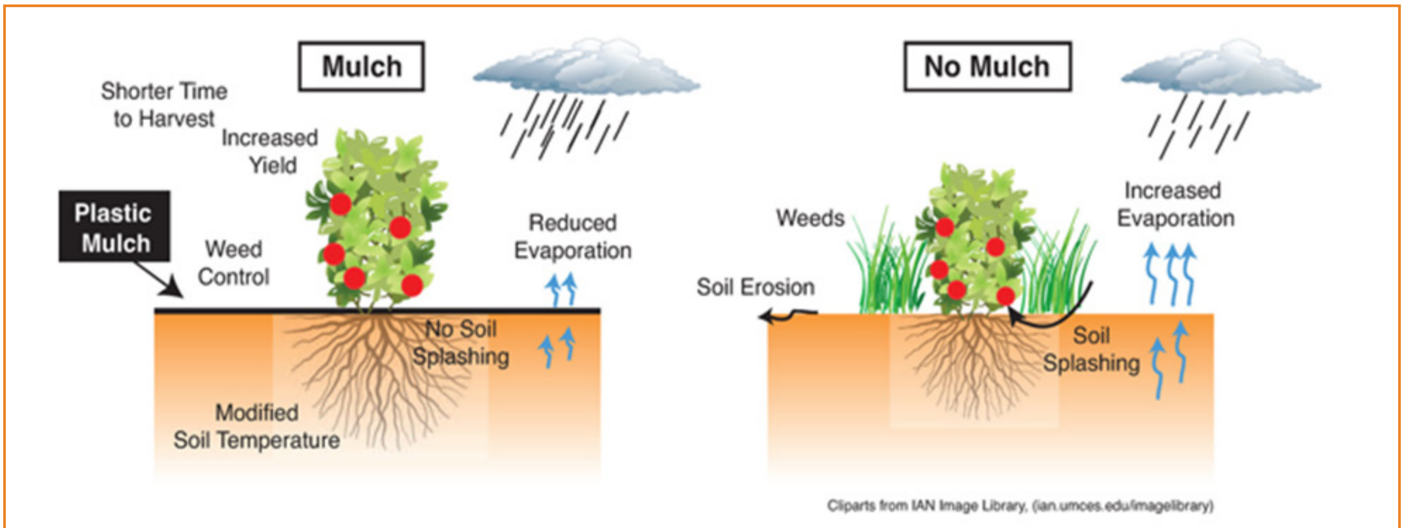

Figure 1: Agricultural cropping system with and without the use of plastic mulch film. [7]

[4]www.fao.org/fileadmin/templates/wsfs/docs/Issues_papers/HLEF2050_Global_Agriculture.pdf
[5]https://www.theworldcounts.com/challenges/planet-earth/state-of-the-planet/is-the-world-running-out-of-food/story
[6]https://link.springer.com/article/10.1007/s13593-011-0068-3
[7]https://pubs.acs.org/doi/full/10.1021/acs.est.6b06042

CSIRO/SIEF's Response

What is the significance of the TranspiratiONal 1 and 2 initiatives?

CSIRO scientists began the development of an aqueous-based Sprayable Biodegradable Polymer Membrane Technology (**SBPM Technology**) in 2012. The Science and Industry Endowment Fund (**SIEF**) funded the TranspiratiONal 1 and 2 initiatives, under the Experimental Development Program (**EDP**) to advance the Technology Readiness Level (TRL) of the initial prototype water-based sprayable biodegradable membrane, which is now called **SBM-TranspiratiONal.**

These 'spray and walk away' formulations (further discussed in Section 6.3 below) applied to the soil surface help improve crop water productivity and control competing weed growth. Field trials to date have demonstrated the ability of the product to decrease plastic (PMF) waste, impede weed growth, reduce herbicide applications, and provide protection against water stress, thereby improving farm profitability. The membrane properties (e.g., thickness) and degradation can be tailored for crop-specific cycles. With the assistance of the soil microbiome, the sprayable biodegradable mulch (SBM) typically biodegrades naturally in 5-7 months into gases, water, biomass, and inorganic salts without leaving any environmental imprint. The polymer membrane also offers ease of application using regular farm equipment such as handheld pump sprayers or large mechanised sprayers.

The efforts to further commercialise the technology confirmed that a new spin-out venture offered the best pathway to market. Currently, the core team is engaged in efforts to realise the creation of a new company (the Newco), an SBM-TranspiratiONal (SBMT) spin-out as a pathway to commercialise the SBPM technology and deliver TBL impacts through the adoption of these environmentally friendly formulations as an alternative to plastic mulch films.

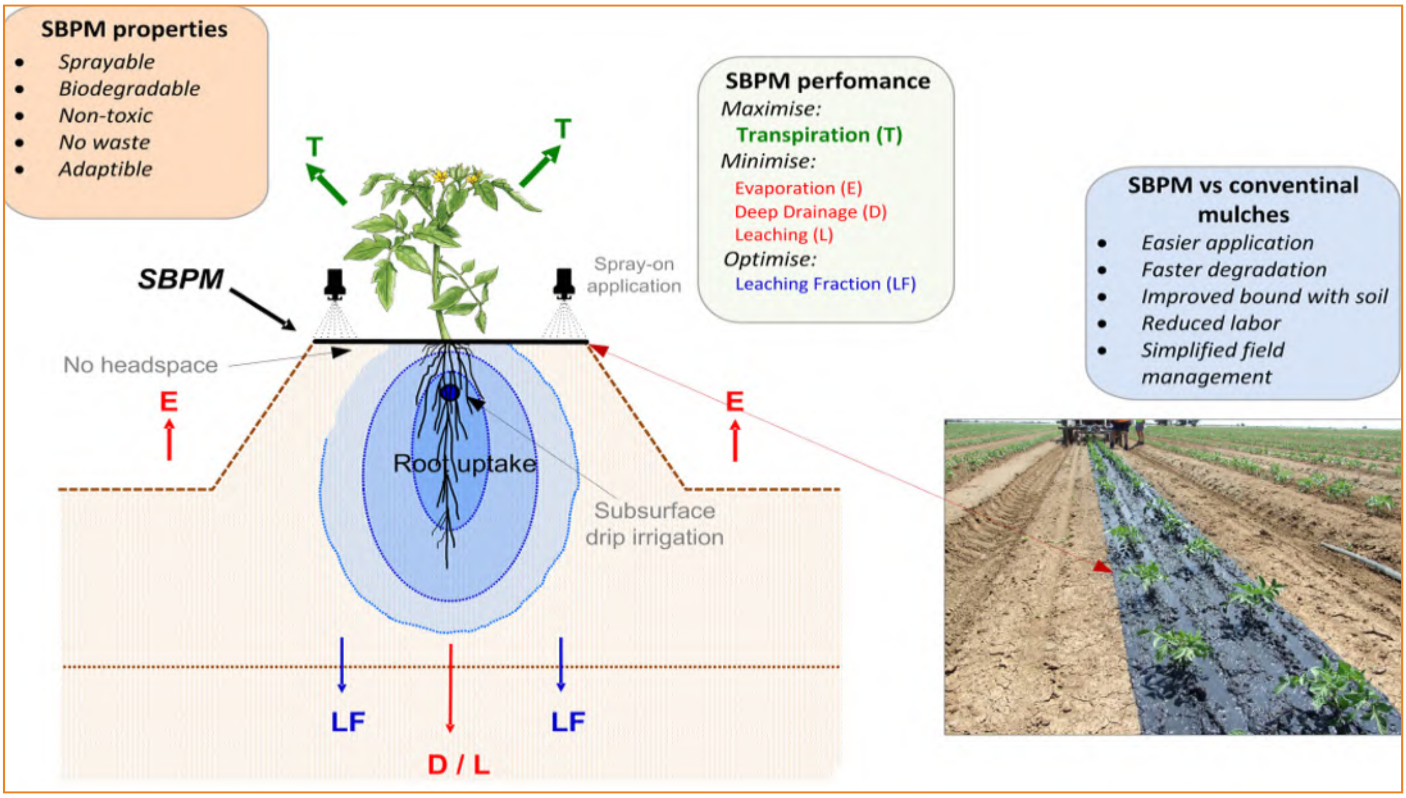

Figure 2: Properties of SPBM technology vs conventional mulches.[8]

[8]https://pubs.acs.org/doi/pdf/10.1021/acs.est.0c00909

What is the purpose of the Impact Assessment?

The purpose of this ex-ante (before realisation) assessment is to estimate the potential triple bottom line (TBL) impacts from the TranspiratiONal 1 and 2 initiatives, and highlight the critical role played by SIEF in advancing this work. The analysis covers the potential direct and indirect future impacts of the R&D. The study outlines the impact logic model (Impact Pathway), risks and recommendations, and also covers lessons learned during the development period to benefit this and other similar initiatives in the future.

Figure 3: Continuous cycle of Impact measurement objectives[9]

Box 1 Ex-ante assessment

As will be clear from the assessment, the benefits estimation of TranspiratiONal 1 and 2 initiatives through the SBM-TranspiratiONal spin-out pathway is largely ex-ante (before realisation) at this stage. An ex-ante evaluation is considered a significant step for impact management of a project throughout its lifecycle, as it:

i. provides an opportunity to identify the causal links underlying the investment's path to impact, and allows investors and other key stakeholders to assess the strengths of these linkages;
ii. helps establish a baseline to effectively determine the changes delivered through the project;
iii. promotes due diligence for sound decision-making;
iv. assists with improved implementation, as well as evaluation planning and monitoring; and
v. allows evidence-basedevaluation and reporting later on in the journey of the technology.

However, a lack of evidence-based data at this stage makes these assessments highly uncertain.

[9] www.hbs.edu/socialenterprise/Documents/MeasuringImpact.pdf

This report can be read as a stand-alone item, or alongside other CSIRO Agriculture and Food (A&F) evaluations. The information is provided for the purposes of accountability, communication, engagement, continuous improvement, and future impact management. The audiences include CSIRO (especially program and leadership teams, A&F and Manufacturing business units (BUs)); SIEF, Commonwealth, state, and local governments; agricultural and manufacturing sectors; and interested members of the public.

3 Background

Journey of SBM technology development

Research and Development

As discussed above, CSIRO began the development of aqueous-based SBPM technology in 2012. In 2014, the first patent, a 'Sprayable Polymer Membrane for Agriculture' under this CSIRO-led initiative was filed. The initial lab and field tests examined the technology on cotton, sorghum, and melon crops. The snapshot of the journey of advancing the TRL of the technology over years is given in Figure 4 below.

SIEF supported initiatives

TranspiratiONal 1: Active between 2016-2017

The SBM trials demonstrated an increase in crop water productivity of as high as 30% in laboratory pot experiments and on small, irrigated field plot trials using melons, sorghum, and cotton.

The TranspiratiONal team carried out more than 200 customer and end-user interviews to confirm large market opportunities, strong demand for the technology, and multiple targets for initial market entry. New patents based on SBM chemistry and applications were also filed during this period.

SIEF's role

SIEF provided funding to undertake an EDP to carry out on-farm field trials in target markets to:

(1) confirm in-field biodegradability and non-toxicity of the polymer membrane, and determine any risks to soil health; and

(2) collect water use, controlled competitive weed, and crop yield data to initiate cost-benefit analyses of different product application rates, across full crop cycles under real-world conditions.

TranspiratiONal 2: Active between 2017-2018

TranspiratiONal 2 project focussed on advancing the TRL of the technology developed during Phase 1 of the work. The initiative demonstrated that SBPM could be manufactured at a multi-tonne scale in Australia and applied on-farm using existing and/or modified farm equipment. The ease and control with which the polymer membrane can be applied showed that it could be used with small handheld sprayers (suitable for household gardens in cities and rural household plots in, for example, Sub-Saharan Africa) and with large, mechanised sprayers (suitable for large scale industrial farming).

Phase 2 focussed on demonstrating the innovation, uniqueness, and flexibility of the technology based on properties designed into the polymer membrane, including sprayability, biodegradability, and non-toxicity.

SIEF's role

SIEF provided funding to:

1. initiate trials to explore the manufacturability (at a multi-tonne scale) and practicality of SBPM technology on-farm;

2. demonstrate the positive benefits of the SBM in terms of weed suppression, water savings, increased germination temperature, and reduced erosion through supporting pre-commercial farm trials (melons, pumpkins, and processing tomatoes) with collaborating farmers; and

3. provide CSIRO with valuable experience in the farm-scale application of the SBM, and information on its performance and longevity on the ground.

Post-SIEF Funding

Interim: 2019-2020

After the SIEF funding, there were efforts to obtain industry traction through the following pathways:

Licensing the technology to a third party for royalties: There was no significant interest, as the technology was not deemed mature enough from the perspective of large agri-chemical companies to be suitably pursued.

Entering into a joint venture with large agri-chemical companies: No joint venture (JV) expressed interest as the pain points in the market at the time were not significant to warrant exposure, and there was still not enough information available for potential partners on scale-up production and distribution costs.

The R&D team also participated in CSIRO's accelerator program, ON, to improve their commercial proposition. During the program, the R&D team were able to further develop the case for the SBM, draw up a marketing pitch, and scope a range of investors.

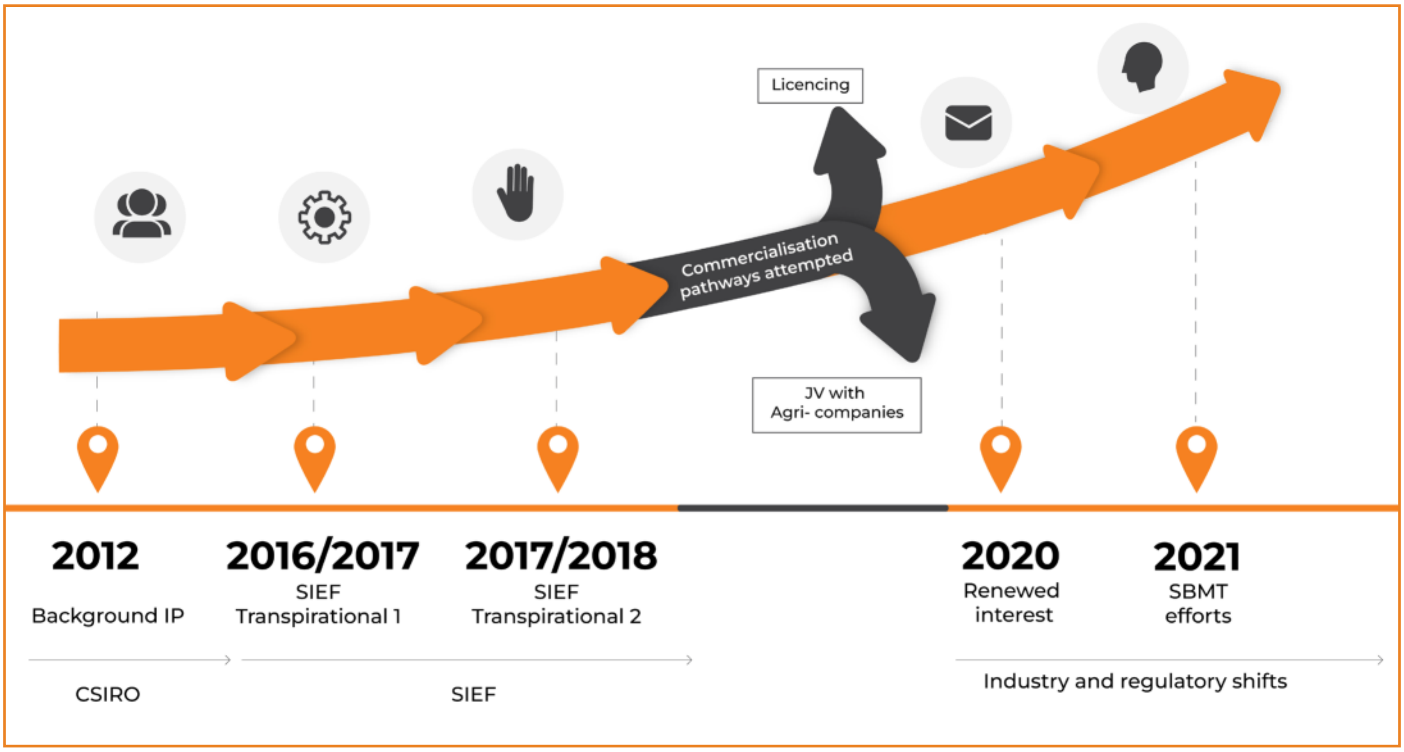

Figure 4: Journey of SBM technology development

Current Scenario

In 2020 there was renewed interest in the technology, driven by industry and regulatory shifts focussed on reducing plastic waste and use, as well as consumer awareness. In late 2020, CSIRO reformed a project team, selected from the Crop Systems Program, A&F Company Creations, and CSIRO Business Development (BD) teams, to refine the business model and investment case to take the SBPM Technology to market. As discussed above, efforts for the creation of a new spin-out, SBM-TranspiratiONal (SBMT), are currently underway. The entity is being envisioned to act as a vehicle to deliver impacts through the successful commercialisation of the SBPM technology. At the time of writing this report, an Entrepreneur in Residence had been engaged, Innovation Acceleration Fund (IAF) funding received, and investor targets approached and pitched to as part of the efforts to successfully spin out SBMT Newco. The initial high product offer price (COGs) due to ingredient and cost-intensive manufacturing has been a major roadblock in the pathway to achieving commercial viability of the technology. The R&D team is focused on devising alternatives to address this issue.

The SBMT Newco aims to develop, manufacture (at scale), and commercialise the current and upcoming formulations of the sprayable biodegradable mulch for crop production systems to allow farmers to control weeds, reduce herbicide sprays, and conserve water, whilst eliminating the use of PMFs (see Section 4 for more details).

CSIRO's key challenges in focus

The SBMT Newco aims to address three of the six CSIRO Challenges, deemed as areas of great significance to Australians in the current environment, namely:

Food Security and Quality: Achieve sustainable regional food security and grow Australia's share of premium AgriFood markets.

Resilient and Valuable Environments: Enhancing the resilience, sustainable use, and value of our environments, including by mitigating and adapting the impacts of climate and global change.

Future Industries: Help create Australia's future industries and jobs by collaborating to boost innovation performance.

Agriculture & Food

Program

Resilient Farming Systems program

Impact Area

Improved Agriculture Footprint

Mission

Drought and Ending Plastic Waste Missions

Impact Drivers

What are the global shifts that have the potential to drive the adoption of sprayable mulch solutions?

- **Regulatory Trends:** Government regulations are shifting across the world to limit plastic use. There continues to be a demand for sustainable farming practices globally. The European Union and the United States have regulated to phase out traditional agricultural plastic films. There is growing public awareness about the extent of the global plastic pollution problem, and its ecological and societal impacts.

  Sprayable mulch films offer a distinct advantage over traditional PMFs in that these can be left on the field at the end of the crop cycle and do not harm the environment. The changing regulations and consumer preferences are creating a favourable sentiment to accelerate market adoption of these formulations and catalyse market growth in the foreseeable future.

- **Market opportunity:** The global mulch film market is forecasted to reach US$5.7 billion by 2026 and grow at a rate of ~7.5% annually.[10] Increasing global food requirement, the need for high-yield production techniques, climate change, andincreasing investment in the sector are drivingthis demand.

  The current biodegradable mulch films represent ~1% of the total global mulch film market.[11] The market research shows that a variety of biodegradable mulch solutions composed of different polymers and additives are attracting early adoption. The Asia-Pacific region, led by China, is projected to grow at the highest rate in the adoption of biodegradable mulch solutions.

- **Consumer preferences:** Driven by the growing awareness, consumers have a higher preference for agricultural products grown on a biodegradable mulch film compared to conventional PMFs mainly due to their environmental benefits.
  A recent study showed that consumer willingness to pay for strawberries grown on biodegradable mulches is 10% more due to stronger environment-friendly attitudes.[12]

- **Technological advancements:** The ongoing R&D across the world in developing eco-friendly mulch films are creating technological advancements and growth opportunities in the global market.

[10] https://www.industryarc.com/Research/Mulch-Films-Market-Research-505106
[11] https://www.grandviewresearch.com/press-release/global-biodegradable-mulch-films-market
[12] https://pubmed.ncbi.nlm.nih.gov/30716938/

3 Impact assessment approach

Section 5 and 6 highlight the **prospective impacts** of sprayable biodegradable polymer membrane technology **based on the potential SBMT spin-out pathway**. A part of the overall estimated benefits are attributable to SIEF's support. As noted, the period between 2012-2016 mainly focused on investigating the application of polyurethane (**PU**) dispersions as sprayable membrane forming mulches for agriculture. CSIRO performed initial laboratory testing followed by field trials during this period and supported the production with internal manufacturing infrastructure. The work performed between 2012-2016 feeds in as background intellectual property for the subsequent SIEF initiatives in the period of 2016-2018 and post SIEF funding period. Since the inception of the R&D in 2012, the technology has progressed to a current TRL of 6-7; however, any measurable benefits have been limited to research and trial outcomes. Assuming the TRL is advanced successfully, quantifiable adoption for practical application through a suitable commercialisation pathway (such as the proposed spin-out) is a critical ingredient in the pathway of translation of outputs into outcomes and impacts to realise any real-world value.

This evaluation is based on the impact hypothesis developed post-discussion with the core team. External stakeholders (i.e., technical partners, collaborators, and end-users) could not be consulted for the evaluation. The assessment adopted CSIRO's Impact Framework to identify the causal relationship of the initiative. The Impact Pathway is divided into five phases – Inputs, Activities, Outputs, Outcomes, and Impacts – and is based on the premise that the process of creating impact begins with deploying inputs, conducting research activities, and producing outputs, which themselves are translated through short to medium term outcomes into the long-term impacts (**Figure 5**). The projected impacts connect back to research and innovation activities undertaken within the unit of evaluation, and their broader context.

To assess benefits from a program of work, a mixed-methods approach is usually adopted to estimate the quantitative (usually by way of Cost Benefit Analysis – **CBA**) and qualitative benefits. As will be evident from the qualitative discussion in subsequent sections of this assessment, there are compelling hypotheses for future economic, social, and environmental benefits through the successful development and adoption of SBPM technology. These include (but is not limited to) the yield benefits to farmers, environmental conservation, creation of jobs and collaborative networks, and new technology options created by R&D. However due to the early-stage nature of the work, a lack of clarity around critical aspects of the commercialisation pathway, and the current scope of this assessment, quantification of benefits could not be conducted at this stage. Tractuum provides a potential approach to quantify the prospective economic benefits from this research once more data becomes available in the next 18-24 months.

IMPACT PATHWAY

TRACTUUM

Impact Statement (Hypothesis): The development and adoption of innovative sprayable biodegradable mulch to eradicate the use of plastic mulch film from agricultural practices and support sustainable farming.

Enablers (2012-2022)

INPUTS
What we invest

National priority-led opportunity – Reducing Plastic Waste (driver)

Background IP
- Polyurethane aqueous emulsion capable of replacing PMFs (developed in 2012)
- IP (2014) for sprayable biodegradable polymer membrane

Investment
- CSIRO BU funding and in-kind support
- SIEF
- Ending Plastics Waste mission
- BM
- Investor funding rounds
- Accelerating Commercialisation Facilitators

Capabilities
Specific science skills:
Formulation chemists
Agronomists
Analytical chemists
Polymer chemists
Microbiologist

Other
Communication experts,
Business Development ,
Impact specialists
Change managers

Infrastructure
CSIRO research infrastructure (titrators, NMRDSL Spectrometer, permeation analyser etc)
Manufacturing infrastructure (BM and future partners)

Networks
ERA Polymer Pty Ltd
Boron Molecular Limited
Agro producer and companies, suppliers, Retailors, farmers
Customers/End-users/ Beneficiaries

Leadership team support
Regulatory Support

Innovators (2012-2022)

ACTIVITIES
What we do

World-class scientific research
Transpirational 1 and 2 RD&I activities

- Technology and Product (focus areas: TRL advancement)
  - development, testing, and validation of claimed benefits
  - application testing
  - manufacturability testing and process improvements
  - on-farm field trials
  - pre-commercial paid farm trials

SBMT
- Company formation
- Continued innovation to optimise the cost and performance of formulations
- Improvement to the manufacturing process
- Trials (incl. paid)on high-value crops and different soil types
- Recruitment of staff, Toll manufacturing partners, and customers

Research Infrastructure / Asset building

Translation
- Supporting partners as required Market analysis
- Preparing for and obtaining regulatory approvals
- Developing business model and investment case
- BD and commercialisation
- Funding applications

Stakeholder communication and engagement

Mobilise and develop the best talent
- Industry discussion forums and training
- Participation in conferences

OUTPUTS
Our deliverables

Product
- Water-based Sprayable Biodegradable Polymer Membrane with confirmed:
  - in-field biodegradability and non-toxicity of the polymer membrane
  - manufacturability and practicality
  - benefits in weed suppression, water savings, increased germination temperature and reduced erosion
  - improved performance and longevity
- Lab facilities for conducting similar R&D activities in future

Execution and Monitoring plans
- Business model
- Stakeholder engagement and communication
- Risk mitigation plan

Network and Data sharing networks
- New collaborations with upstream partners (manufacturers), downstream adopters and intermediate suppliers for TRL advancement and catalysing uptake of solution
- New networks with interested stakeholders

Capacity and capability building services
- New avenues for cross-disciplinary skill-building within CSIRO
- New industry consultancy support and training programs
- PhDs and Postdoctoral fellow training
- Training end-users to use technology effectively

New Knowledge
- CSIRO's proprietary technology (IP) Scientific Publications
- Business model PoC to support similar initiatives

Knowledge and data sharing
- Industry/Govt consultations
- New data-sharing networks
- Symposia and conferences

Awards, and other publications
- Impact Case Studies
- Media articles
- Awards

Scalers (2023 →)

OUTCOMES
The uptake, adoption, or consumption of our work

Adoption
End-users
- Incremental production gains from improved WUE, lower weeds, and erosion, and provision of temperature control
- Additional income/private benefits from price premiums on food products grown on biodegradable mulches
- Access to better quality and low environmental footprint product options to support sustainable farming solutions under a new regulatory environment that discourages the use of conventional plastic mulch films
- The flexibility of applying mulch regardless of the size and natural landscape of the farm. Ability to tailor mulch application as per crop-specific requirements
- No/low longer-term environmental footprint of the agricultural activities on the farm
- Reduced risk and uncertainty
- Cost and time savings and convenience benefits from not needing to dispose of PMFs as regulated

Government
- New solutions to support cleaner, sustainable farming and growing food demand
- New revenue streams in the form of taxes, selling a licence to the private sector, and potential export income
- New supply chainsand value-added products for Australian consumers
- Reduced government outlays to address/remediate longer-term detrimental effects of using PMFs
- Establishment of Australia's sovereign capabilities in this space

Industry
- The establishment of a more coordinated national focus improves threshold confidence, key stakeholder traction and the inflow of new investments in RD&I to underpin the technology advancement (TRL) and scale-up
- New networks and collaborations that harness the collective capability of industry, research partners, government, and community to drive advancements
- New research, services, products, experiences, supply-chains,and market niche options created by the new knowledge as a result of this initiative (e.g.,manufacturing options for degradable emulsions and adoption of SBPM as a platform technology to reduce environmental hotspots in the agricultural production)

Research and Partners
- Growth of new research options and infrastructure to support similar infrastructure

SIEF
- The work recognises the value generated by SIEF on Australia's innovation system including (but not limited to):
  - generating financial returns, advancing new areas of research and birth of new SMEs
  - capacity and capability building through training and supporting the new generation of Australian researchers
  - encouraging and improving new collaborations within Australia and internationally
  - providing a boost to new manufacturing processes and infrastructure

SBMT and founding partners
- Producer surplus benefits
- Improved customer awareness and confidence regarding products offered by SBMT
- Uptake of SBMT formulations promotes R&D of new products
- New opportunities for collaboration and commercialisation with an Australian small business –Boron Molecularthrough demonstration of capabilities in this space

CSIRO
Support key commercial outcomes byCSIRO's Drought and Ending Plastic Waste Missions
Recognition of CSIRO's competitiveness in this space and improving technical, translational, and commercial capabilities of the industry
New partnerships generate new sources of research income and engagement in new areas of R&D
Company creation model: Demonstration of significance of non-R&D innovation (business model) to drive competitiveness and delivery of impact and benefit other similar initiatives within CSIRO

Benefits

IMPACTS
Benefits to economy, environment, society

Economic
- National Economic Performance
- New services, products, experiences, and market niches
- Energy security
- New Jobs
- Australia's competitiveness

Environmental
- Land quality
- Aquatic environments

Social
- Food Security
- Health and wellbeing
- Innovation and human capital

Feedback Loop

Figure 5: SIEF TranspiratiONal - Impact Pathway

5 Impact pathway discussion

6.1 Inputs

Resources applied to deliver activities.

This section provides information on the key resources invested in the TranspiratiONal initiative.

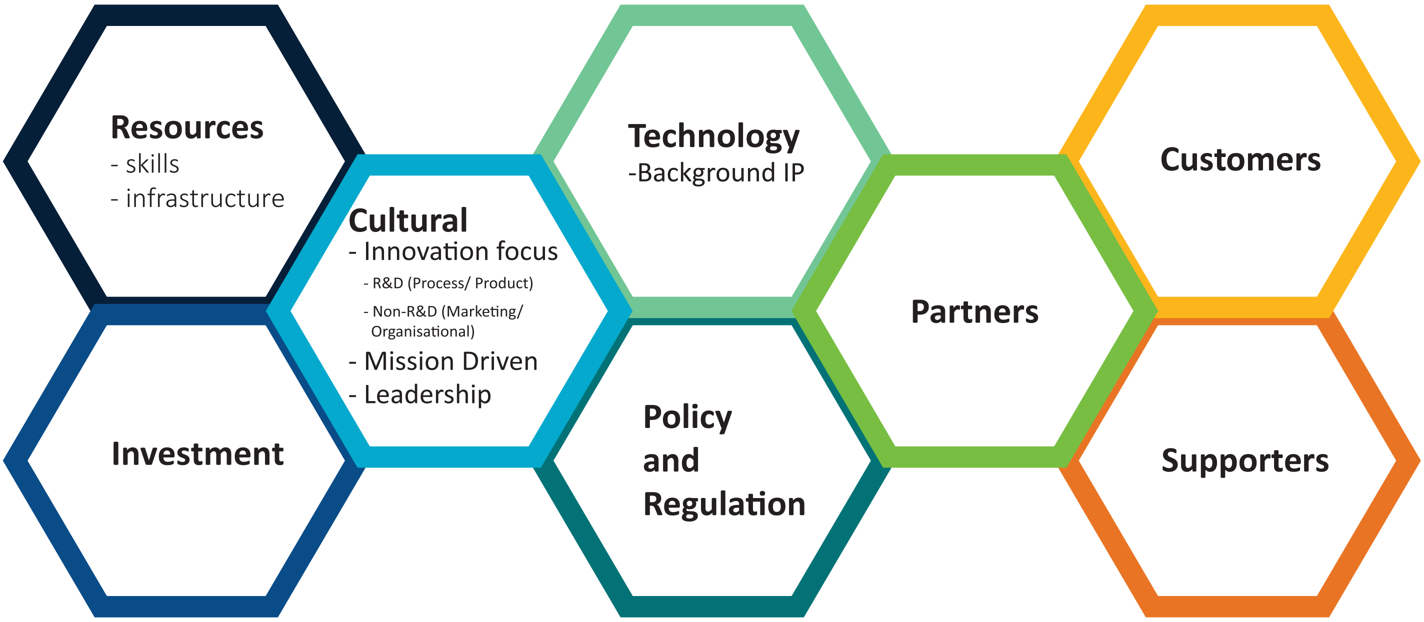

Figure 6: Key inputs to advance the science arm of the TranspiratiONal initiative

The key input requirements to accomplish the science deliverables are identified in **Figures 6** and **7**. As discussed earlier in the report, the foundational work in the development of SBPM technology started in 2012 as a joint venture between CSIRO Manufacturing, and Agriculture and Food BUs. SIEF provided funding during two phases (2016-2018) to advance the TRL and CR of the technology.

Table 1 depicts the investment made by CSIRO, SIEF and SBMT partners starting FY2017.[13]

Table 1: Financial and in-kind support for the project

Contributor/type of support	FY2017	FY2018	FY2019	FY2020	FY2021	FY2022
	SIEF period			Post-SIEF		
	Cash					
SIEF 1	$445,842					
SIEF 2		$523,433				
Newco Sprint (A&F funds)					$115,712	
EPW (Mission funds)						$43,334
APAIR (APAIR funds)						$43,334
IAF Funding (IAF funds)						$115,712

[13]Investment data preceding the first phase of SIEF investment was not available to the Impact Team. As noted in Section 4, any investment as well as R&D conducted before 2016 feeds in as background intellectual property (IP) for the SIEF program.

Contributor/type of support	FY2017	FY2018	FY2019	FY2020	FY2021	FY2022
	In-Kind					
CSIRO		$483,169				
Overall Annual investment (nominal)	$445,842	$1,006,602	-	-	$115,712	$202,380
Overall Annual investment (real)[14]	$492,322	$1,090,504	-	-	$119,757	$202,380
Overall Investment (PV in FY2022$)[15]	$2,450,455					

6.2 Activities

Actions taken or work performed through which inputs (such as funds, technical assistance and other types of resources) are mobilised with the intention of achieving specific outputs.

The SIEF investment during 2016-2018 supported the production scale-up and larger field trials to demonstrate the benefits of application rates from 0.5-3kg/m^2 in weed suppression, and testing benefits in terms of enhanced water use efficiency (WUE), and erosion control. The activities to establish biodegradation rates and non-eco-toxicity were also performed during this period.

With the renewed commercial interest, the role of CSIRO's new core team post SIEF funding has been centred around advancing the TRL and CR of the SBPM technology. Currently, the core activities are targeted to enable:

- Launch of a spin-out;
- SBM scale-up to reduce the cost of goods sold (COGS);
- The inclusion of new ingredients to improve the SBM cost of manufacture. CSIRO also provided manufacturing process development support to Boron Molecular (BM) during scale-up trials and conducted education and outreach activities to support toll manufacturers (BM and Era Polymers) and their skill development in this space;
- Optimisation of the manufacturing operation;
- Evoking interest in SBM options in domestic and overseas markets (e.g., the United States and Europe), including new farm trials for additional high-value crops, and different soil types (in Australia and overseas); and
- Recruitment of new staff (R&D and Manufacturing), toll manufacturing partners[16], and customers for advanced trials.

6.3 Outputs

The research solutions, services, and/or capacities that result from the completion of activities within the SIEF TranspirtiONal initiative

Product: Water-based Sprayable Biodegradable Polymer Membrane

Past efforts have led to the delivery of an innovative SBM, processes to successfully manufacture the SBM at larger scale, and better information about its application to horticulture, orchard, and high-value broadacre crops. The developed SBM allows end-users to control weeds, reduce herbicide application, preserve soil moisture, and provide heat or cooling benefits, while eliminating the use of PMFs and providing sustainable farming solutions.

[14]Nominal value adjusted for inflation using Consumer Price Index
[15]Converted to present value using7% real discount rate
[16]Toll manufacturing can be simply defined as an arrangement, where a company with specialised equipment processes raw materials or unfinished goods for a different company

Manufacturing capability

Proof of concept around the industrial-scale manufacturing of SBM has been demonstrated by BM to support the expansion of SBMT's offerings.

Business Model

The launch of a spin-out SBMT based on the company creation model is being targeted by the core team to realise the impact potential of this work. The core team has also projected some future commercialisation pathways based on scenario planning.

New Networks (technical partners, customers, end-users)

Stakeholders: CSIRO/EiR/Industry Partner

Distribution Partners: Nufarm, tbpi

Trial Partners: Kagome/Green Cloud Nursery/Myrtle Park Farms

Capacity and capability building

- Training programs and consultancy support for industry and remote communities for uptake of technology
- PhD students' training, university collaborations, knowledge sharing through publications (non-confidential information)
- Cross-disciplinary industry collaborations in this space (polymer, manufacturing partners, emulsion science, agriculture, etc.)

Other potential outputs that will propel innovation within CSIRO and more broadly across Australia include:

- New knowledge and infrastructure to support scientific advancements in this space
- POC for company creation model to deliver accelerated value and impact for benefit of similar ventures
- New networks of partners, end-users and beneficiaries for knowledge, data sharing and collaborative research

Awards, intellectual property (IP), and publications

These include, but are not limited to:

- CSIRO Agriculture & FoodDirector's Award for the "Breakthrough Innovation – Finding new ways to create impact" Category, 2016
- IP such as
  - Sprayable Polymer Membrane for Agriculture (CSIRO Ref. TW8842) PCT/AU2015/000334, WO2015184490A1 National Phase Applications filed in Australia, NZ, EP, Brazil, India, Israel, USA & China.
  - Sprayable Polyurethane/Urea Elastomer for Agriculture (CSIRO Ref. TW8988) PCT/AU2016/051171, WO2017091853A1 National Phase Applications filed in Australia, NZ, EP, Canada, Brazil, India, Israel, USA & China.
  - Hydrophobic-Hydrophilic Switchable Polymers for Use in Agriculture (CSIRO Ref. TW8998) PCT/AU2017/050255, WO2017161418A1 National Phase Applications filed in Australia, NZ, Japan, EP, USA & China.
  - Trade secrets = manufacturing process and know-how acquired from experience during the development and extension of the minimum viable product and its scale-up by toll manufacturers. Know how on application rates acquired from trials.
- Impact Case Study
- Media articles that highlight the potential benefits of technology covered on different platforms in the last few years
- SIEF communications – SIEF technical reports, newsletters, SIEF website
- CSIRO Annual report
- Recent journal publications
  - Braunack, M.V., et al. (2021), Evaluation of a sprayable biodegradable polymer membrane (SBPM) technology for soil water conservation

in tomato and watermelon production systems. Agricultural Water Management, 243, 106446

- Borrowman, C. K., et al. (2020), LC-MS analysis of the degradation products of a sprayable, biodegradable poly(ester-urethan-urea). Polymer Degradation andStability, 178, 109218Filipovic, V. et al. (2020), Sprayable biodegradable polymer membrane technology for cropping systems: Challenges and Opportunities. Environ. Sci. Technol., 2020, 54, 4709-4711

- Braunack, M.V. et al. (2020), A sprayable biodegradable polymer membrane (SBPM) technology: effect of band width and application rate on water conservation and seedling emergence. Agricultural Water Management, 230, 105900

- Braunack, M.V., et al. (2020), Initial experimental experience with a sprayable biodegradable polymer membrane (SBPM) technology in cotton. Agronomy, 2020, 10, 584

- Gu, X. et al. (2020), Effects of degradable film mulching on crop yield and water use efficiency in China: A meta-analysis. Soil & Tillage Research, 2020, 104676

- Participation at recent conferences (publications), seminars and workshops

- Gordon, S. G., A sprayable biodegradable mulch, CSIRO's TranspiratiONal project, Agriculture Film Outlook, September 2021

- TranspiratiONal Booth at the AgCatalyst Event, December 2016 in Sydney.

- Bristow, K.L. 2018. A Sprayable Biodegradable Polymer Membrane (SBPM) Technology: Challenges and Opportunities. Roscoe Ellis Jr. Soil Science Lecture, Faculty of Agronomy, Kansas State University, Manhattan, Kansas, USA (11th April 2018) (Invited Speaker)

- Bristow, K.L., Adhikari, R., Casey, P.S., Freischmidt, G., Johnston, P., Braunack, M.V., Sangwan, P.,Thomas, B. &JirkaŠimůnek. A sprayable biodegradable polymer membrane as an alternative topreformed plastic mulch films used in crop production systems. Irrigation Australia Limited (IAL)International Conference and Exhibition "Addressing the Big Issues", Sydney NSW Australia (13-15th June 2018)

- Bristow, K.L., Adhikari, R., Casey, P.S., Freischmidt, G., Johnston, P., M.V. Braunack, Sangwan, P., Jirka Šimůnek4 and C. Way. 2017. A sprayable biodegradable polymer membrane for use in crop production. ASA-CSSA-SSSA International Annual Meeting, "Managing Global Resources for a Secure Future", Tampa, FL USA (22-25th October 2017) (Abstracts 2017 CD-ROM)

- Adhikari, R., Freischmidt, G., Bristow, K.L., Casey, P.S., Johnston, P., Sangwan, P., Way, C. & M.V.Braunack. 2017. Sprayable Biodegradable Polymer Membrane for Crop Production Systems. PolymerVic 2017 Conference, Melbourne, Australia (27-28 September 2017)

6.4 Outcomes

The intended or desired medium-term effects /change expected to be realized from the successful uptake of research outputs by users. It usually requires the collective effort of partners (commercialisation partner/ initial user/ end-user etc).

The advanced development and successful adoption of SBM are expected to deliver environmentally friendly sustainable farming solutions. Positive outcomes would emerge from the collective effort between CSIRO, SBMT foundational partners, collaborating partners, customers, and supporters.

The outcomes for the key stakeholder groups are covered in **Figure 5** above.

Impact Risks *(Outcomes phase)*

The risks identified below are based on inputs from core project team and Tractuum's experience of carrying out assessments of a similar nature. It is important to note that a formal impact risk assessment has not been performed at this stage.

- **Commercial barriers** such as:
  - lack of economies of scale
  - high COGS and manufacturing costs
  - new, improved and competitive biodegradable solutions that are reliable, cost-effective, easy to implement with adequate lifetime, provide better weed suppression, WUE, and erosion protection
  - Health, Safety and Environmental (HSE) constraints during transportation, storage, and application of SBM formulations
- **Regulatory barriers such as:**
  - lack of compliance with applicable regulations, codes, and standards
  - fragmented regulatory approaches across Australian jurisdictions, misplaced incentives, and lack of coordinated activities to drive uptake of biodegradable solutions in the agricultural industry
- **Customer barriers such as:**
  - no/low adoption interest due to low market pain points
  - reluctance to shift to a sprayable mulch system due to familiarity with conventional film-based approach, and low cost and ease of use of alternate options
  - market unreadiness of the technology due to availability of cheaper solutions and less stringent regulations to minimise plastic use
- **Technical barriers such as:**
  - low TRL at the time of launch (causing adoption challenges);
  - limited knowledge and training requirements to use the solution safely and effectively on farms
- **Health and safety** concerns associated with the use of the new product

6.5 Prospective Impacts

Overall impact = Direct impact + Sector level impact

Direct impact: Σ (benefits generated through directly working with customers and partners)

Sector level impact: Σ(benefits generated through raisingindustry'sbenchmark understanding and awareness, and sparking new innovations)

Table 2: Potential direct impacts from the adoption of SBMT products using CSIRO's TBL benefits classification approach*

TYPE	CATEGORY	INDICATOR*	DESCRIPTION
Economic	National Economic Performance New services, products, experiences, and market niches	- ↑ overall revenue/profits from the demand of SBMT products - ↑crop production yield - ↑WUE - ↑SBM formulation offerings - ↓risk and uncertainty for end-users due to the availability of eco-friendly options - ↓government outlays on the management of plastic waste driven by SBM adoption	The adoption of SBMT products within Australia and globally has the potential to generate new revenue streams for the producer as well as export income for Australia. Eco-friendly Australian solutions in the form of SPBM will benefit direct consumers through incremental yields and enable access to environmentally friendly products that comply with new regulatory requirements of minimising plastic use while allowing sustainable farming operations. Farmers are also expected to benefit from the price premiums on food produced on the eco-friendly biodegradable mulch as well as the low environmental effects of the agricultural operations. There are expected to be additional time and convenience benefits through eliminating the need for PMF removal. Adoption of new products would also reduce government outlays on the management of plastic waste from PMFs.
	New Jobs	- # new jobs created (FTE and PTE)	Creation of new higher-skilled jobs to address the needs of the new industry (direct and indirect)
	Australia's competitiveness	- New export products - New export income	The growth of a new industry that contributes to Australia's GDP. Recognition of Australia's competitiveness in this space. Export opportunities, especially in the Asia Pacific.
Environmental	Land quality Aquatic environments	- ↓plastic waste from mulch films - ↓plastic particulate pollution in oceans, groundwater, air, and soil - ↓use of chemicals such as weedicides - ↓water requirements	Lower environmental footprint of agricultural activities through reduced use of PMF, water and chemicals such as herbicides. Reduction in plastic mulch film waste that causes ground, air, and water pollution, damage to aquatic life, etc.

TYPE	CATEGORY	INDICATOR*	DESCRIPTION
Social	Food Security	- ↑food availability and accessibility	Options to improve food productivity, availability and accessibility of food.
	Health and wellbeing	- ↓GHG emissions and microplastic pollution associated with PMFs	Improved community health from the reduction in environmentally detrimental effects caused by production, post-use treatment, and microplastic pollution caused by the use of PMFs.
	Innovation and human capital (creativity and invention)	- ↑ venture capital investment in this space - New start-ups supported by industry advancement - ↑research, industry and government collaborations and integration in this space	New technologies, start-ups, and markets that raise the skills, expertise, and opportunity baseline for Australia and open new avenues for learning and innovation in this space.

*All indicators relate to the adoption of SBMT's formulations unless specified otherwise.

7 Clarifying the prospective impacts

Counterfactual

What would have happened with no involvement by SIEF and CSIRO?

CSIRO delivered the fundamental science to develop a no/low environmental footprint sprayable mulch technology. SIEF provided critical support to define the requirements for product assurances needed for entry into commercial markets. The program helped lay building blocks for advancing TRL and CR of technology to facilitate the transfer of technical knowledge into a commercial solution

The two phases of SIEF funding helped define the commercial path to end-users for the adoption of technology and build a platform to attract external interest and investment for prospective SBMT spin-out with the goal to realise the impact potential of this work. The work also drove interesting developments around the role of local companies such as BM in providing manufacturing support to deliver significant technical, scale-up and path to market for SBMT. SIEF's support also helped the project gain significant media attention.

Had CSIRO and SIEF not supported the R&D, on-farm field trials and commercially relevant key investment objectives for this initiative, it would have led to the following potential scenarios:

1. Choice of other research providers

- As a research organisation, CSIRO provides some unique attributes (compared to other similar organisations in Australia) to successfully conduct the foundational and applied research for this initiativeand deliver against its impact objectives. These include:

  - Sprayable mulch films is a new domain that started as a joint venture between CSIRO A&F and Manufacturing BUs. The inception of the R&D, as well as further technology development, requires cross-disciplinary experts that include (but are not limited to) agricultural scientists, manufacturing process engineers, product developers, and materials engineers working together. CSIRO offers the capability of providing varied expertise under one roof.

  - The TRL advancement requires integration with interdisciplinary players such as manufacturing partners, governments, research institutions, the private sector, the farming sector, etc. CSIRO's network connections, as well as its ability to harness the collective capability of different stakeholders internally and externally, are of immense value.

  - The commercial uptake of any new technology is significantly contingent upon brand confidence. CSIRO, as Australia's national science organisation, provides the necessary confidence to stakeholders during the developmental step to advance the TRL, as well as the CR of the technology to improve its commercial attractiveness. This trust also helps drive the commercial adoption of the formulations, a critical ingredient to enable the delivery of impact. CSIRO also provides access to new crops and farmers via its industry networks for demonstration, validation, paid trials, and new market acquisition.

  - There are limited scientific research organisations or universities within Australia that can integrate capabilities from interdisciplinary experts and reliably provide standing capacity to support the objectives of this initiative.

  - Some state government organisations could potentially contribute, but most lack the ability to coordinate and deliver scalable solutions at the national level. Some private enterprises might also be capable of execution but may lack the level of trust and degree of independence of a respected public institution such as CSIRO, thereby potentially affecting downstream uptake.

- In addition, the biodegradable mulch film industry is at an embryonic stage, both in Australia and globally. Hence, there are no established commercialisation pathways from which experience can be drawn. This may be a key deterrent tothe development of technology by other research organisations, especially smaller entities.

2. Importing biodegradable mulch solutions from other countries

- At the international level, there are organisations with the capacity and capability to undertake this work, but this would result in dependence upon imported technologies (for example from the United States and Europe), instead of building and offering Australian-specific solutions.

In addition, although importing is a viable option, these solutions may not see similar uptake within the market compared with Australian products, due to strong consumer preference for domestic products. Under this scenario, there would also be a need to tailor the available options toAustralia's specific requirements. This implies that establishing a market and creating a consumer base (demand) will be more difficult for the same kind of product if it were imported. Also, this would mean losing the opportunity of building a domestic industry based on sovereign capabilities. COVID-19 has underscored the importance of building Australian industries to drive the prosperity of the nation.

3. The industry keeps using the conventional solutions

- In the absence of this technology, the industry will keep using the conventional PMFs or rely on the alternative biodegradable plastic mulch films available in the market. The issues associated with their use have been discussed earlier in this assessment.

The inputs from the core R&D team, as well as external stakeholders during the case study interviews, suggest that, under the current scenario, the development of a cost-competitive sprayable mulch technology would be delayed by 5-10 years in the absence of SIEF involvement.

Adoption

How much of the anticipated impact is still to occur?

The adoption level of technology is expected to increase once threshold confidence is achieved through early adopters. As indicated in Figure 7 (A) below the SPBM technology being evaluated is currently sitting in its early phase of adoption, and most of the anticipated impact is yet to occur.

It must be noted that Figure 7 is for indicative purposes only. For the monitoring and evaluation of impact (as further explained in Section 8 below) mapping the adoption pathway and indicators of progress towards targeted adoption levels might be useful.

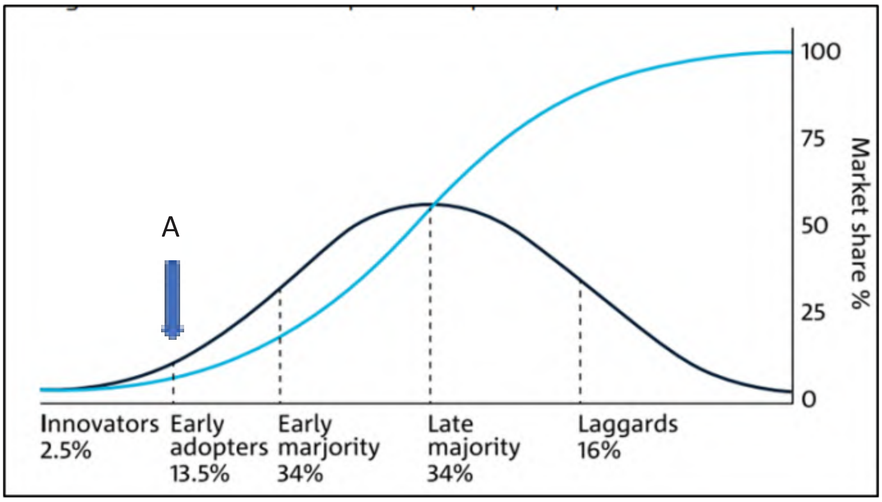

Figure 7: Indicative impact adoption profile.[17] 'A' indicates the current adoption level of SBM technology.

[17]Source: Rogers, 1995, p.247 (provided in CSIRO Impact Evaluation Guide Feb 2020). The gentle bell-shaped curve represents the groups of consumers adopting a new technology and the S-curve represents the market share which reaches 100% following complete adoption.

8 Evaluating prospective economic benefits

Cost Benefit Analysis (CBA) is used by governments to help assess whether a project or policy increases the welfare of society. A primary decision criterion is that additional social costs must be exceeded by the additional social benefits; and that there is no other project that can offer a higher level of net social benefit. A CBA can be conducted from various standpoints. An ex-ante analysis – as is conducted in this assessment – typically estimates the likely future net social benefit.

The analysis focuses on incremental impacts from the uptake of a portfolio of SBMT products, based on CSIRO's technology. The net impact is estimated by comparing the observed or expected benefits with the base reference point (i.e., a hypothetical scenario in the absence of CSIRO's intervention – see the ***Counterfactual*** section above for further details). It is important to note that the purpose of this section is to focus on the potential socio-enviro-economic benefits of SBMT's sprayable biodegradable mulch solutions to improve the welfare of Australian society, and to estimate that part of the net benefits which are attributable specifically to SIEF and CSIRO; it is not meant to assess the viability of the SBMT.

Investment (Research) Objectives

- The original research investment objective was the development, TRL advancement, and commercial feasibility testing of the SBPM technology. The ultimate impact goal is tolower the environmental footprint of agricultural activities through providing a solution to eliminate PMFs while delivering a sustainable solution to support the higher food demands of the growing world population.
- The future investmentswill be utilised to improve COGS and the quality of formulations to serve the intended purpose.

An important step in a rigorous CBA is to determine whether some form of market failure could discourage private-sector production of results comparable to those of a proposed government-funded project. The use of taxpayer funds for project development can have an adverse effect on general economic activity if additional taxation is required to fund a project; and government involvement may crowd out private sector investment. In the current case, comparable domestic or overseas solutions are not available; and the initiative was recognised as an innovative project at the time of its inception.

CBA Cases

Base (Counterfactual) Case: 'Business as Usual' scenario under which consumers have limited access to environmentally friendly options to replace PMFs. If PMFs continue to be used, these will lead to environmentally detrimental effects and high costs to society. The banning of PMFs would result in lower farm productivity due to quality and/ or supply constraints associated with the current biodegradable options available in the market.

Project Case: Successful development and adoption at scale of commercially viable sprayable biodegradable mulch solutions to deliver benefits in the form of producer, consumer, and government surpluses and externalities.

Standing

CSIRO is a national institution that is funded primarily by the government, and its work affects Australian society as a whole. Hence, for most CSIRO research, the impact assessment must be conducted from Australia's perspective; and the quantification of benefits is limited to the national level. Given the global nature of the agricultural industry, the footprint of benefits will not be limited to adoption within Australian markets; for instance, there is also potential for uptake of SBMT's formulations in the US and European markets, as well as the Asia Pacific region during later years. This will generate export income for national benefit.

The assessment highlights producer, consumer, and government surpluses based on a set of assumptions. It includes additional economic costs and benefits arising from the SBMT initiative for key stakeholder groups which include (but are not limited to):

- SBMT's stakeholders – investors, partners, customers
- Supply chain participants (raw material suppliers, distributors, wholesalers, etc.)
- Farmers
- Biodegradable polymer manufacturing
- SIEF
- CSIRO
- State and Federal governments.

However, distributional analysis of the welfare gains to the Australian community from the research and development of the SBMT is not possible at this stage due to data and scope limitations.

Modelling Approach

The SBM technology provides an environmentally friendly solution to the plastic waste problem to underpin sustainable farming. While quality-enhancing research has become increasingly important, economic assessments of different kinds of research that aim to improve the desirable characteristics of a product are limited. Cost-reducing research generally has been the main focus for assessment thus far. In addition, appropriate ways to model research-induced quality improvements are not always straightforward.

A demand curve that indicates consumer willingness to pay for an improved product or service (**WTP**) necessarily reflects the factors that people value, such as environmental friendliness, costs, reliability, supply, performance, sustainability, and convenience. However, these are difficult to quantify in the absence of data at this stage.

The current study estimates quality improvements as a shift in demand towards SBMT's formulations.[18] The approach for assessment of the economic benefits on the basis of current hypotheses is outlined in greater detail below.

Benefit Cost Ratio

Cost-benefit analysis compares the projected benefits of a project against its costs to provide a Benefit Cost Ratio (**BCR**) and Net Present Value (**NPV**).[19]

The costs considered include the costs incurred by CSIRO and its research partners to produce the research outputs in the chosen assessment period. Where data is available, usage and adoption costs borne by end-users should be included. The benefits calculated in the analysis are the net benefits from the program, that is, the difference between the 'with program' and 'without program' scenarios.

> The following sections outline the approach for conducting a CBA for this initiative. As explained above (Section 4), due to the early-stage nature of this work, and a lack of data on the costs as well as the nature and extent of benefits, an assessment of BCR or NPV is not possible at this stage. This will also be evident from the discussion covered below.

With and Without scenarios

What are key impact drivers and inhibitors that will influence the adoption of CSIRO's TranspiratiONal-SBM PU-based mulch compared to other market solutions?

The traditional PMFs, the biodegradable plastic mulch film options, and other sprayable mulches are key competitor product lines that can influence the uptake of CSIRO's TranspiratiONal-SBM PU-based mulch by the end-users. The commercially relevant attributes that differentiate TranspiratiONal-SBM PU-based mulch from the other available options and influence its future impact potential are discussed below (see **Tables 3, 4 and 5**).

[18]Unnevehr, 1986

[19]The formula for calculating a benefit cost ratio is defined as:

Benefit Cost Ratio=PV(B_t)/ PV(C_t)

Net Present Value=PV(B_t)-PV(C_t)

Where

PV(B_t) is the present value of the benefits at time t

PV(C_t) is the present value of the costs at time t

Social Surplus

A CBA would typically examine the effects on Australian society from the perspective of the overall net increase (or surplus) in economic welfare. This can be represented in terms of the total social surplus:

Δ Total Social Surplus = Δ Producer Surplus + Δ Consumer Surplus + Δ Government Surplus + Δ Externalities

One perspective of Australian society is to examine the economic impacts on the producing entity (SBMT), the users of the SBMT products, and the Australian Government (as an initial funder on behalf of taxpayers). The overall social surplus is partially attributable to the SIEF investment, as explained above. Each of these elementsis discussed below.

Producer Surplus (PS)

PS is an economic indicator of producer benefits. It is essentially the 'profit' made by a commercial entity when the additional revenue received for a product exceeds theadditional resources used to produce it.

In the present case, SBMT is assumed to offer SBM formulations. The difference in the present value (PV) of revenues and costs yields producer surplus (essentially profit).

Impact hypothesis: SBMT will generate incremental producer surplus from the adoption of SBM formulations directly for foundation/ large horticultural farms and through selected distribution companies.

Estimation of Producer Surplus

The approach is based on the profit margin projections for SBMT which are estimated on the basis of reservation price[20], actual market price, and demand for quantitative estimation of benefits represented as the area of **ΔP1APo** in Figure 8.[21] An estimate of the cost function for the industry (estimation of supply) is also needed to determine the reservation prices for the unit quantity of formulation being supplied to the market. **At this early stage, none of this information is available.**

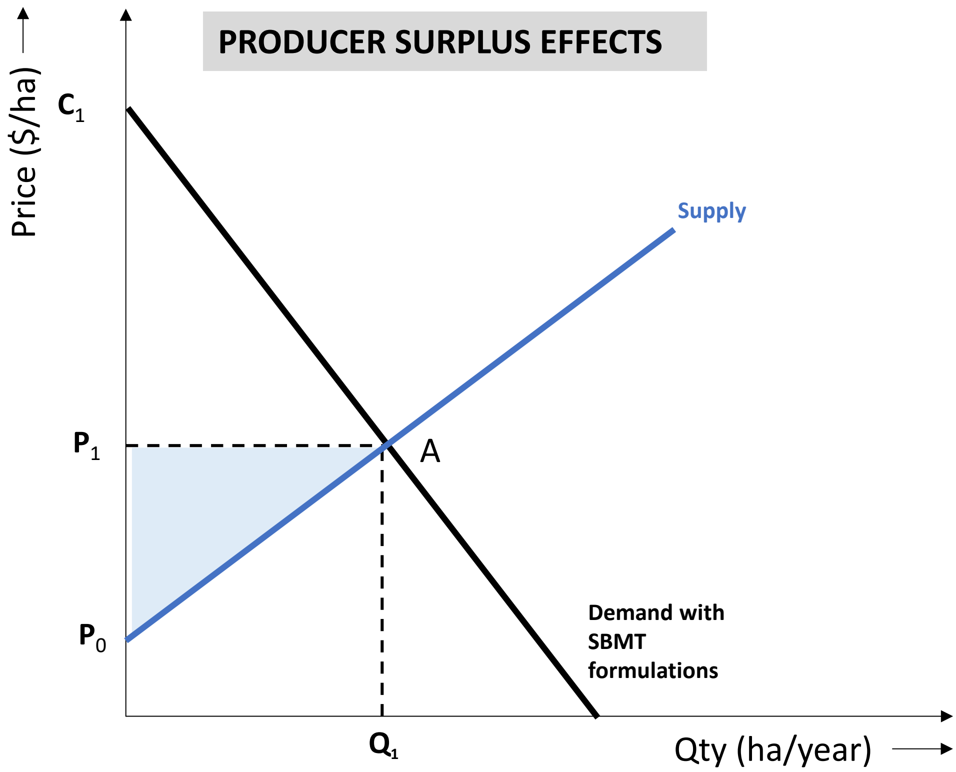

Figure 8: Producer surplus from CSIRO's TranspiratiONal-SBM R&D

P_0	Reservation Price of SBMT formulations ($/ha)	P_1	The actual price of SBMT formulations ($/ha)
Q_1	The annual demand with SBMT formulations (ha/yr)		

[20]That is, the minimum price producers are willing to accept to cover their costs of production.
[21]Typically ≤2 tons of SPM quantities are required per hectare of farm, depending upon the soil type.

Discussion

With the inevitable regulated use of plastics, the agricultural sector needs alternate options to PMFs. The issues associated with ecotoxicity, and slow degradation of currently available biodegradable plastic mulch films, have hampered its uptake; the supply of serviceable volumes of starch-based sprayable mulch films also is currently a constraint. The SBMT formulations provide the balance between mechanical resilience and biodegradability to address these limitations and are capable of filling a part of this supply deficit for industry while reducing the cost to society of using agricultural mulch films (Table 3). One approach to assess benefits, therefore, is to examine the PS generated from the adoption of SBMT formulations which represents a part of the overall social benefit.

The core team is focussing on Australia's horticultural market as the initial target market for the adoption of SBMT products. Based on the initial market assessment, the addressable market is estimated at US$361 mil/year. The project team estimates the obtainable market at US$90 mil/year in 4 to 6 years. For perspective, ~14,000 hectares of land in Australia is covered with PMFs,[22] compared with ~1.8 million in China.[23] Hence, once the technology is economically viable and attains threshold confidence, it offers a potential for significant export opportunities as well. Any export opportunities will understandably be guided by country-specific regulations.

Currently, the production costs of the SBM formulations are not commercially viable; and this represents the biggest roadblock to their adoption and delivery of impacts. The aspirational offer price of SBM (@2 ton/ha) is $2,500, as against the cost of plastic mulch films at $1700/ha and biodegradable films at $1,800-2,800/ha.[24] Even at low-moderate producer profit margins, the adoption costs of SBM are currently significantly higher than the conventional PMFs (including the retrieval and dumping costs) and other biodegradable film solutions available in the market. The manufacturing cost remains a considerable unknown at this stage. Over the last two years, the team has further optimised the production process; however, since the manufacturing currently occurs on the batch scale with low volumes, the current costs are very high. While BM will provide infrastructure for the early-phase production and roll-out of the SBM formulations, the lack of access to larger manufacturing facilities that can offer high scale production capacity to achieve economies of scale remains an impediment. Limited biodegradable emulsion production capability in Australia limits domestic options. The team is actively exploring suitable manufacturing partners in Australia and overseas for delivering high commercial volumes to lower costs and drive demand.

Table 3: Comparison of attributes of different mulch options available in the market -1.

Features	Traditional (film) mulch	Biodegradable (film) mulch	Sprayable mulches	TranspiratiONal-SBM PU-based mulch
Key Ingredients	Polyethylene (PE)-based plastic Detrimental to the environment. Expected to be phasedout in a few years due to the stringent regulatory environment.	PLA, PBS, PBAT, PTT, PEF Ecotoxicity is possible if the mulch contains PE or degrades too slowly. Some of the raw materials have better utilisation in other value-chains such as pharmaceuticals.	Carbohydrate (starch), siloxanes Starch supplies for high production volumes may be a constraint. Siloxanes can persist in soil. Some forms are toxic and have the potential to bioaccumulate in aquatic organisms.	Polyurethane-based emulsion The raw material is currently imported. Supplies are not a constraint to supporting high production volumes

[22]in the major horticulture and dairy regions including south-east and central Queensland, the Hunter Valley and Murray-Darling basin in NSW (and Victoria), and the Goulburn Valley and Gippsland in Victoria
[23]https://www.afr.com/companies/energy/farmers-harvest-the-benefits-of-research-20210812-p58i9n

Features	Traditional (film) mulch	Biodegradable (film) mulch	Sprayable mulches	TranspiratiONal-SBM PU-based mulch
Production Costs	Established manufacturing processes to drive economies of scale		Concept stage	Based on the batch manufacturing process, low volumes, and high costs. Limited biodegradable emulsion production capability in Australia is a constraint.

(green)	Better compared to market solutions	(light red)	Needs some improvement compared to current solutions	(red)	Needs significant improvement compared to current solutions

In addition to the above, the formulations are developed from imported raw materials. The supply chain inefficiencies induced by COVID 19 have the potential to negatively influence the access to raw material and production opportunities, as well as overall adoption costs in the near future. Currently, the core team is conducting only limited, small-scale trials, with entities that can provide controlled trial conditions (e.g., Western Australia's (WA) Department of Primary Industries and Regional Development (DPIRD) and other larger corporate agricultural production companies). Commercial volumes of SBM for industry adoption are not expected to be ready for roll-out for at least 18-24 months.

As evident from the above discussion, the data required to estimate PS is commercially sensitive/ unavailable/ hard (more than one or all of these factors) to estimate at this early stage. Hence PS cannot be quantified for the purpose of this assessment.

Consumer Surplus (CS)

CS is an economic indicator of consumer benefits. This occurs when the price paid by the consumer is less than the price they are willing to pay.

Impact hypothesis: The adoption of the SBMT formulations will increase the consumer willingness to pay due to the ability of formulations to deliver incremental yields, tailor application as per crop and land-specific requirements, low/no environmental footprint, increased convenience, and access to uninterrupted supplies. There is also expected to be new demand due to the increasing need for sustainable farming solutions, driven by the regulatory environment and consumer preferences. These shifts will generate incremental consumer surplus.

Estimation of incremental Consumer Surplus

The approach is based on the estimation of incremental CS generated by the adoption of SBMT formulations by the agricultural industry. The CS is calculated as the difference between the price a consumer pays and the price they would be WTP. Hence, the CS for the competitor products and SBMT formulations are represented in **Figure 9** as **$\Delta P_1'BC_1'$ and ΔP_1AC_1** respectively. Any incremental CS is evidently a function of the market price of competitor products, the expected market price of SBMT's formulations, and the consumer WTP for these products. Therefore, the incremental CS calculated as **ΔP_1AC_1 – $\Delta P_1'BC_1'$**, in reality, can be positive, neutral, or negative, depending upon these factors which are too immature to quantify at this stage for the SBMT case.

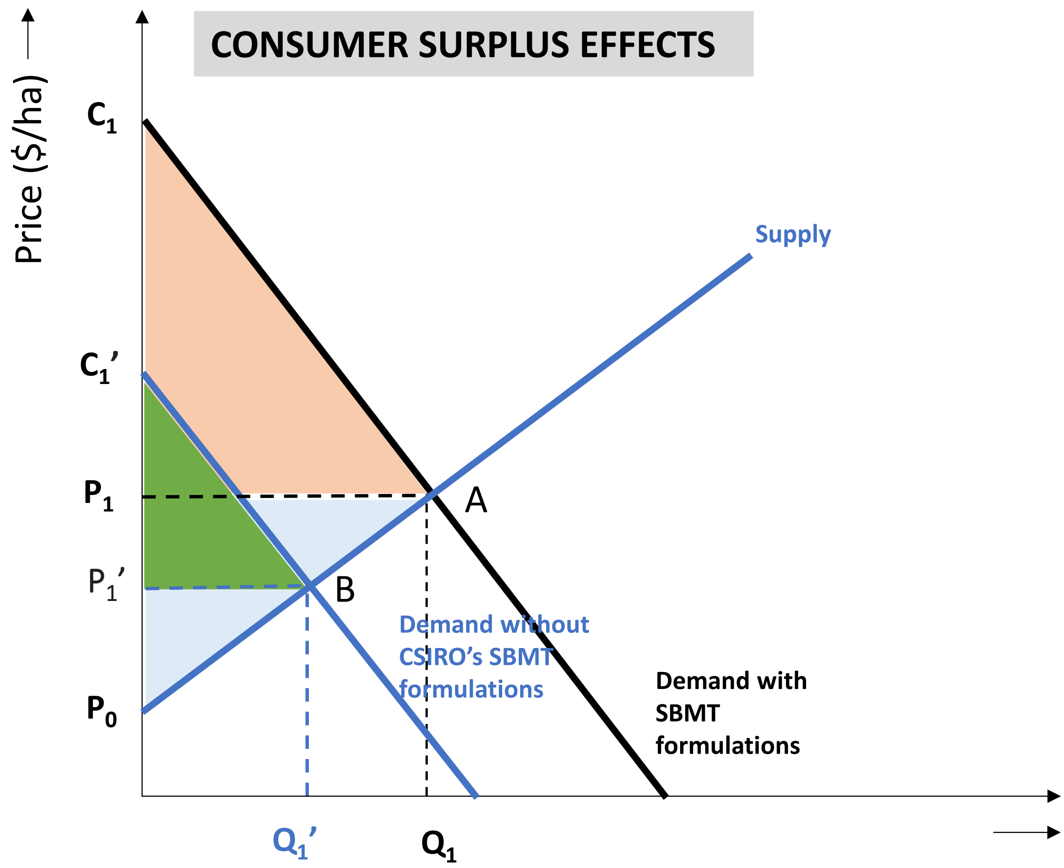

Figure 9: Incremental Consumer Surplus (CS) from the adoption of SBMT formulations

P_1	The actual price of SBMT formulations ($/ha)	P_1'	The actual price of other biodegradable films ($/ha)
C_1	Consumer WTP of SBMT formulations ($/ha)	C_1'	The consumer WTP of other biodegradable films ($/ha)
Q_1	The annual demand with SBMT formulations (ha/yr)	Q_1'	The annual demand with other biodegradable films (ha/year)

Discussion

While Tractuum was provided with the early estimates of the market pricing of competitor products and aspirational pricing of SBMT formulations, the projections for new consumer WTP are unavailable. The estimation of consumer WTP requires knowledge of the demand curve for the SBMT formulation and can be determined using stated preference techniques such as Choice Modelling. This technique derives WTP by asking people to indirectly state their choice between options with different attributes. Also, consideration must be given to the definition of 'consumers', which may be either direct consumers and/or distributors. There is a strong case for including the interests of the whole of Australian society when estimating CS. However, this exercise can be expensive and time-consuming to undertake as it requires consumer surveys.

The overall demand and adoption of SBMT would be driven by critical factors that influence the 'user' capital and operating costs such as (see **Table 4**):

- The regulatory environment around the use of PMF.
- Cost of using SBMT formulations compared with alternate market offerings. As discussed above, the current aspirational offer price is still significantly higher than other market offerings. There are higher logistics, health, and safety implications; and additional costs around the transportation and storage of SPM formulations. One or more of these factors can be a potential deterrent to adoption.

While the team is working towards testing the idea of providing dry powder that can be re-formulated at the farm site to optimise transportation costs, this is still at an early stage. If successful, it will also create additional training requirements for the users around ensuring consistency of emulsion at the time of application and post-application clean-up. Additionally, since the emulsions destabilise with time, they cannot be stored for long periods of time (>1 year). This creates a potential for wastage, as well as the need for hazardous chemical waste disposal at the storage sites for the end-users.

- Incremental crop yield benefits from using SBM formulations compared with other biodegradable options available to consumers is a critical factor that will highly influence CS. The benefits to the end-users with PMFs are higher than the biodegradable options. However, since the PMFs are expected to be phased out at some point in the future, this comparison focuses on the biodegradable films and sprayable mulch solutions. The project team considers that SBMT formulations are capable of delivering an incremental yield of 5-10% compared with other biodegradable solutions available in the market. Hence the agriculture producers who use SBMT formulations could realise private benefits from incremental yields.

  The performance to control weeds and water usage is also at par or better, compared with these alternate market solutions. SPM has a high interest in reducing the herbicide application in the horticulture industry; being water-based formulations, these deliver additional benefits when applied to dry soil.

- The flexibility to tailor SPM formulation as well as its application as per crop-specific and agricultural land (size and type) to provide a customised solution offer some unique advantages compared with the conventional film solution. In addition, their non-ecotoxicity, and ability to decompose completely in 5-7 months vs other market solutions, are also key benefits that are expected to drive consumer WTP. Conversely, the agricultural industry is more used to film-based options, such that a shift to biodegradable film options is more natural. Accordingly, the adoption of sprayable mulch options require a behavioural shift which has the potential to negatively influence customer adoption.

Due to the absence of underpinning data and uncertainty at this early stage, estimation of CS is not possible.

Table 4: Comparison of attributes of different mulch options available in the market -2.

Features		Traditional (film) mulch	Biodegradable (film) mulch	Sprayable mulches	TranspiratiONal-SBM PU-based mulch
Health and Safety		No major concerns. Well established industry operating practices.	No major concerns. Well established industry operating practices.	Transportation and on-site storage of agri-chemicals need Health and Safety considerations.	Transportation and on-site storage of agri-chemicals need Health and Safety considerations.
User Costs	Material	$650-1,000/ha	$1,000-2,000/ha	$2,000-4,500/ha	$2,000-4,500/ha
	Additional	Removal & disposal costs EXTRA Up to $800/ha	Removal & disposal costs EXTRA Up to $800/ha	No removal costs Additional transportation and storage costs	No removal costs Additional transportation and storage costs
Application		Specialised mechanical application Additional cost and time investment and inconvenience	Specialised mechanical application Additional cost and time investment and inconvenience	General or specialised spray systems No significant application costs	General or specialised spray systems No significant application costs
Yield benefits		~40%	~20%	Concept stage	Small trial plots have measured ~25% improvement in yield
Use case		Single but life can be extended over two crop cycles	Single	Single	Single
Adaptability to user requirements		Standard sizes supplied in rolls Sometimes not suitable for small landholding farmers	Standard sizes supplied in rolls Sometimes not suitable for small landholding farmers	Formulations provided in tanks/buckets Adaptable as per user requirements. Can be used regardless of the size of the landholding	Formulations provided in tanks/buckets Adaptable as per user requirements. Can be used regardless of the nature or size of the landholding which sometimes doesn't allow the application of conventional films.

Features	Traditional (film) mulch	Biodegradable (film) mulch	Sprayable mulches	TranspiratiONal-SBM PU-based mulch
Societal Costs[25]	Significant post-usage costs to society, environment, and economy PE film and fragments will impede soil biota and nutrient and water flow	Possible post-usage costs to society, environment and economy (e.g., from ecotoxicity) if mulch contains PE	No/low societal costs Siloxanes will bio-accumulate	No/low societal costs No ecotoxicity

(green)	Better compared to market solutions	(light red)	Needs some improvement compared to current solutions	(red)	Needs significant improvement compared to current solutions

Government Surplus (GS)

Government Surplus (**GS**) is an economic indicator of government benefits. It occurs when the spending in a particular area is less than expected.

Impact hypothesis: The successful development and adoption of SBMT formulations will deliver government surplus through channels such as costs avoided from the management of plastic waste, as well as restoration costs (ground, water, and air pollution etc.) due to microplastic contamination.

Estimation of Government Surplus

Microplastic waste has proven to be an ecological disaster. The deteriorated plastic fragments from the conventional PMFs have the potential to cause several detrimental effects to the environment (atmosphere, soil, water); are a threat to aquatic life; and harm microbiota and organisms. Incineration of plastics has also been associated with many health effects, such as the increased risk of stroke, asthmatic attacks, decreased lung function, respiratory diseases, and premature death. These aftermaths of using plastics require government outlays for restoration.

Hence, eliminating the use of PMFs in Australia is expected to deliver significant GS. However, its quantification requires extensive data from varied sources such as a range of government departments; and some studies such as life cycle assessments of PMFs based on end-of-life management routes etc., some of which have not yet been fully evaluated. Due to the early developmental stage of the formulations, data limitations, and the current scope of this assessment, it is not possible to estimate GS.

Discussion

The key benefit delivered by the use of sprayable mulches is the avoidance of the lifetime cost of PMFs to society, the environment, and the economy (Table 5). There is a lack of consistent data to quantify these benefits at this early stage of technology development, and under the current scope of this assessment. However, to provide some perspective, a recent study reports global societal costs of plastic produced in 2019 as US$3.7 trillion, more than the GDP of India. These costs are set to double by 2040 unless corrective action is taken.[26] Some of these costs are undoubtedly attributable to the dominant use of PMFs in the agricultural industry.

Some government subsidies might help ease cost pressure from farmers on purchasing costlier sprayable mulch formulations and drive adoption. The end-users need to be made aware of the impact strength of the product to drive adoption.

[25]Covered under both Consumer and Government Surplus due to its significance
[26]https://wwf.panda.org/wwf_news/?3507866/These-costs-for-plastic-produced-in-2040-will-rise-to-US71-trillion-unless-urgent-action-is-taken

Table 5: Comparison of attributes of different mulch options available in the market -3.

Features	Traditional (film) mulch	Biodegradable (film) mulch	Sprayable mulches	TranspiratiONal-SBM PU-based mulch
Societal Costs	See Table 4 above			
Degradation	No	Biodegradation requires industrial composting conditions. The product may still contain polyethylene to provide structural integrity.	Starch-based systems will degrade or dissociate quickly. Siloxanes do not degrade.	Complete biodegradation within 5 to 7 months. Tunable degradation times and application rates to cater for specific crop cycles.

(green)	Better compared to market solutions	(light red)	Needs some improvement compared to current solutions	(red)	Needs significant improvement compared to current solutions

Externality effects

An externality or 'third party effect' is any impact – positive or negative – on individuals or groups not involved in a given economic transaction.[27] This impact (value) is not considered as part of the production or consumption activity.

Impact hypothesis: Adoption of SBMT formulations will protect animals; deliver carbon emission savings and health benefits; and reduce the growing toxicity of air and water. The new technology and knowledge will also create new research and commercial options.

Discussion

- **GHG emissions:** The PMFs are produced using non-renewable fossil fuels. Adoption of alternate eco-friendly mulch solutions such as SBM reduces the GHG emissions in the processes of both production (lowering the demand for these plastic-based products) and consumption (lowering recycling requirements that generate carbon footprint).

- **Human health and wellbeing:** The microplastics produced through the breakdown of PMFs leach into the ground, water, as well as air; and eventually make their way into the food chain. The chemicals that leach out of plastic are toxic and can cause appalling health issues. Reducing the use of PMFs can reduce some of these issues.

- **Animal health:** Globally 10 to 20 million tonnes of plastics go into the ocean. The toxic microplastics make their way into the bodies of aquatic animals leading to diseases as well as affecting their ability to reproduce. Animals get entangled in the plastic waste produced by human activities. Reduced use of PMFs will help address some of these issues and contribute towards animal wellbeing.

- **Technology and knowledge:** External agencies have demonstrated their WTP for this initiative in millions of dollars since its inception (FY2021) (see Table 1). Industry may also increase its future WTP for access to advance CSIRO's R&D and licence SPM technology if its benefits compared with current capabilities are demonstrated to be greater. However, these figures are not commensurate, as CSIRO's costs/expenses have been directed primarily at advancing TRL of technology starting in 2016 and improving the commercial competitiveness of the overall system. CSIRO built the background IP in this space over a period of >10 years; and the underlying cost of developing this knowledge would have been a very substantial amount. However, due to a lack of data, it is not possible to include this in the analysis.

Considering the embryonic nature of the sprayable mulch industry in Australia and globally, this research has the potential to add to the general body of knowledge, which could contribute to other discoveries and development while creating options across a wide range of

[27] https://www.investopedia.com/terms/e/externality.asp

research and industries. Some of the potential benefits from these new options emerge from enhanced capabilities, improved knowledge, better research infrastructure, improving industry benchmark, a clearer understanding of the most fruitful areas for future research. As many of these are not readily evident at this stage, despite the depth and breadth of CSIRO's work and the gamut of generated options, it is impracticable to assess these benefits within the current scope of this impact assessment.

Limitations

- Externalities are expected to be significant. However, their quantification requires results from other studies and is beyond the scope of this impact assessment.

Results

As evident from the above discussion, it is not possible to do a CBA at this stage due to a lack of critical data relating to both costs and benefits. Based on discussions with the core team, it will likely be possible to do a high-level CBA based on Producer and Consumer surpluses in approximately 24 months. Also, it is important to note that significant social benefits from the adoption of this technology will be in the form of reduced cost to society as well as Government surplus. The estimation of GS requires data from other advanced studies for further analysis.

Suggested Metrics

To ensure SIEF and CSIRO capture the reach of the SBM R&D and can evidence impact in the future, it is recommended that effort be applied to the collection of detailed data across the implementation trialling sites and during commercial roll-out. Table 6 presents some suggested metrics that may be tracked by the team to evidence impact. Increased data granularity, end-users, and data sites (including crop and soil types) will help increase the robustness of future quantitative evaluations. Tracking of outcomes and impact will also highlight whether this area of research might best be prioritised/scaled back/abandoned in future.

Table 6: Suggested metrics for monitoring and evaluation of SBMT impact

Impact pathway	Internal (CSIRO)	External (Agricultural industry)
Inputs	- CSIRO further R&D investment - CSIRO BD&C costs - CSIRO staff in-kind contributions	- Further external partner R&D investment - Manufacturing costs - Training costs - End-user adoption costs
Economic Impacts	- # new jobs created ***Producer Surplus*** - Any royalties/licence fees raised from the extension of SBM technology development	- See metrics identified in Table 2 - See metrics identified in Figure 8 - Domestic sales - Export sales
	Consumer Surplus	- See metrics identified in Figure 9 - Yield benefits with SBMT products - SBMT offerings
	Government Surplus	- ↓ Government outlays on the management of plastic waste driven by SBM adoption
Environmental Impacts		- See metrics identified in Table 2
Social Impacts		- See metrics identified in Table 2

9 Other benefits of research

i. New jobs

As the TRL and CR of initiative advances, it has the potential to create some direct, indirect (backward-linked industries), and induced employment (forward linkages) in the internal (CSIRO) and external networks (such as partner organisations, e.g., BM, agri-chemical industries, SBMT, etc.). However, it is difficult to quantify at this stage within the current scope and resources of this project (see Appendix B).

ii. New markets and supply chains

Successful development and adoption of SBMT formulations have the potential to develop new upstream and downstream supply chains. With the global requirements for eco-friendly and sustainable farming solutions, the initiative has the potential to lead to new domestic, as well as export, opportunities.

For example, the Asia Pacific region is dominated by smallholder family farmers. SBM offers a flexible solution to these farmers to increase yields in a sustainable way, whereas conventional mulch films are not always feasible.

iii. Higher-skilled workforce

Although still in its infancy, the SBMT team is proactively working with industry partners to improve the maturity of the platform technology; engender new collaborations; support long-term collaborative research; improve CR; and catalyse adoption of the technology. Over the last 12 months, this work included interactions with:

Number of university/ academic institution engagements = 3 (Deakin University, Monash University and University of South Australia)

Number of industry engagements = 13 (incl. international corporations such as Bayer, ICL, BRA and Kagome, as well as state government DPIs and regional grower groups)

Number of SME engagements = 14 (SMEs include horticulture, flower, orchard, and forestry interests)

Number of farmer trials = >200

Since the initiative is still in its early days, it is anticipated eventually to add depth and breadth to these collaborations, which, again, is difficult to quantify. However, some of the potential ways of delivering qualitative benefits to the wider innovation ecosystem from the new networks include:

- ↑ research efficiency with lower cost to taxpayers
- ↑ depth and breadth of research
- ↓ convoluted path to market
- ↓ time to market
- ↑ trust between parties to drive innovation and uptake
- ↑ resilience and resourcefulness to address the sudden surge in demand.

iv. Venture science and company creation model

The team envisions establishing SBMT on the basis of an impact-focused company creation model targeted to provide a full-stack solution to deliver technology at scale, scope, and speed. This constitutes a shift from the conventional collaboration models under which an impact initiative is led by a diverse group of stakeholders working together, encouraging each partner to undertake their specific set of expert activities through a mutually reinforcing plan of action.

The demonstration of successful learnings from collaboration under this business model can potentially benefit other upcoming entrepreneurial ventures at CSIRO, as well as within the wider innovation system in Australia.

v. Future Industries

SBPM has the potential to be used as a platform technology. The formulations can be used in a controlled manner and utilised for other applications, such as coating urea, and a carrier for herbicides, pesticides, etc. There is also potential to develop formulations for utilisation in other industries, such as mining and infrastructure with dust suppression, encapsulation of fertilizers etc. These have been identified as a potential future use cases but not been assessed commercially at this stage.

Australia is strong in the production of non-degradable emulsions. Successful adoption of SPM has the potential to open new doors and drive development in the domain of biodegradable emulsions.

10 Recommendations and support requirements

Recommendations

i. As the next steps, it is recommended that a high-level CBA be performed once the TRL improves, and high-scale manufacturing viability is established (expected in 18-24 months).

ii. The key objective of this SIEF EDP initiative is to convert science to impact for the benefit of Australian society. The following are recommended to help monitor and track this critical goal:

- An impact planning workshop with key internal and external stakeholders is suggested to:
    - reflect on, improve, and update the preliminary impact pathway presented in Figure 5. The impact pathway provides program logic and requires calibration as unpredictable social and commercial pressures affect the input and output variables over time.
    - establish fit-for-purpose indicators for the purposes of baselining, planning, monitoring, and evaluating impact. Identifying the right indicators to assess the level of outcome achieved using the impact pathway/logic model is not always straightforward. Hence, a workshop with experts could help generate what is both needed and useful, and would limit consuming extensive resources.
- In addition to the above, outcome/performance monitoring and measurement are imperative both to assess whether the initiative is delivering the intended benefits and to demonstrate its evidence-based value-add to key stakeholders. A feedback loop from the Outcomes to the Activities space that informs new/shifts in activities to deliver intended impact is critical.
- The strategic importance and significant level of current and future investment necessitate bespoke methodologies to develop a longer-term/continual approach(es) to impact evaluation, in the absence of which there is a risk of losing valuable data about the value generated (or lack thereof). Making impact data collection a routine activity would help gather evidence to demonstrate impact; support future funding applications; inform management and strategic planning; and demonstrate public accountability.
- With potential of different partners being involved, developing a shared measurement system can be useful to measure collective impact. Agreement on a common agenda is frequently illusory, in the absence of agreement on the ways success will be measured and reported. A support team potentially can be involved at an early stage to both simplify and ascertain the process of measurement and reporting of impacts.

iii. It is also recommended that the team provides a thought-through, clear, and coherent articulation of the support requirements to the relevant leadership team for this longer-term initiative. An understanding of the expectations from the outset will help add efficiency to the innovation. cycle; translate R&D into best practice solutions and impact; and increase the probability of all stakeholders benefitting from enhanced capability

Support Requirements

i. Investment: The team is seeking investment to:

- produce and supply formulations to the interested base of early customers and demonstrate market interest
- test other potential applications
- address technical and commercial challenges in finding a suitable toll manufacturer for scale-up.

11 Conclusions and confidence rating

The SBPM R&D is aspirational, with the potential to reduce the environmental footprint of agricultural activities, and improve the efficiency of agricultural operations on a sustainable basis through the SBMT spin-out commercialisation pathway. This ex-ante assessment is an early-stage analysis, based on preliminary empirical data and direct consultations with key stakeholders. Although the project is yet to reach a point where it is possible to quantify the nature and magnitude of economic benefits, the current body of evidence for future economic and social impacts is presented here. At this early stage of technology development – and with uncertainty associated with the launch of the spin-out or access to future funding, the projection of benefits is based on several assumptions. Some of the key benefits identified (such as incremental yield gains from the application of SBM) cannot be assessed until the technology is sufficiently advanced with a clear manufacturing pathway and is commercially viable. Assessment of costs (disposal and regulatory) to be avoided from reducing plastic use in agriculture should be straightforward without requiring advanced studies, however evidence from large-scale (trial) input costings, which are beyond the current scope of assessment, would provide greater confidence.

To this point, the current core team note a consistent, and persistent, stream of enquiries from producers (growers) across Australia, Asia, Europe, and the USA about the opportunity to test and utilise the SBM product. However, the outcomes of innovative actions in a complex social world are inherently unpredictable. The success of the initiative is highly contingent not only on the costs of SBMT formulations, but also involves changing the norms, habits, and beliefs of people (e.g., employing a new sprayable mulch solution instead of a decades-old mulch film-based approach). The initiative is also subject to key risks such as the uncertain regulatory environment; access to desired manufacturing capability, funding, and skilled resources for technology development; the supply-chain challenge induced by COVID-19; increasing geopolitical tensions; and natural disasters.

As mentioned earlier, robust impact management from the outset would help assess whether the intervention is delivering the intended value to society in the target areas of assessment and highlight the need to make adjustments (feedback loop) where necessary, thereby assisting with technology development and scaling-up adoption. The identification and collection of impact relevant data early on will enable any benefits to be more easily attributed to the intervention as well as build more evidence and understanding about its activities.

Due to the inherent ambiguity associated with the TRL development and adoption of SBM at this stage, the **confidence rating in this impact assessment is rated very low** by Tractuum. The interviews with stakeholders suggest that there will be clarity around company formation, as well as better data available, in 18-24 months (with respect to adoption as well as customer willingness to pay). The assessment should be revisited once this data is available, to conduct quantification of benefits (including attribution for specific use cases), and assess other benefits streams to enable a more robust evaluation with a higher confidence rating.

Appendix A Significance of impact management

Globally, there has been an unprecedented focus on demonstrating impacts generated from R&D investments; however, little effort has been put into establishing baseline information by which impact can be measured. **A recent survey suggests that early impact measurement and management practices are key contributors to market growth; 88% of respondents reported that it drove better than expected returns on financial investments, and 99% reported meeting or exceeding their impact expectations.**[29] This provides an additional boost to the incorporation of impact estimation, planning, monitoring, and evaluation frameworks as a part of project activities.

Some of the leading research organisations globally track and report their impact across the economic, environmental, and social landscape.[30,31,32.] It demonstrates to the positive and negative 'shifts' as a consequence of the activities of a program. A well-executed impact management and reporting process helps create brand affinity, accountability and transparency, industry leadership, and a solid strategy roadmap.

Impact assessments require structured and coordinated measurement for the benefit of key stakeholders to estimate and monitor progress (investors); benchmark investment effectiveness (portfolio managers); measure progress (enterprises or investees); and catalyse adoption (beneficiaries). **Impact measurement efforts provide a useful resource to prioritise and plan research expenditure.**

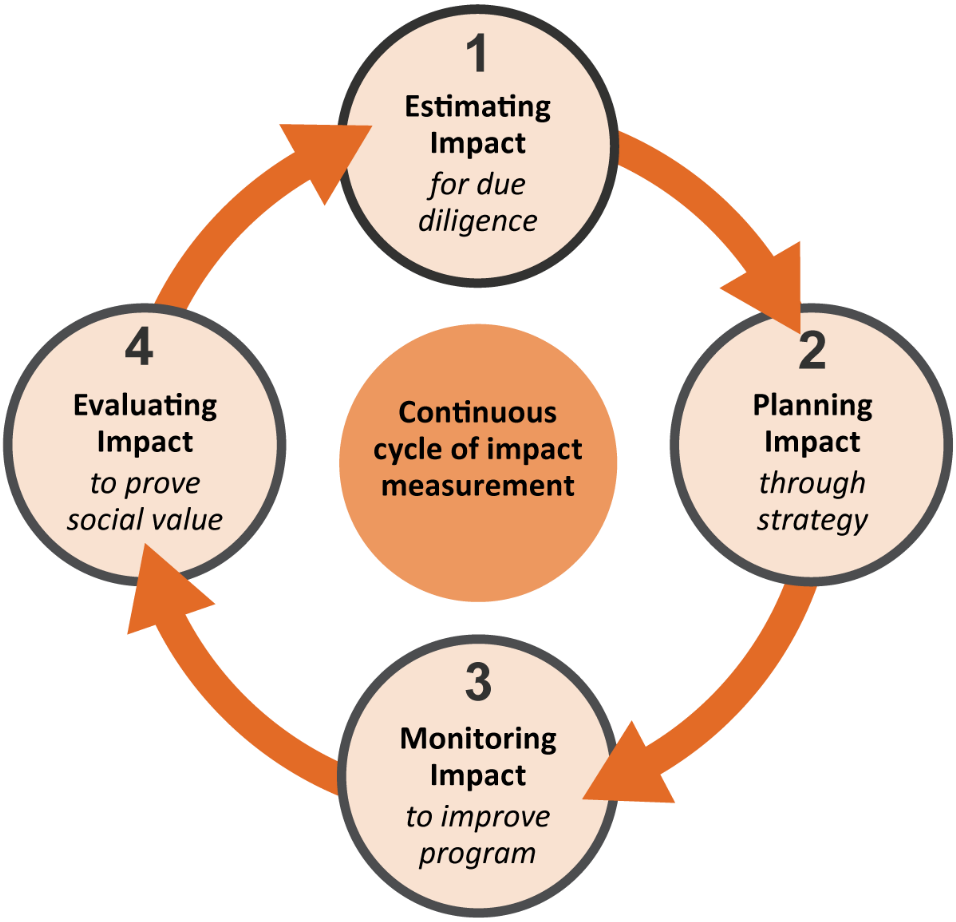

Figure 10: Continuous cycle of Impact measurement objectives[33]

[29] https://www.pionline.com/esg/global-impact-investment-market-going-strong-despite-pandemic-giin
[30] S&P Global Impact Report
[31] Shopify Impact Report
[32] Diabetes UK Impact Report
[33] www.hbs.edu/socialenterprise/Documents/MeasuringImpact.pdf

Appendix B Employment contributions

It should be noted that any additional employment (typically stated as 'jobs created') is not an economic benefit. Just as for any other resource, the use of additional labour resources imposes an opportunity cost on Australian society, because those workers cannot be used elsewhere to produce goods or services. In addition, some workers will simply transfer from other jobs (potentially including CSIRO positions), so the net creation of jobs will be zero. Those workers who are employed in new positions will obtain a wage, but the cost of the wage is borne by employers, so the net benefit to society is zero, except for any additional profit (producer surplus) that is generated. **Nevertheless, estimates of job creation opportunities are generally of interest to decision-makers, and they can be reported separately from the cost-benefit analysis to provide a comprehensive outline of expected impacts.**

In principle, the engagement of an unemployed worker with no other clear job prospects imposes no opportunity cost on society. **In a situation of structural (i.e., non-cyclical) unemployment, therefore, society can benefit from the creation of new jobs that are filled by the unemployed. But this benefit can only be realised if the skills of the currently unemployed workers match the competencies required in the newly-created jobs**. Further, any benefit to the newly employed workers, and hence society, would be offset to some extent by their loss of leisure (i.e., non-work) time, which can also result in social benefits through activities such as child-minding, gardening, relaxation, exercise, etc., that are valued by the worker.

Taxes have a depressive effect on the economy by reducing aggregate demand and/or output. They, therefore, reduce job opportunities and profits. To the extent that the SBMT is funded by CSIRO and other funding sources through government taxation, there will be some potential loss of jobs in the economy. In other words, it cannot be claimed without qualification that there will be a straightforward increase in employment levels attributable to the assessed work.

Appendix C References

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