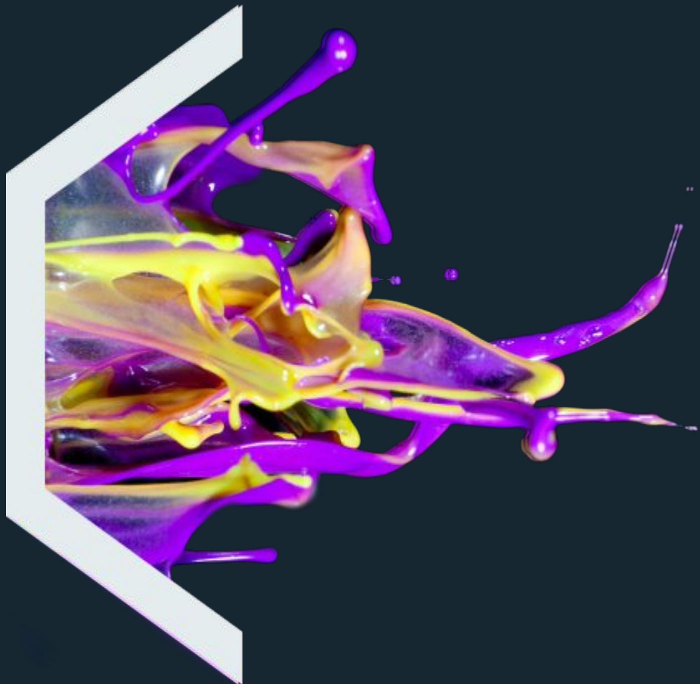

Mushroom production waste streams: novel approaches to management and value creation

Phase 3 Final Report

Hort Innovation Xinova Asymmetric Innovation

Xinova

Xinova is a global collective of 12,000 innovators dedicated to turning big problems into bigger solutions.

We work with companies like Pepsi and Honda to help them solve their largest research and product development challenges. Xinova brings value to customers by connecting technology, talent, capital and demand. The company is headquartered in Seattle with staff located in Beijing, Bangalore, Helsinki, Israel, Seoul, Singapore, Sydney, Tel Aviv, Tokyo and Vienna.

We leverage the power of our global network to connect the toughest problems with the smartest minds and best resources. This opens up an end-to-end innovation pathway that moves companies and industries from idea to on-shelf product faster and with greater returns.

In Australia, Xinova have chosen to partner with Asymmetric Innovation to deliver value for our local clients.

Asymmetric Innovation

We help organisations innovate faster by working on valuable problems and bringing a global network to bear on solutions that are desirable, viable, feasible and scalable.

We are a growing team of designers, systems thinkers, business case developers and innovators. We work with organisations to solve problems and deliver new products. Our consulting services, education and impact designs are motivated directly by the impact to your business. We do this because your success is our success. We believe this so much, that when we see products that align with our investment goals, we'll even explore co-investing with you to further accelerate and scale your impact.

Our partners realise new benefits through our approach of the right mix of skills and methods for each case. We create new value through:

- Hardware, software and business model solutions to problems that have vexed internal innovation teams
- Validation and development of new products and services that scale
- Finding new sources of value that align with industry wide objectives

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Executive Summary

The key objective of this project was to identify and assess solutions that have the potential to deliver tangible benefits to the Australian mushroom industry and its stakeholders. The Mushroom SIAP focussed the scope of this project on generating operational cost savings and new revenue from the primary sources of waste - the disposal of SMS and subprime, edible mushrooms.

Advancing the solutions identified in the first two Phases of this project involved developing financial models, field trials and “running to ground” eight solutions, four of which are recommended to proceed. In total, these four solutions have the capability to generate $55 million of operational cost savings and/or new revenue to the industry per year, while utilising hundreds of thousands of tonnes of waste. Beyond substantial returns on waste, new technologies, partners and strategies were identified to expedite the industry’s movement up the commercial value chain.

The project focussed substantial efforts on the merits of solutions deemed highly attractive to the industry at the Ideation Workshop in March and the End of Phase 2 Meeting in May. Where a reliable pathway to cost savings or revenue could not be achieved, a rationale for not proceeding is presented along with trends that could affect the recommendations in the future.

Summary of engagement

$55 million	In savings or revenue were identified from recommended solutions
13	Total site visits
30+	Solutions collected and assessed
35+	Interviews with industry to gain a deeper understanding of operations, market dynamics and business financials
5	Commercial trials to test technical feasibility of solutions
40+	Academics, domain experts, business owners, entrepreneurs and mushroom industry participants met with to formulate the business cases
8	Solutions fully assessed in depth
4	Recommended solutions for further development

Acknowledgements

The entire project team would like to extend a thank you to all the experts and growers in Australia and around the world who have contributed to this project. This project is simply not possible without enthusiastic and transparent engagement with those at the forefront of the mushroom industry. Special thank you goes to those Australian businesses who volunteered their time, materials and expertise to conduct field trials. Demonstration of some of the technology and process options require it to be seen to be believed.

Finally, we congratulate the Australian mushroom industry through its Strategic Investment Advisory Panel (SIAP) and Hort Innovation on their engagement of Xinova and Asymmetric Innovation to perform this work. It has been a pleasure and a privilege to spend the past several months working with many of the folks that are dedicated to addressing challenges associated with mushroom industry waste. There are some fantastic opportunities to be exploited in the Australian mushroom industry in the coming years, as well as some large local and global challenges. Be resolute in your resolve to test technologies and business models and drive your business, large or small, to be leaders because, “Anyone can hold the helm when the sea is calm.”
- Publilius Syrus

Disclaimer

All recommendations in this report are an opinion based on desktop research, information collected from industry experts and technology owners, and the commercial experience of the project team. There is no guarantee that investment in any recommended solutions will result in the returns projected in this report or associated materials. Field trials were conducted as technology or process demonstrators for the benefit of Australian mushroom growers. Growers are encouraged to engage the project team to plan and execute their own trials and analysis on the solutions presented, tailored for their unique circumstances.

The information in this report is for general information only and should not be taken as constituting professional investment advice from Xinova or Asymmetric Innovation. Neither organization is a financial adviser and are not liable for any loss caused, whether due to negligence or otherwise arising from the use of, or reliance on, the information provided directly or indirectly, in this report.

Project approach

Phase 1

Through site visits and interviews, the project team worked with industry to define the project scope, guide rails and develop three opportunity areas contained within the Phase 1 project intent:

1. **Improved efficiency in the production process**
2. **Adding value to the production process by repurposing waste**
3. **New commercial opportunities - new products, new markets**

Phase 2

Guided by the intent and mushroom growers, Phase 2 included a broad search across industries, academic literature and geographic boundaries - culminating in the Ideation Workshop which converged themes and solution types that would be best suited to the industry. From a total set of **more than 30 concepts, four broad solution areas** were presented to the SIAP from which **three were selected for further development, eliminating Mycelium Materials and Co-Products (***a full of list of concepts can be found in the Appendix i*)

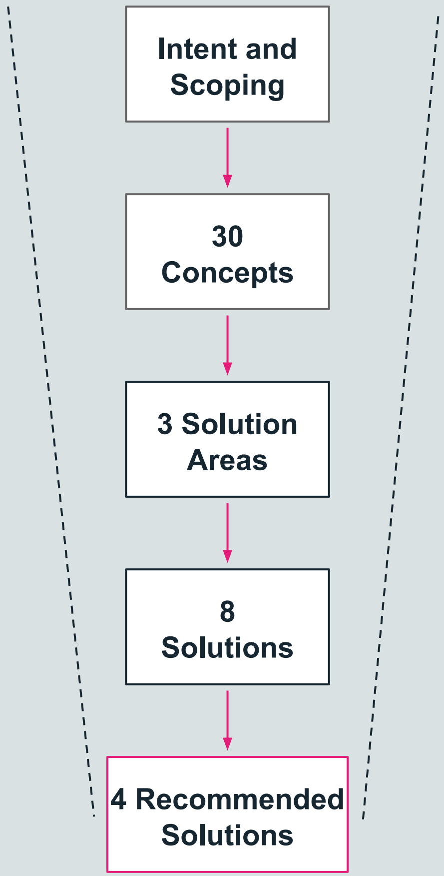
SOLUTION AREAS	1. Energy and Fertilisers	2. High Value Foods (HVF)	3. Recycling Waste for Further Production

Phase 3

Each of the three solution areas included multiple solutions. As inputs from academics, experts, enterprises and the mushroom industry were further integrated into the project design, scopes were changed and new solutions emerged.

SOLUTIONS	Pelletiser Anaerobic digester Insect bioconversion	Mushroom powder Edible shelf life extender	Recycling SMS Exotic mushrooms from SMS Recycling CO_2

Inputs from these groups and further business case development helped to create solution criteria for **desirability**, technical **feasibility** and economic **viability**. These criteria facilitated the selection of the **eight solutions** contained within this report as well as the overarching recommendations and suggested next steps.



Converging on solutions

The solution criteria of desirable, feasible and viable were adapted to the unique characteristics of the Australian mushroom industry after additional engagement with the growers during Phase 3 of this project.

Desirable solutions are those that deal with **large quantities of the mushroom industry waste** and can effectively answer the question, **“why mushrooms?”**

Feasible solutions minimise the changes to existing production

Viable solutions limit the levels of CapEx and provide **payback in less than 5 years**

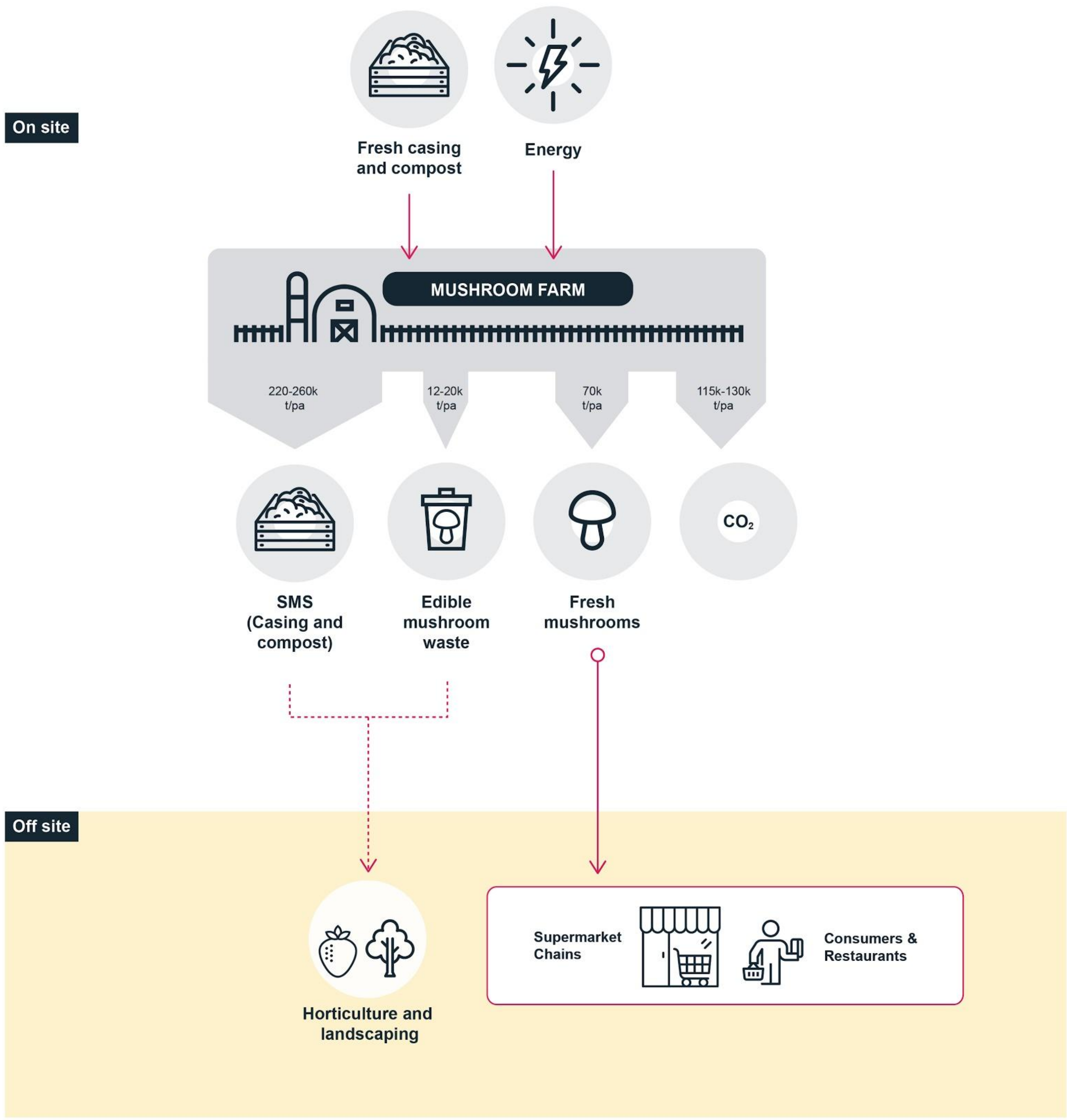
	Low	Medium	High
Desirability	Utilises minimal quantities of mushroom waste	Utilises modest quantities of mushroom waste	Utilises close to 100% of mushroom waste
Feasibility	Not currently technically possible and/or requires a substantial change to current practices	Proven equipment, process or practice at small scale and/or requires moderate changes to current practices	Proven equipment, process or practice at a commercial scale that minimises required changes to current practices
Viability	High CapEx and OpEx with unlikely pathway to payback in less than 5 years	Moderate levels of CapEx and OpEx with at least one pathway to payback in less than 5 years	Low levels of CapEx and OpEx with multiple pathways to payback in less than 5 years

Focussing on real solutions

Solution 1	Solution 2	Solution 3	Solution 4	Solution 5	Solution 6	Solution 7	Solution 8
P. 11	P. 26	P. 38	P. 48	P. 61	P. 69	P. 74	P. 81
Recycling SMS	**Pelletiser system**	**Anaerobic digester**	**Mushroom powder**	**Exotic mushrooms from SMS**	**Insect bioconversion**	**Recycling CO_2**	**Edible shelf life extender**
Recycling SMS back into the production process as either casing or compost	Investment in capital equipment for non-thermal dewatering of SMS for on-site energy or off-site sales into energy and fertiliser markets	Investment in capital equipment to process SMS with an available co-input into biogas for on-site energy usage	Drying and powderisation of edible mushroom waste into a shelf-stable powder for the high value food (HVF) market	Reusing the compost component of SMS as the primary substrate for cultivation of oyster mushrooms	Feeding SMS and mushroom stems to black soldier fly larvae for bioconversion into animal feed and soil additive	Replacing the existing CO_2 supplementation of greenhouses and algae farms with the CO_2 emitted during the cultivation of mushrooms	Edible coating applied to fresh mushrooms to extend shelf life and reduce costs and spoilage
Proceed	**Proceed**	**Do not proceed**	**Proceed**	**Do not proceed**	**Do not proceed**	**Do not proceed**	**Inconclusive**

Project approach

Current State



Project approach

Potential Future State

1 Recycling SMS

2 Pelletiser system

3 Anaerobic digester

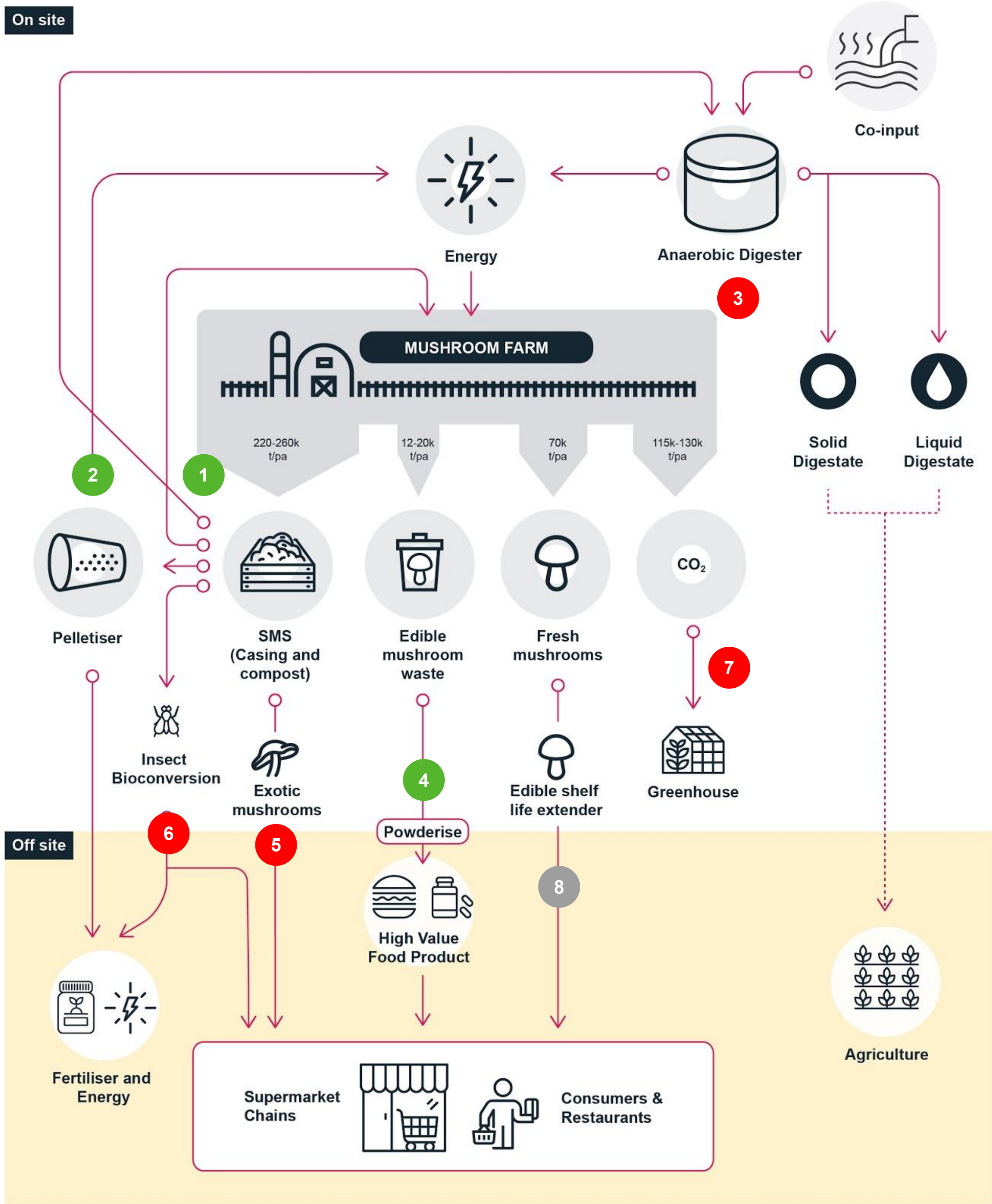
4 Mushroom powder

5 Exotic mushrooms form SMS

6 Insect bioconversion

7 Recycling CO_2

8 Edible shelf life extender



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Recycling SMS

Recycling SMS back into the production process as either casing or compost

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Solution 1

Recycling SMS

Recycling SMS offers the potential to reduce the quantity of input materials for each mushroom growing cycle and generate significant operational cost savings as well as positive environmental outcomes.

SMS can be recycled in three ways:

1. SMS as casing
2. Casing as casing
3. Compost as compost

Casing and compost comprise a high proportion of the costs for Australian mushroom growers (40%, compared with 10-15% in Europe). When compared with other solutions, recycling SMS back into the production process is the most efficient method to ensure improved dollar value for SMS.

The project team consulted mushroom and compost experts across Europe and Australia to understand the current world's best practice for recycling SMS. The team devised test protocols, analysed academic literature and co-ordinated the first industrial scale trial for recycling compost back into the Phase 2 and 3 composting processes in Australia.

Business Case in Brief

Desirability	■	■	
Feasibility	■	■	■
Viability	■	■	■

Cost to implement

- ➔ SMS as casing: $60k OpEx per annum
- ➔ Casing as casing / Compost as compost: $260k CapEx for mechanical separator

Viability ✓ **Viable**

- ➔ At current compost and casing prices, all three recycling options for SMS are viable

Recommendation ✓ **Proceed**

- ➔ Recycling SMS as casing is financially viable, but technical feasibility challenges of re-pasteurising the casing, a lack of available materials and environmental and land availability will limit its adoption in Australia
- ➔ Recycling casing as casing & compost as compost both represent good business propositions. To gain maximum benefit and reduce CapEx payback period, both options should be initiated simultaneously

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Recycling SMS

How does it work & what are the required process changes?

SMS as casing

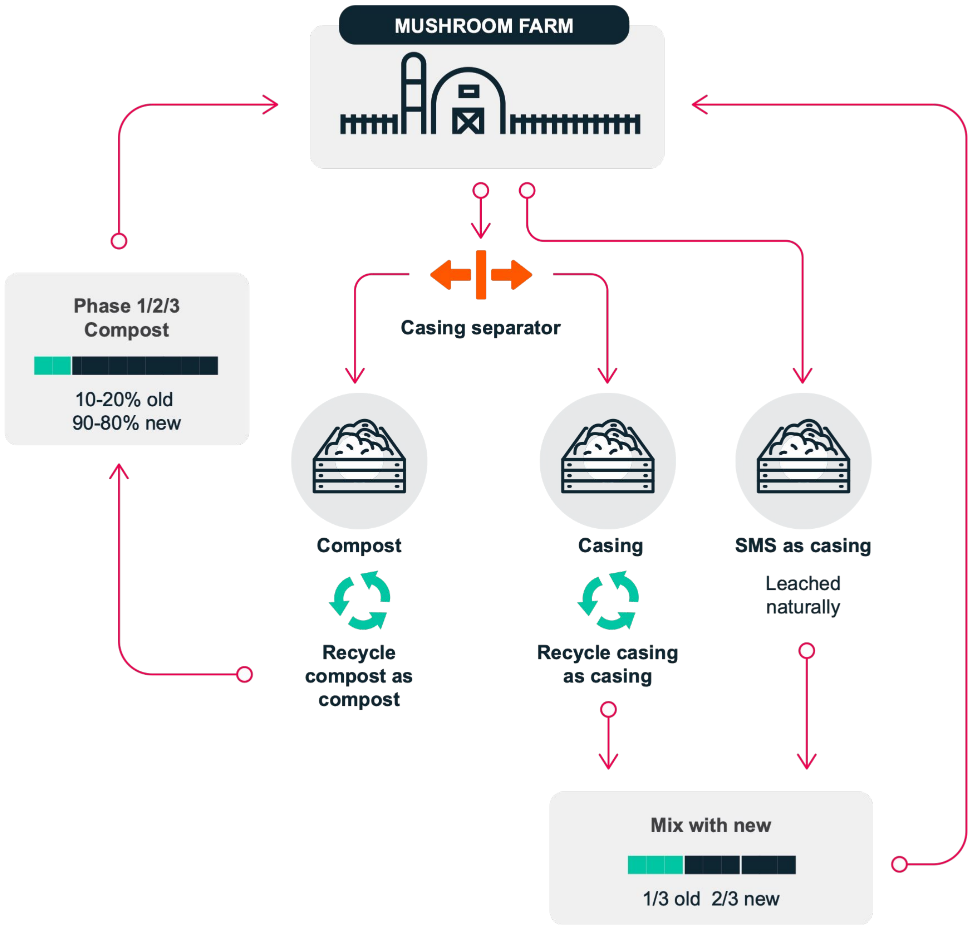
- ➔ A third of SMS must be kept at or near the facility and placed into several dozen 2m x 4m piles for further processing and leaching.
- ➔ Additional cook-out step is required before or after mixing with fresh casing, which requires additional space in the growing rooms to re-pasteurise recycled SMS.
- ➔ If annual rainfall is <75cm, mechanical desalination through “flooding” is needed.
- ➔ Different utilisation of labour to manage processes for recycling such as monitoring SMS structure and nutritional content.

Casing as casing

- ➔ Separation required. Utilisation of a mechanical casing separator requires Dutch shelf systems for optimal compatibility.
- ➔ Ample space at the facility for processing and an additional truck to capture the split casing and compost from separator.
- ➔ Must assess oxygen uptake rate (OUR) in split casing and appearance of organisms.
- ➔ If not cooked-out in the growing rooms, additional cook-out step is required before or after rewetting and mixing with fresh casing.

Compost as compost

- ➔ Separation required. Utilisation of a mechanical casing separator requires Dutch shelf systems for optimal compatibility.
- ➔ Close geographical proximity to composting facilities.
- ➔ Recycling back into Phase 1 of the composting process could be aided by floor tunnel fans to alleviate density issues.
- ➔ Recycling compost into Phase 2 will require an additional resting period to allow mycelium to overtake the blocks.
- ➔ Increased labour to manage processes; separate streams to manage recycled compost vs 100% fresh compost.



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Why do it and what are the challenges?

	Rationale	Demonstrated successes	Challenges
SMS as casing	→ Restricted supply of peat from Europe. → Input prices of compost and casing have risen substantially and will continue to rise.	→ Reuse of SMS has been widely reported and investigated by researchers such as Joe Poppiti at Creekside Mushrooms and Dr John Burden. There is anecdotal evidence of success from the Australian industry. → An international firm, Malard Mushrooms - Iran, found that a mix of 50% SMS and 50% European peat casing presented economically viable results. → SMS casing can accept and hold sufficient water for high flushes, although care must be exercised when watering the crop.	→ There are no existing stores of aerobically digested SMS to be tested in Australia. → Previous success (i.e. Creekside Mushrooms) was under different conditions with different substrate and it may not be able to be industrially replicated in Australia. → Leaching is required. Drought and low rainfall could be problematic. → Leaching may present environmental issues in the long term.
Casing as casing	→ Projected financial models indicate this option is financially viable, even with the use of a mechanical separator.	→ Promoted by manufacturers of casing separators and proven successful in trials conducted by CNC Grondstoffen (Netherlands). → CNC reported no yield variance with up to 40% mixed casing. → Recycled cooked-out casing used at 25% had no overall effect on mushroom yield (ref. AHDB report).	→ Casing separators require capital investment. → Sterile material with dead mycelium increases biosecurity risk, as it acts as a breeding ground for bacteria in fresh casing.
Compost as compost	→ Current scientific research into alternative compost ingredients is poorly funded and progress is slow.	→ In a study conducted by Ralph Noble and researchers at Penn State University, spent compost replaced 33% of the wheat straw and poultry manure in the compost formulation, with no significant effect on mushroom yield or quality.	→ Not proven at an industrial scale, but shown to be successful in studies by Dr Ralph Noble and researchers from Penn State University (USA). → Results perhaps not the same if using blonde peat. → Less cellulose to feed the mycelium.

Grower views and expert analysis

Casing as casing

EC still too high in the casing to use… it might actually be higher than the compost

- Grower

EC actually accumulates in the compost more than the casing, but this can be managed by combining fresh and old casing in the right proportions

- U. Sydney report

SMS as casing

The leaching process takes at least 5 years and is just too long to dedicate to something if you are not sure it will work

- Grower

Necessary rainfall makes it feasible for all growers in <3 years. However, this option may not be as practical as separating SMS and using it immediately

- Research

SMS as casing

If we want to leach SMS, it is difficult to re-wet after it dries out

- Grower

As long as the SMS does not fully dry out, re-wetting is not an issue

- Expert interview

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Grower views and expert analysis

Casing as casing & compost as compost

Labour and separators are expensive. I'm not sure that doing this is worth the investment

- Grower

The viability of separation improves if both the casing and compost are recycled. In terms of composting, farms located near Phase 1 composters have an advantage

- Expert interview

Casing as casing

Using old casing with new stuff introduces a disease risk

- Grower

In Australia, separated casing is cooked-out and should be re-used with fresh casing immediately. Disease risks are only introduced if spent casing is left in piles. EC will be controlled by the continual introduction of fresh material

- Expert interview

Compost as compost

If you recycle, the density of the substrate is too high and the air won't be able to move through it

- Grower

Most Phase 1 composting facilities in Australia have floor fans and increased density can help maintain or improve yields in the winter

- Expert interview / Trial results

Field Trial

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A field trial of "Recycling SMS – compost as compost" into Phase 2 and Phase 3 blocks was undertaken. To our knowledge, this was the first industrial scale field trial of this type in Australia.

Scatoplus and Parwan Valley Mushrooms collaborated with the project team and conducted the trial on-site.

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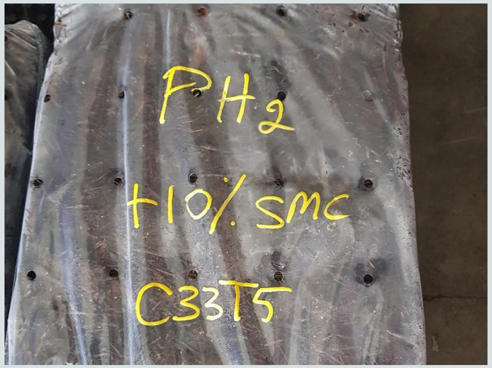
Overview of field trial

Selecting a field trial - Considerations & rationale

- ➔ SMS was not recycled back into Phase 1 because there is limited ability to cordon off a section of the compost with the recycled material from the rest of the process.
- ➔ Recycling SMS as casing was excluded from a field trial because naturally weathered SMS is not available to growers.
- ➔ Recycling casing as casing was also excluded because of perceived biosecurity risks and because the cost savings are insufficient on their own.



Trial protocol

1. SMS was pasteurised as usual, following the third flush at Parwan Valley Mushroom Farm.
2. Black bags were held open with clean gloves while another individual loaded the SMS from the growing shelf. Casing layer was left on SMS as it was suspected that levels of casing in the final block would be inconsequential and that this could potentially improve moisture retention.
3. 10 bags were each loaded with approximately 12 kg and then tied shut to avoid contamination and dust. The bags were immediately transported from Parwan Valley Mushrooms to Scatoplus's composting facility in Newbridge (Victoria), then placed in a storage container to await blocking the following day.
4. SMS was added to 20 kg blocks at a ratio of 10% recycled / 90% fresh compost and 20% recycled / 80% fresh for both Phase 2 and 3 blocks. Each block was clearly marked on the outside of the shrink-wrapped packaging.
5. Phase 2 blocks were rested for a period of 28 days, whereas Phase 3 blocks were sent directly to Parwan Valley from Scatoplus.
6. The blocks were loaded into 2 m^2 windows. Control windows were made from 100% fresh compost from Scatoplus.
7. Success was determined by the following criteria: yield and quality in flushes 1-3, yield per day, $/$m^2$ of the windows at current pricing, and absence of disease.

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Results of field trial

Snapshot

The project team collaborated with industry to organise and design the field trial, with Scatoplus and Parwan Valley mushrooms actively leading the delivery of the trial. Once the field trial was formulated and agreed upon by all parties, the trial was set up and undertaken for a period of 2.5 months. Xinova and the Asymmetric Innovation team assisted with the trial and monitored outcomes.The approach was informed by new information collected by the team through a review of academic literature plus interviews with industry and experts.

First flush mushrooms from Phase 3 block trial control group

First flush mushrooms from Phase 3 block trial 10% recycled group

Results

Phase 3 Block Trial Yield

10%	**29.3kg / m²**
20%	**28.49kg / m²**
Control	**28.46kg / m²**

Phase 2 Block Trial Yield

10%	**25.76kg / m²**
20%	**26.82kg / m²**
Control	**28.87kg / m²**

Results of field trial in detail

Recycling directly into Phase 3 blocks

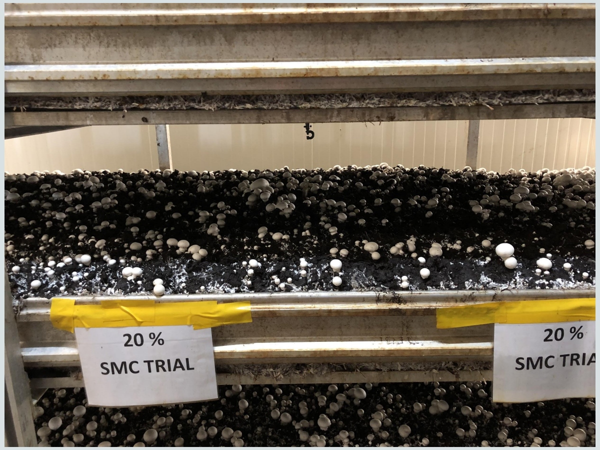
- ➔ As expected, the mycelium initially grew slower in the substrate with the 10% and 20% recycled ratios. However, this slower mycelium growth did not affect first yield breaks
- ➔ This room had a below average first break but a very large second break, in both trial windows and the rest of the room
- ➔ Across all three flushes, the 10% recycled substrate outperformed the control and 20% recycled groups - vastly outperforming the control in flush 2
- ➔ The yields differences between the control and 20% recycled substrate were negligible. For producer growing only 2 flushes, 20% could be recommended as this group outperformed 10% and control through 2 flushes
- ➔ Possibility that increased density of recycled groups mitigated yield drops from lower temperatures during growing

Phase 3 Recycled SMS Trial*

Type	Flush 1	Flush 2	Flush 3	Performance
10%	10.46kg	13.36kg	5.32kg	+2.35%
20%	12.32kg	12.47kg	3.7kg	+.1%
Control	10.37kg	12.8kg	5.29kg	----

*All results per square metre - m²

10% Recycled - 90% Fresh Compost



20% Recycled - 80% Fresh Compost

100% Fresh Compost - (Control)

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Results of field trial in detail

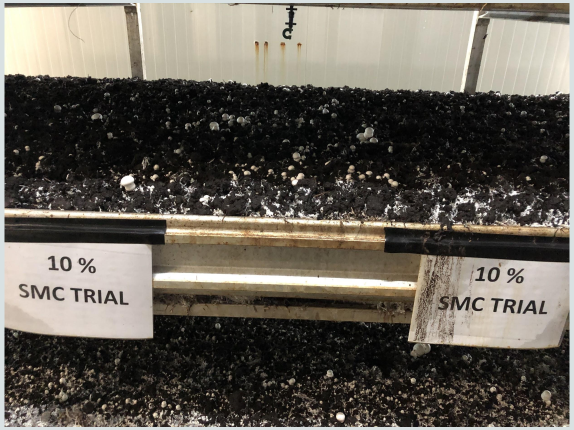
Recycling into Phase 2 blocks

- ➔ Unlike recycling into the Phase 3 blocks, first breaks of both the 10% and 20% recycled ratios underperformed in comparison to the control
- ➔ The third break yield was the highest in the 20% recycled ratio, suggesting the recycled SMS could add volume to later yields
- ➔ The bio-efficiency of fresh compost to kg of mushrooms was essentially neutral for the 10% recycled ratio, and was actually improved for the group using 20%
- ➔ If the difference in value of the straw vs the SMS compensated for the smaller expected yield, this practice could be a breakeven proposition, improving when mushroom prices are low.
- ➔ Results from both trials suggest that if you filled normal dry weights and added extra SMS as compost, it could improve supplemental yield values

Phase 2 Recycled SMS Trial*

Type	Flush 1	Flush 2	Flush 3	Performance
10%	11.15kg	12.46kg	4.3kg	-10.8%
20%	8.31kg	13.02kg	5.49kg	-7.1%
Control	12.48kg	11.62kg	4.77kg	----

*All results per square metre - m²



10% Recycled - 90% Fresh Compost

20% Recycled - 80% Fresh Compost

10% Recycled - 90% Fresh Compost Pinning

Recycling SMS

Viability by the numbers

Recycling SMS back into the production process is one of the few solutions where viability is not driven by the size of the grower or the current sale price of SMS.

If utilising a casing separator, viability is increased if both casing and compost are recycled, generating a payback in less than six months.

SMS as casing

- ➔ **$0k CapEx / $60k per annum OpEx.**
- ➔ Much lower CapEx because a casing separator is not required.
- ➔ Payback period is limited only by the energy and personnel costs required for re-pasteurisation of the material.

Casing as casing

- ➔ **$150k CapEx / $85k per annum OpEx.**
- ➔ Requires a casing separator, which increases CapEx and OpEx.
- ➔ Decreased economic viability due to added CapEx and because casing represents a smaller percentage of the total cost (compared with compost).

Compost as compost

- ➔ **$150k CapEx / $85k per annum OpEx.**
- ➔ Even with the use of a casing separator, the financial argument for recycling anywhere between 10-20% of compost is compelling.
- ➔ This solution is viable for growers who make compost on-site or at a distance that does not increase cost.

The tables below provide a viability assessment for an example grower based on **current wheaten straw and casing prices** in the Australian mushroom industry.

Recycling casing as casing and compost as compost are accompanied by a **detailed viability analysis on the following slides.**

Assumptions	
SMS sales	$5/t
Wheaten straw	$150/t
Casing	$400/t
Scale pw	30t

SMS as Casing	
CapEx	$0
OpEx p.a.	$60k
Net Savings p.a.	$60k
Payback	0y

Casing as casing (33% rec.)	
CapEx	$150k
OpEx p.a.	$85k
Net Savings p.a.	$60k
Payback	2.5y

Compost as compost (20% rec.)	
CapEx	$150k
OpEx p.a.	$85k
Net Savings p.a.	$238k
Payback	0.6y

Viability Assessment - Casing as casing

At current peat costs, it is financially viable to recycle 33% of casing as casing with mechanical separation.

Viability is increased by using naturally leached SMS as casing, as this decreases initial capital investment.

Pros

- ➔ Large net savings per tonne of mushrooms compared with pelletising for energy (high casing cost).
- ➔ Higher casing price = greater savings.
- ➔ Savings are almost independent of SMS sale price: casing price/tonne > SMS price/tonne.
- ➔ Decreased reliance on imported input.
- ➔ Relatively low CapEx relative to the savings.
- ➔ Technology available to separate the casing and compost.

Cons

- ➔ Separator only compatible with Dutch style shelving system and requires casing mixer.
- ➔ Fluctuations in peat quality (black to brown) could affect the reliability of recycling ratios.
- ➔ If casing is separated in a separator, it must still be sold.

The graph below demonstrates dollar savings per tonne of mushrooms across a range of casing prices for three SMS sale prices.

Assumptions

1. Producing 1t of mushrooms consumes 0.75t of casing.
2. Casing density: 25kg/m^{2}.
3. 33% of spent casing is recycled.
4. Recycling causes no change in yield.
5. Recycling capital cost (casing separator, truck, mixer): $200k, fixed (independent of farm size).
6. Maintenance cost = 4% of CapEx/year.
7. Recycling labour cost: $75k/year (1 person), independent of farm size.

Viability Assessment - Compost as compost

At current wheaten straw prices, it is financially viable to recycle 10-20% of compost as compost (with mechanical separation).

Pros

- ➔ Large net savings per tonne of mushrooms compared with other waste solutions, as compost is such a large component of overall cost.
- ➔ Higher straw price = greater savings.
- ➔ Savings are almost independent of SMS sale price: compost price/tonne far greater than SMS price/tonne.
- ➔ Reduces impact of wheat price on the business.
- ➔ Strong sustainability message - "Mushroom industry takes the lead on climate change and waste reduction".
- ➔ Limited CapEx and minimal OpEx for guaranteed returns.

Cons

- ➔ Time and resources diverted from current, optimised operations.
- ➔ The benefits of this solution are only available to growers that make their own compost.
- ➔ Increased biosecurity risk if recycled directly into Phase 2 and 3.

The graph below demonstrates dollar savings per tonne of mushrooms across a range of wheaten straw prices for three SMS sale prices

Assumptions

1. Producing 1t of mushrooms consumes 0.75t of casing and 3t of Phase 3 compost.
2. Each tonne of Phase 3 compost requires 0.5t of wheaten straw + $190 of other ingredients.
3. 20% of SMS is recycled as compost.
4. Recycling causes no change in yield.
5. Recycling capital cost (truck, mixer - no casing separator): $160k, fixed (independent of farm size).
6. Maintenance cost = 4% of CapEx/year.
7. Recycling labour cost: $75k/year (1 person), independent of farm size.

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Recommendation and next steps

Recommendation ✓ **Proceed**

All recycling options are financially viable solutions for industry to generate significant operational cost savings.

While recycling SMS as casing is financially viable, the current lack of naturally weathered SMS and feasibility challenges of continual management and re-pasteurisation likely preclude its adoption by the industry.

Combining recycling options (compost and casing) provides the best opportunity for rapid payback. Further trials will be required to weigh cost reductions against decreases in yield and quality.

Suggested next steps are:

1. Commit to developing this operational capability as a competitive advantage.

2. Growers proceed to site-specific trials at their own facilities utilising expertise gathered during trials conducted as part of this project:
   - ➔ Recycling SMS as casing - engage advocate grower to create 3-4 small piles of SMS - turn regularly, and assess EC in one year.
   - ➔ Recycling casing as casing - conduct a trial using manually separated casing to confirm results from academic literature before engaging with casing separator manufacturers.
   - ➔ Recycling compost as compost - conduct an additional industrial trial of recycling compost for compost to confirm results at a larger scale and/or for Phase 1 of the composting process.

2

Pelletiser system

Investment in capital equipment for non-thermal dewatering of SMS for on-site energy or off-site sales into energy and fertiliser markets

Solution 2

Pelletiser system

Pelletisation can reduce SMS moisture content and convert it into a transportable, storable and versatile pellet form.

Pelletisation has the ability to reduce substrate moisture content from 60% to <15%, with moderate energy use (<25 kWh/tonne). Pelletisation equipment is commercially available from several sources and offers three distinct options for the mushroom grower to add value to SMS:

1) Dewatering - SMS with 25-30% moisture content can be sold as a soil additive, stored longer term on-site, or processed further.
2) On-site energy - SMS pellets with <15% moisture can be burnt on-site to supplement energy supply.
3) Off-site sales - SMS pellets with <15% moisture + co-input can be sold to third party energy and fertiliser companies.

The project team produced sample pellets, conducted analysis of the samples (composition and energy content), consulted with mining and business experts to assess the various technology options and conduct financial analysis.

Business Case in Brief

Cost to implement

- ➔ Dewater: $395k
- ➔ Pelletise for on-site energy: CapEx $2.4m
- ➔ Pelletise for off-site sales: CapEx $1.8m

Viability — Viable

- ➔ The most immediate financially viable option is to dewater SMS and sell as a soil additive.
- ➔ On-site energy and off-site sale of pellets are more suitable for big players that currently do not have a revenue-generating option for SMS disposal. Government funding and access to a free and reliable co-input improves viability.

Recommendation — Proceed

- ➔ There are many technology options, with no company offering a clear advantage. Explore equipment and pricing.
- ➔ Government incentives should be explored to subsidise CapEx.
- ➔ Consider maximising utilisation of CapEx by processing materials from local businesses.

Pelletiser System

How does it work?

Process in brief

Dewatering

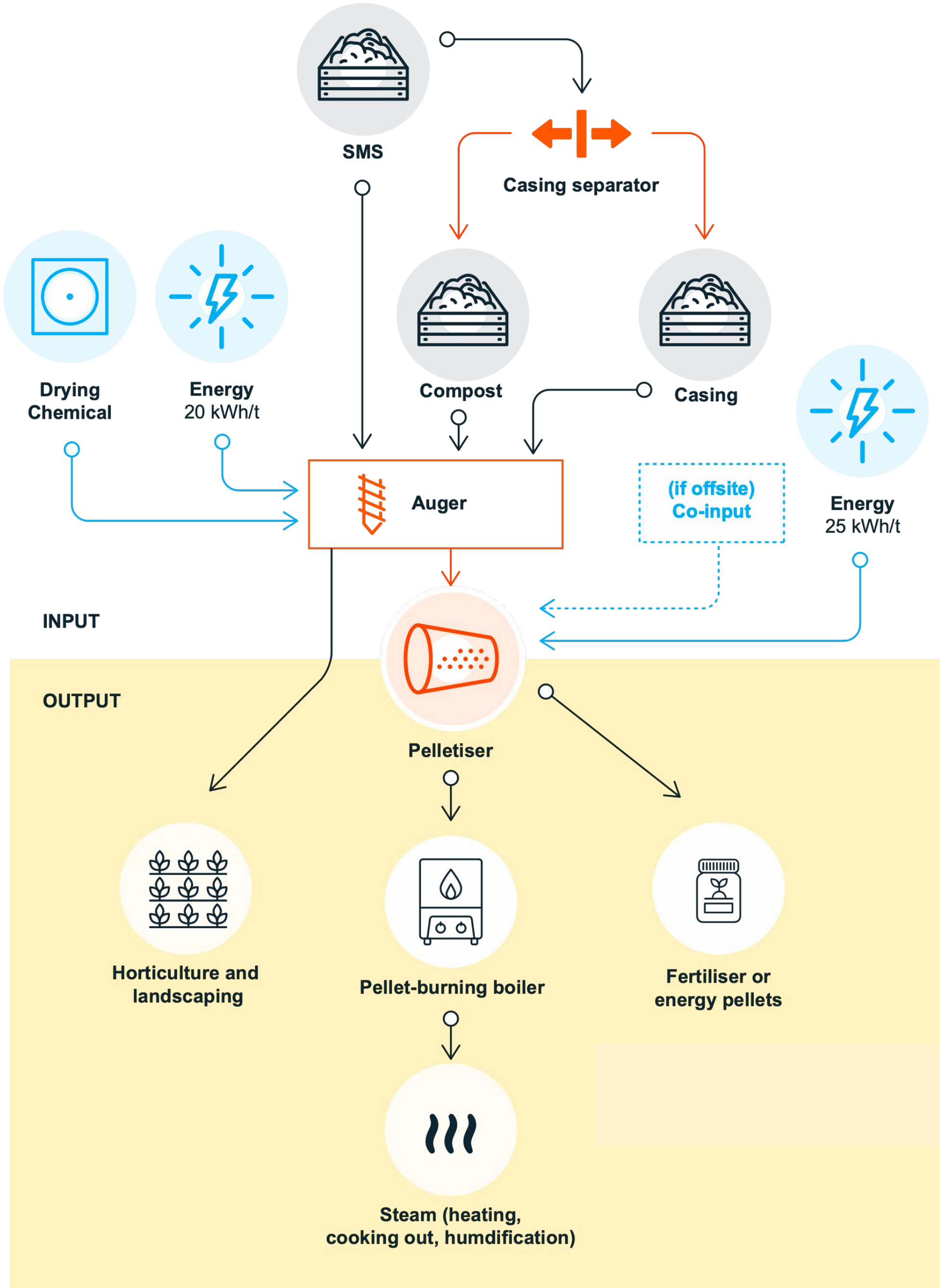
- ➔ Depending on the desired end product, SMS is either mechanically separated or fed directly into an auger with a drying chemical for simple dewatering.
- ➔ An auger or mixing blender dewaters input material from 65% to <30% with the aid of drying chemicals.
- ➔ Dewatered SMS can be sold to current purchasers of SMS at a higher price or utilised further on-site.

On-site energy

- ➔ If pellets are to be used for energy, separation is necessary.
- ➔ Post-auger material can be fed into the pelletiser for further dewatering, producing pellets with <15% moisture at rate of 1-5 tonnes/hour.
- ➔ In our trials, pellets with 19% moisture have an energy content of 13.9 MJ/kg (equivalent to brown coal and some sub-bituminous coals). This is sufficient to meet substantial energy needs of the mushroom grower.
- ➔ SMS could be combined with a co-input such as coal dust or animal waste to create higher-energy pellets and greater savings.

Off-site sales with co-input

- ➔ Pelletisation for off-site sales requires a co-input. Without co-input:
  - ◆ Pellets do not possess the required calorific value and their ash content is too high for energy markets.
  - ◆ Elemental concentrations require modification for fertiliser markets.
- ➔ Off-site sales of pellets as fertiliser could be explored in partnership with fertiliser companies, with the fertiliser formulated on-site. Modern Mushroom Farms (USA) is an example of successful implementation of this approach.



Pelletiser System

Process changes and risk mitigation

	Process changes	Risk mitigation
Dewatering	➔ Cook-out is not necessary. ➔ If further pelletisation for energy is desired, separation of the casing from the compost is required. ➔ SMS and/or compost component needs to be fed from the truck into the auger at the facility. ➔ Drying chemical is added (1-2% of total weight). ➔ Collection and treatment of water is required. ➔ Further processing needed if energy or fertiliser pellets desired.	➔ Minimal risk arises from this process beyond the need to keep the SMS at the facility for longer. Current equipment can easily process between 8-40 tonnes of SMS or separated compost in 8 hours, minimising the time unprocessed SMS must remain at the facility. ➔ Drying chemicals can be customised depending on cost considerations for the grower. Flocs of chitosan, derived from a naturally occurring glucosamine polymer (chitin), may be appropriate for SMS dewatering. ➔ Collected run-off water could be utilised as a mushroom “tea” and sold with dewatered SMS.
On-site energy (with or without co-input)	➔ Requires mechanical separation before pelletisation for energy. ➔ Pelletisation requires labour of 1-2 staff as pellets move on a conveyor from the pelletiser to boiler. ➔ Requires transportation & storage of co-inputs on-site. ➔ Gas or electric boilers need to be replaced by biomass boilers. ➔ On-site energy requires splitting of compost from casing. Casing must be managed separately. ➔ Pellets are burnt at the mushroom production facility. ➔ Ash from the on-site boiler must be collected and removed.	➔ Management of pelletisation equipment is a passive process that is likely to be necessary only once or twice per week. ➔ SMS ash can be sold as a soil additive. SMS pellet ash has higher concentrations of valuable elements than whole SMS and a moisture content close to 0%. ➔ Current biomass boiler systems have a myriad of safeguard systems. ➔ Installation at greenfield sites reduces the need for duplicate boiler systems.
Off-site sales	➔ Energy and fertiliser sales require the acquisition of new customers or partners. ➔ Involves additional regulations and handling requirements depending on the selected co-input.	➔ Financially viable to utilise a co-input that is free or easily transported to the pellet production site. ➔ Project team has formed partnerships with pellet purchasers to assist growers with pellet off-take agreements.

Pelletiser System

Equipment to facilitate change

Pelletisation requires the use of specialised equipment. The project team **vetted the capabilities and costs of equipment types and provider** options to inform the financial models and recommendations (*full financial models can be provided upon request)*. Below is a high level overview of the most cost effective equipment types required for dewatering, pelletisation and on-site energy.

Mixing Auger

- ➔ Drying chemicals (hydrophilic or hydrophobic polymers such as chitosans flocs or PDADMAC) are added to the auger along with the SMS (or separated compost) to facilitate the non-thermal drying process.
- ➔ Low CapEx machinery that can easily reduce moisture content to <30% and process 1-5 tonnes per hour.
- ➔ The machinery and drying chemicals can be adapted to customer preferences and the desired end product.

Pelletiser

- ➔ Non-thermal pelletisers are not novel in many industries. The technology is energy-efficient, averaging <50 kwh/tonne of input processed (product-dependent).
- ➔ CapEx and OpEx are relatively fixed regardless of scale (i.e. between 1-5 tonnes/hour, processing cost is about the same).
- ➔ A pelletiser can run continuously and be used in conjunction with solar power during non-peak sun hours, providing the flexibility to choose when and how to generate energy and revenue.
- ➔ Large pelletisers with higher pelletisation rates can minimise the number of days the pelletiser is operational and thereby decrease OpEx costs.

Biomass Boiler

- ➔ Widely used technology in Europe, Japan and Korea for steam generation and heating.
- ➔ Biomass boilers are an established technology, readily available in Australia and compatible for integration with current on-farm systems for steam generation.
- ➔ Calorific value of SMS is within the necessary input range of most biomass boilers.
- ➔ If co-inputs are added to pellets, boilers can be fitted with steam turbines to generate electricity and further reduce costs.
- ➔ There are relatively few boilers that utilise a wide range of biomass inputs. Testing of boilers for compatibility with SMS pellets is required in conjunction with technology owners.

Pelletiser System

Viability by the numbers

Depending on grower size, current SMS sale price and access to a low cost or free co-input with consistent supply, all the options are financially viable.

Dewatering SMS is financially viable to the largest segment of the industry. This is contingent upon dewatered SMS achieving a higher sale price than unprocessed SMS. The other two options are better suited to the largest players. Given the increasing costs of energy and compost inputs, this financial assessment will likely improve over the next five years.

Dewatering SMS

- ➔ **$395k CapEx / $6k per annum OpEx.**
- ➔ Financially viable if price of dewatered SMS per dry tonne (+ drying chemical cost) > SMS sale price per wet tonne + CapEx/OpEx.
- ➔ Decreases moisture content with less CapEx than entire pelletisation process.

On-site energy

- ➔ **$2.4m CapEx / $27k per annum OpEx.**
- ➔ Financially viable for the largest industry players at today's utility energy prices and for a range of SMS sale prices. Higher SMS sale price means less revenue and less net savings. Higher utility gas price equals greater savings.

Off-site energy/fertiliser with co-input

- ➔ **$1.8m CapEx / $27k per annum OpEx.**
- ➔ Financially viable if pellet sale price per dry tonne + co-input cost > SMS sale price per wet tonne + CapEx/OpEx.
- ➔ Lower CapEx and OpEx for the grower than on-site energy because a pellet-fuelled boiler with ongoing maintenance is not required.

The tables below provide a viability assessment for an example grower based on current gas prices showing projected dewatered SMS and pellet prices necessary for off-site viability.

Each of these options are supported by an in-depth viability analysis on the following slides.

Assumptions	
Mushrooms p/w	30t
Gas price	$16/GJ
Dewatered SMS sale price	$31.50/t
Pellet sale price	$165/t

Dewatering	
CapEx	$395k
OpEx p.a.	$6k
Net Revenue p.a.	$80k
Payback	5.0y

On-site energy	
CapEx	$2.4m
OpEx p.a.	$27k
Net Savings p.a.	$167k
Payback	14.4y

Off-site sales + co-input	
CapEx	$1.8m
OpEx p.a.	$27k
Net Revenue p.a.	$371k
Payback	5.0y

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Viability assessment - Dewatering

The basic drying system is financially viable for most growers if dewatered SMS achieves a modest premium per tonne relative to today's SMS sale price per wet tonne.

Small increases in dewatered SMS sale price generate very viable payback periods to the largest players in the industry.

Feedback from third-party soil amendment and fertiliser experts is that $35-45/t is achievable for dewatered SMS. SMS, with its high trace element content, should be considered as a high value soil amendment, not just a input into other compost products - additional information can be found in Appendix ii..

Pros

- ➔ Creates a larger revenue stream for the mushroom growers in existing and adjacent markets.
- ➔ Demand for organic fertilisers is growing, both domestically and abroad.
- ➔ Minimal CapEx required.
- ➔ Decreases operational risks as major changes to current mushroom production process are not required.

Cons

- ➔ Need long-term price guarantees for dry soil amendment sales to eliminate payback risk.

The table below demonstrates the necessary sale price of the dewatered SMS in order to achieve payback in less than 5 years, for three combinations of grower size and SMS sale price.

Dewatering, off-site dry SMS sales

Tonnes of mushrooms produced / week	SMS sale price, $/t	CapEx, $	Dry SMS sale price ($/t) to achieve 5 year payback
25	$10	$395k	$41.20
50	$10	$395k	$26.00
100	-$5	$395k	$3.30

Assumptions generated through industry interviews

1. "Step 1" system = mixing auger + ribbon blender only ($136k), plus design and installation costs ($259k), capacity 5 tonnes/hour (expert estimates).
2. System consumes 4.7 kW electrical energy per input tonne processed (expert estimates).
3. System runs 50 hours/week, and processes ALL available SMS.
4. No new labour is required to feed the system.
5. Maintenance cost = 2% of equipment cost/year.

Pelletiser System

Viability assessment - On-site energy

As utility gas prices rise above $12/GJ, on-site energy generation becomes financially viable to a larger proportion of the Australian mushroom industry.

Currently, this option is unattractive for smaller growers because of high upfront CapEx plus the relatively low energy content of SMS. Government funding can increase the viability of this option substantially (see Appendix iii).

Pros

- ➔ Eliminates growers' dependence on utility natural gas (rapidly rising in price) and reduces dependence on utility electricity.
- ➔ Sends strong sustainability marketing message to Australian mushroom consumers.
- ➔ Producer can shift pellet usage from on-site energy to off-site sales depending on energy prices vs pellet prices.
- ➔ Large quantity of SMS can be processed without leaving the facility.

Cons

- ➔ In the absence of government assistance, there is high CapEx and operational changes for non-core business endeavours.
- ➔ Does not totally eliminate the need for utility electricity or solar power.

The table below demonstrates the necessary utility gas price in order to achieve payback in less than 5 years, for three combinations of grower size and SMS sale price.

On-site energy generation, SMS only (no co-input)

Tonnes of mushrooms produced / week	Dry fertiliser sale price, $/t	New CapEx, $	Utility gas price ($/GJ) to achieve 5 year payback
25	$41.20	$2,418k	$77.90
50	$26.00	$2,418k	$37.30
100	$3.30	$2,418k	$11.30

Assumptions
1. Additional "Step 2" equipment is installed once "Step 1" investment has been paid off.
2. 1 MW.h electricity + 5.5 GJ gas consumed / tonne mushrooms produced.
3. Spent mushroom compost: 65% moisture, net calorific value 4.1 MJ/kg (based on measurement).
4. Dryer/granulator runs 60 hours/week and processes ALL available SMC, boiler/generator runs 24/7.
5. "Step 2" equipment (casing separator, chemical dryer/granulator, boiler, 500kW CHP): equipment cost $894k, design & install cost $1335k, consumes 18.4 kWh/t.
6. No new labour is required to feed the equipment.

Viability assessment - On-site energy with co-input

On-site energy generation using pellets made from SMS and a free, high energy co-input is financially viable to a greater proportion of growers at lower utility gas prices.

The analysis in the table at right uses coal dust as the free co-input. However, viability is not contingent upon the usage of coal dust. In fact, there are drier, more energy-dense co-inputs available in Australia. Key will be to procure high quantities at a low to zero cost to the grower.

Pros

- ➔ Greater energy production and cost savings at no additional cost to the grower.
- ➔ Further reduces dependence on utility electricity.

Cons

- ➔ A co-input such as coal dust may become restricted if there are changes in government or legislation.
- ➔ The co-input would need to be reliably supplied so that energy output does not constantly fluctuate.
- ➔ Requires grower to manage logistics and storage of the co-input.

The table below demonstrates the necessary utility gas price in order to achieve payback in less than 5 years, for three combinations of grower size and SMS sale price.

On-site energy with free co-input, SMC + free coal dust

Tonnes of mushrooms produced / week	New CapEx, $	Utility gas price ($/GJ) to achieve 5 year payback
25	$2,418k	$53.00
50	$2,418k	$24.20
100	$2,418k	$5.70

Assumptions

1. installed once “SMS” investment has been paid off.
2. Brown coal dust is delivered to mushroom farm at no cost.
3. Spent mushroom compost: 65% moisture, net calorific value 4.1 MJ/kg (based on measurement).
4. Add 0.2 tonnes of brown coal dust (net calorific value 8.4 MJ/kg) to each tonne of SMC.
5. Dryer/granulator runs 60 hours/week and processes ALL available SMC, boiler/generator runs 24/7.
6. Combined heat & power (CHP) system produces all required steam plus ⅓ of required electrical energy.

Viability Assessment - Off-site energy or fertiliser sales with co-input

Off-site sales into the fertiliser or energy markets is financially viable for the mushroom industry if pellets can achieve prices between $42.50-$188.20 - depending on grower size and current SMS sale price.

An industry assessment of the fertiliser and energy markets was conducted as part of this project. In general, organic fertilisers retail from $525-800/t and fuel pellets from $100-150/t. Fuel pellet prices are only limited by the MJ/kg energy content and relative moisture of the input material (full pellet testing results and current assessment of fertilisers can be found in Appendix iv-v).

Pros

- ➔ Creates a second revenue stream for the mushroom grower that is independent of the price of fresh mushrooms.
- ➔ Markets for biofuel pellets already exist in Australia and internationally.

Cons

- ➔ Co-input would need to be reliably supplied to ensure that composition of output is constant.
- ➔ A co-input such as coal dust may become restricted if there are changes in government or legislation.
- ➔ Requires grower to manage logistics and storage of the co-input.
- ➔ Does not reduce the need for utility electricity or solar power.

The table below demonstrates the necessary value added pellet price in order to achieve payback in less than 5 years, for three combinations of grower size and dewatered SMS sale price.

Off-site sales, SMS + free value added co-input

Tonnes of mushrooms produced / week	New CapEx, $	Value added pellet price ($) to achieve 5 year payback
25	$1,850k	$188.20
50	$1,850k	$101.00
100	$1,850k	$42.50

Assumptions

1. Same equipment, same capital, installation, maintenance costs as for Step 2, installed once “Step 1” investment has been paid off.
2. Pelletiser drying chemical cost: $0.
3. Co-input is delivered to mushroom farm at no cost.
4. Add 0.2 tonnes of co-input to each tonne of SMC.
5. Dryer/granulator runs 60 hours/week and processes ALL available SMC.

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Recommendation and next steps

Recommendation Proceed

A pelletiser system is a technically feasible and financially viable solution for industry to increase revenues and to generate operational cost savings.

All growers should review the detailed analysis conducted in this project to check how their individual circumstances fit. Producers with the highest quantities of SMS and the lowest sale price have the most compelling case to proceed.

Pursuing equipment options for the dewatering of SMS is the most immediately viable opportunity and first step towards pursuing the entirety of the pelletiser system.

Next steps are:

Dewatering SMS

1. Producers can work with the project team to organise an auger at their facility, and to match the equipment and drying chemical to the substrate and needs of the business.
2. Consider partnership with players or affiliated businesses to spread the cost of capital and maximise its utilisation.
3. Apply for alternative funding from ARENA and Bioenergy Australia to subsidise CapEx (this can be facilitated by the project team).

Recommendation and next steps

Next steps for Options 2 and 3:

On-site energy (with and without co-input)

1. Engage biomass boiler equipment providers with results of testing conducted as part of this project.
2. Project team can provide full plan cost model and adapt dimensions depending on needs of the business and available co-input (if possible).

Off-site energy or fertiliser sales

1. Test pelletised SMS with sourced co-input for calorific value and elemental composition. The project team can make introductions to energy off-take and pellet fertiliser companies in the local area.
2. Map suitable co-inputs available in the region of the production facility.

3

Anaerobic digester

Investment in capital equipment to process SMS (plus an available co-input) into biogas for on-site energy usage

Solution 3

Anaerobic digester

Anaerobic digestion is the process by which organic matter is broken down in a sealed vessel to produce biogas (for energy) and biofertiliser. The biogas produced when SMS is the sole digester input can generate only about half of the required energy (7 MJ/kg of input) to make the whole process viable.

This solution investigated the combination of SMS with a locally available co-input fed into an anaerobic digester (AD) for on-site energy generation and the production of anaerobic digestate for potential off-site sales.

Anaerobic digesters are a well-established technology, with the ability to scale up and down to match the size of the grower. ADs can potentially utilise the largest quantity of SMS.

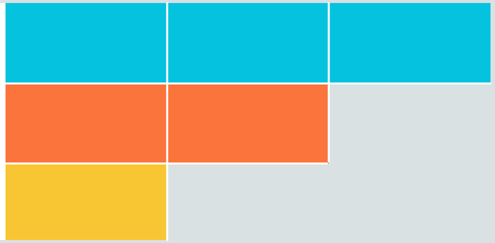
This project involved research and assessment of the energy content of available co-inputs, initiating partnership discussions with wastewater treatment facilities, synthesising existing work by the industry, and engagement with biogas experts.

Business Case in Brief

Desirability

Feasibility

Viability



Cost to implement

- ➔ 20 tonnes/week farm - $300k CapEx
- ➔ 100 tonnes/week farm - $900k CapEx
- ➔ Co-input feasibility trials

Viability ⊗ **Not viable**

- ➔ Not financially viable to produce cost savings or revenue to the mushroom industry unless a free co-input (that when digested with SMS, produces sufficient biogas to generate >7.0MJ/kg of input) can be sourced and/or the digestate can be sold for >$10/tonne.

Recommendation ⊗ **Do not proceed**

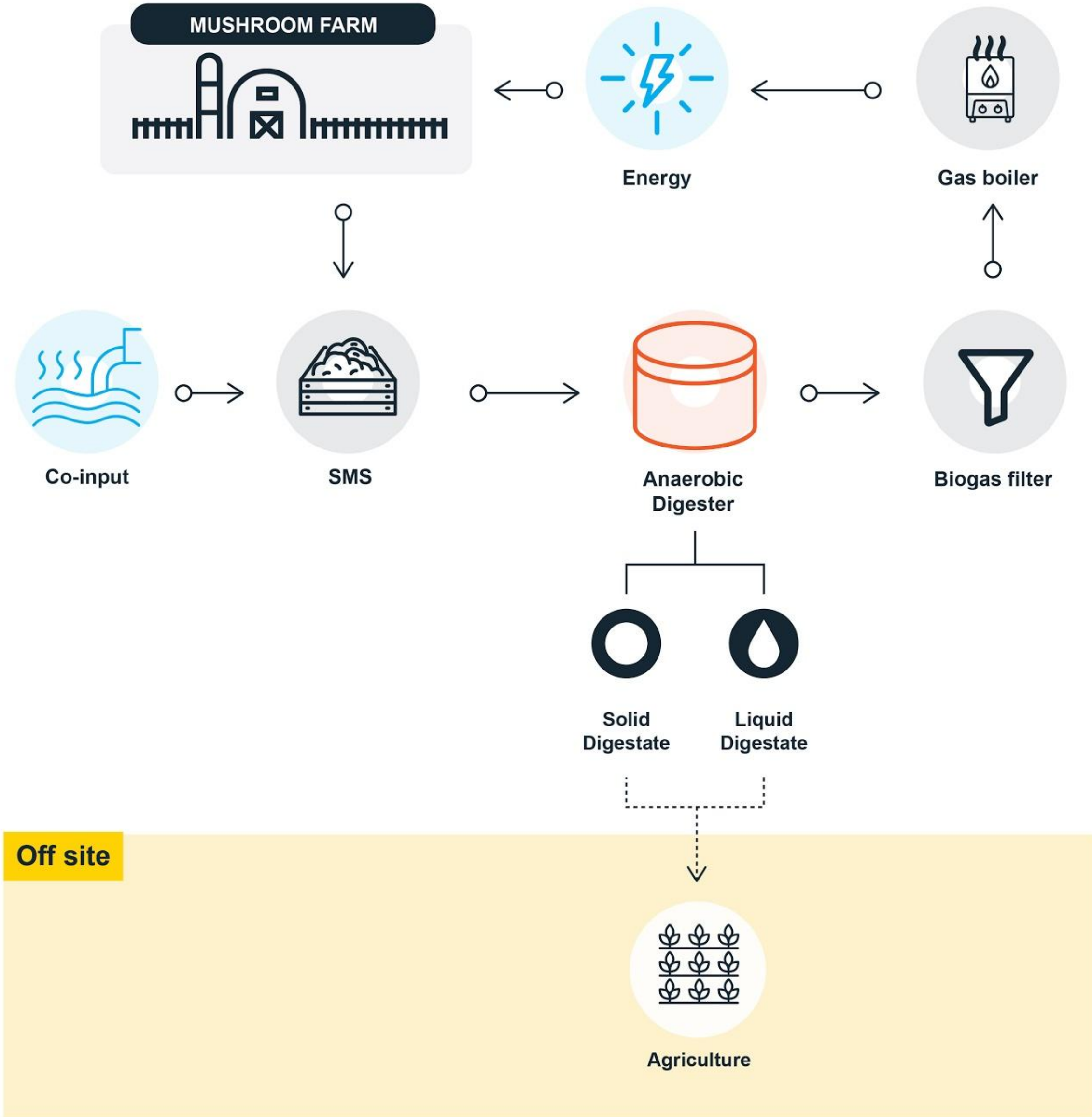
- ➔ The need to source and contract a low cost or free co-input with stable long term supply introduces significant risk to this solution.
- ➔ Viability is improved through the sale of digestate, but currently no such market exists in Australia.
- ➔ Compared to pelletisation, AD is far less efficient at converting SMS into potential energy.

Anaerobic digester

How does it work?

Process in brief

- ➔ A co-input is combined with SMS and loaded into the digester. SMS and the co-input will need to generate enough gas to produce >7.0 MJ/kg of input in order to produce a financially viable level of energy.
- ➔ Depending on the methane gas potential of the co-input, it may not be necessary to separate the casing from the compost.
- ➔ The mixture is fed into a holding tank where digestion occurs in the absence of oxygen. The appropriate digester type depends on the total solids content of the mixture (Appendix vi). Within 3-6 weeks, the tank will begin to emit biogas (methane/CO_2).
- ➔ Tank will likely require a filter (“scrubbers”) to minimise gas impurities such as hydrogen sulphide generated from some co-inputs.
- ➔ Gas can then be used in a gas fired boiler for steam generation and heating.
- ➔ Solid and liquid digestate (sludge) from the AD tank must be removed following the extraction of gas.



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Changes to the process

The use of mushroom waste in an anaerobic digester is **challenging** given the biochemical methane potential of SMS and the necessity of sourcing a co-input and selling the digestate. The options of using SMS and a co-input for energy represents **potential changes** to the current process of growing mushrooms and disposing of waste. Associated with each of these changes are **risks** that must be balanced against any cost savings and potential revenue.

Options	Potential Changes	Risks
SMS and co-input for on-site energy with no digestate sales SMS and a co-input with a combined energy potential of 7.0MJ/kg are added to the AD.	➔ Use of a large land area capable of housing the anaerobic digester and odours from the digestate. ➔ Increased water consumption: All AD designs require more moisture content in the input than is present in SMS, so increasing the moisture content will be necessary. ➔ Technologically advanced monitoring and safety systems capable of handling potentially dangerous gas production on-site. ➔ Gas boilers will either need to be replaced or upgraded to run on biogas. ➔ Producers will be required to source and transport a suitable co-input to their production facility. Ideally, the co-input will be freely available, geographically close, and will not involve an undue burden of regulation to bring on-site.	➔ If the co-input is not supplied in the necessary quantities, energy generation and thus production of fresh mushrooms could be negatively affected. ➔ New on-farm process that will require continual iterations to maintain quality, even after fine-tuning exact specifications of the digester. ➔ Time and resources required to manage the procurement of the co-input. ➔ Potentially dangerous process and equipment to manage on-site. ➔ In more urban environments, proximity to neighbours may restrict the use of an anaerobic digester. ➔ SMS is actually too dry for most digester types and droughts could restrict availability of water. ➔ Regulatory issues of transporting, managing and disposing of a co-input at a facility where food is produced.
SMS and co-input for on-site energy with sale of digestate The entirety of the SMS and a co-input digestate is sold for more than $10/tonne.	➔ As above including: ➔ Quality assurance testing of the stabilised digestate will be necessary to ensure a saleable product. ➔ A market for AD sludge would need to be established in order to ensure a return of >$10/tonne. In both options, the removal of the sludge from the facility will be a required change.	➔ As above including: ➔ Certain co-inputs could limit the application of the solid and liquid digestate in food producing industries. ➔ No guarantee that current purchasers of SMS would be willing to purchase digestate. Currently, most of the digestate in Australia is given away for free. ➔ The majority digestate is over 95% liquid. This liquid component is valuable but costly to transport.

Viability by the numbers

An anaerobic digester is only viable if a free, high methane potential co-input can be sourced. The ability to sell the digestate at the end of the energy production increases the viability of the anaerobic digester.

Continued increases in gas prices and decreases in SMS revenue expands the viability of the AD to a larger proportion of mushroom growers. Gas from the digester will only supplement (not replace) utility gas, as the energy conversion is still too low to meet the entirety of the farm's energy needs.

AD + co-input

- Financially viable to generate operational cost savings at projected future gas prices with an energy potential above 7.0 MJ/kg.
- The less a a grower earns for their SMS, the more financially viable this option becomes.

AD + co-input + $10/t sale of digestate

- Financially viable to generate revenues and operational cost savings at projected future gas prices and an assumed digestate sale price of $10/t.
- Necessitates the creation of a new market for anaerobic digestate.

A more detailed analysis of viability by scale and current SMS sale price can be found on Appendix vii.

The tables below provide a viability assessment for an example grower based on **current energy gas prices** and an example **SMS sale price**. SMS + co-input and SMS + co-input +$10/t sales are supported by an **in-depth viability analysis later in the report.** An SMS only option is provided for reference.

Assumptions	Mushrooms pw	30
	SMS sale price	$5/t
	Gas price	$15/GJ

SMS only	CapEx	$340k
	OpEx p.a.	$25k
	Net Savings p.a.	10k
	Payback	35y

SMS + co-input	CapEx (larger digester)	$572k
	OpEx p.a.	$30k
	Net Savings p.a.	$147k
	Payback	3.9y

SMS + co-input + $10/t sales	CapEx (larger digester)	$572k
	OpEx p.a.	$30k
	Net Savings and new revenue p.a.	$239k
	Payback	2.4y

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Anaerobic digester

Viability assessment - SMS + co-input for on-site energy

An anaerobic digester is economically viable for some growers with a reliable co-input that generates sufficient levels of methane to produce 7MJ/kg of input material.

To increase viability across the industry, a co-input with increased methane potential and/or increased supply of the co-input is necessary.

Pros

- ➔ If found, a free input with high methane potential could eliminate the need for utility provided gas.
- ➔ An AD has the ability to handle large quantities of SMS.
- ➔ Viability for smaller growers is only limited by their ability to source high yielding co-inputs.

Cons

- ➔ Difficult to maintain consistent energy output when sourcing various co-inputs.
- ➔ Viability of the process depends on a non-mushroom waste source provided cheaply and easily - mushroom industry becomes dependent on another industry to meet their energy needs.
- ➔ Additional costs to the business could include transporting and disposing digestate off-site.

The graph below illustrates the relationship between dollars out (net savings) to dollars in (net CapEx) per tonne of mushrooms for three combinations of gas and SMS sale prices and for a 5 year payback period.

Assumptions

1. Co-digestant is free and is procured at no additional cost to the business.
2. Digestate sale price = $0.
3. $150 CapEx per tonne of mushrooms is maximum CapEx threshold.
4. Labour to manage AD and digestate sales = 0.
5. Co-input to SMS ratio is 1:1.
6. Co-digestant energy content = 10.1MJ/t.

Anaerobic digester

Viability assessment - SMS + co-input for on-site energy

In order to source a large, consistently supplied co-input, the project team explored potential partnership agreements with wastewater treatment facilities near mushroom growers outside of Melbourne and Sydney. Many wastewater treatment facilities have **already begun pursuing their own arrangements** to source co-inputs into their excess digester capacity and it is **unclear whether it is possible for any cost savings or revenue to be gained by mushroom growers under this scheme.**

Use of municipal sewage as a co-input **will require adherence to restrictive state-based regulations** for the digested sewage (biosolids). If the AD is on the farm, any logistical and regulatory obstacles involved in transporting and storing sewage on the farm will also need to be surmounted.

"It won't be easy getting EPA approval for transporting raw sewage onto mushroom farms"

- Waste Manager (Hawkesbury City Council, NSW)

Name	Details	Business case with the mushroom industry
South Windsor Sewage Treatment Plant, NSW	Conventional activated sludge sewage treatment plant with bioreactors, tertiary filtration, UV disinfection, water recycling. Run by Hawkesbury City Council.	Does not appear to be have an anaerobic digester.
McGraths Hill Sewage Treatment Plant, NSW	Trickling filter sewage treatment plant with tertiary ponds, constructed wetlands and alum dosing facility. Anaerobic digestion of biosolids, dewatering, beneficial reuse of the waste in agriculture and mining. Run by Hawkesbury City Council.	Has an anaerobic digester. Manager currently '*can not see any nexus*' for combining SMS with their waste management system, although their options for waste are currently under review.
Sunbury Recycled Water Plant, VIC	Wastewater treatment capacity is 9.2 million litres per day. Very recently upgraded using new technology at the site, with a key feature being the membrane bioreactor ('MBR') tank. Run by Western Water, Victoria.	Does not appear to have an anaerobic digester.
Melton Recycled Water Plant, VIC	Biogas cogeneration facility that partially powers the plant. Newly-built AD facility expected to be operational in mid-2020. Expected to have spare capacity for digestion of regional organic waste for 15 years. Run by Western Water, Victoria.	Only seeking liquid organic waste to meet their spare AD capacity. Will establish formal agreements and contracts to source appropriate volumes of suitable wastes. Waste will need to meet quality standards and be supplied at appropriate volumes and time intervals.

Viability assessment
- SMS + co-input for on-site energy

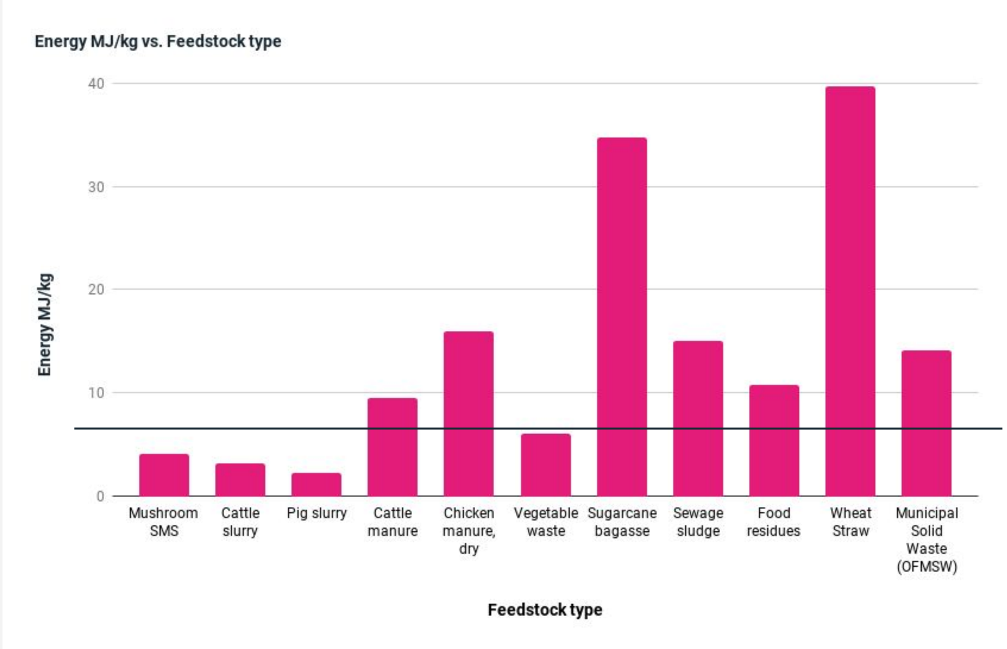
Co-input

- **Because anaerobic digestion is an organic process, the methane per kg of input (and the subsequent energy produced by the methane - MJ/kg) cannot be taken as an average between SMS and the co-input.**
- Feedback from biogas testing labs, industry and European experts indicate that SMS (with and without casing) does not produce necessary quantities of methane to warrant investment.
- However, we were not able to procure the results of previous testing conducted here in Australia.
- When selling digestate off-site, quality/composition of the digestate will depend on the quality/composition of the input feedstock.

Issues for consideration

- Supply must be uninterrupted - cannot become dependent on another, unreliable input.
- Best course of action would be to utilise an input material that is already supplied to the farm (i.e. chicken manure) or solidify an advantageous off-take agreement with a reliable provider (i.e. municipal solid waste or waste water plant).

The chart below illustrates the energy potential for various candidate co-inputs. The line represents **the size of the gap between the potential energy generated by SMS and required energy** for an economically viable anaerobic digester.



Anaerobic digester

Viability assessment
- SMS + co-input + digestate sales

An anaerobic digester with a co-input is economically viable for industry at projected future gas prices and a digestate sale price of >$10/t.

A sufficiently high sale price of the digestate could eliminate the need for a co-input - however a market for digestate does not currently exist in Australia.

Pros

➔ The potential sale of digestate expands the viability of this option to a larger proportion of industry and mitigates the loss of SMS sale revenue.
➔ This is one of the few solutions that is capable of decreasing costs ***and*** increasing revenues.

Cons

➔ This option opens the grower up to input and output risk - depending on both a reliable co-input and the expansion of the digestate market in Australia.
➔ Volume of digestate produced by an AD can be substantial and requires a careful management strategy. Substantial labour and operating costs (depending on technology used) may be associated with managing digestate.
➔ Stabilised digestate can be nutrient rich, so uneven land application can cause issues with nutrient overloading and runoff (especially nitrates).
➔ SMS/sewage co-digestate will have to compete with the established compost market, and the current value is uncertain.

The graph below illustrates the relationship between dollars out (net savings and new revenue) to dollars in (net CapEx) per tonne of mushrooms, for three combinations of gas and SMS sale price, and for a 5 year payback period.

Assumptions
1. Co-digestant is free and is procured at no additional cost to the business.
2. Digestate sale price = $0.
3. $150 CapEx per tonne of mushrooms is maximum CapEx threshold.
4. Labour to manage AD and digestate sales = 0.
5. Co-input to SMS ratio is 1:1.
6. Co-digestant energy content = 10.1MJ/t.

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Recommendation and next steps

Recommendation ⊗ **Do not proceed**

Anaerobic digestion incorporates an abundance of externalities into the business through the sourcing of a co-input, but remains an inefficient process of generating energy.

Therefore, anaerobic digestion of SMS and a co-input for on-site energy is a desirable solution and technically feasible, but generally not economically viable for the majority of the Australian mushroom industry.

Viability for the rest of industry can be expanded if a reliable market for digestate sales and co-digestion sourcing can be established.

For those growers with intent, next steps are:

1. Assess the feasibility of sourcing a low or zero cost, suitable co-input from near the mushroom facility. Can long term contracts be established that ensure a consistent input specification and supply?
2. Biochemical methane potential (BMP) testing of SMS and sourced co-inputs - several tests over a period of time to determine the best-fit SMS to co-input ratio. AD is an organic process that will require thorough understanding of the formula.
3. Market analysis to identify purchasers of solid and liquid digestate. Determine likelihood of long term purchase agreements.
4. Connect with wastewater treatment facilities in local area that do not currently have an anaerobic digester to determine their willingness to provide sewage sludge to a new on-farm anaerobic digester.

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Mushroom powder

Drying and powderisation of edible mushroom waste into a shelf-stable powder for the high value food market

Solution 4

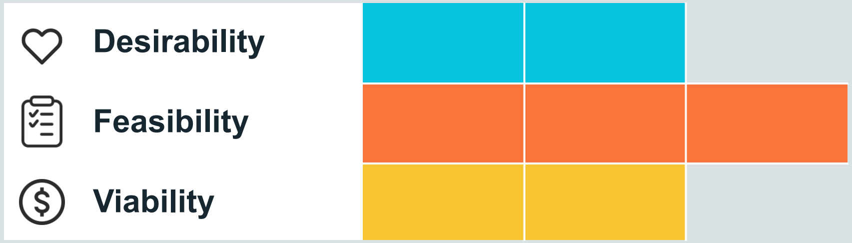
Mushroom powder

“Subprime” mushrooms (including stems) can be utilised to make powders that facilitates a multitude of high value food (HVF) opportunities. The grower can participate in the opportunity in ways that fit their business risk profile. For example, a grower could simply supply subprime mushrooms to others making powdered products for a negotiated fixed price, or invest in infrastructure and value chain relationships required for successful product commercialisation.

A powder is an example of a HVF food format that provides the grower with a new business income stream, product diversity, a longer shelf life, and improved nutritional attributes when compared to fresh mushrooms. Target markets would include high-margin supplements or ingredients for meat alternative products.

For this project, SjW Mushrooms provided over 100 kg of subprime mushrooms for powdering. The powdered product was analysed by nutritionists and food manufacturers. The project team worked with food companies operating in the flexitarian and natural supplement space to explore business models.

Business Case in Brief



Cost to implement

- Toll manufacturing - +$0.98/kg of fresh mushrooms (including harvesting and processing costs).
- Collaborative venture- $100k-150k CapEx investment.

Viability — Viable

- Feedback from experts and food manufacturers indicates that a viable price per kg of powder is achievable - including the increased harvesting and production costs

Recommendation — Proceed

- **Low/Moderate risk** - invest and build capability in selected tasks required for successful product commercialisation, e.g. toll manufacturing. (Partner in the value chain).
- **High risk** - invest and build capability and/or relationships that provide the grower with end-to-end product development, supply and distribution. (Own the value chain)

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Mushroom powder

The HVF headache - Which product?

Not all food products are created equal, with some food formats receiving higher margins than others. Powdered mushrooms are a food format that enables access to the high margin supplement and meat replacement markets. Powdering **extends shelf life, concentrates nutrient content and provides flexibility in the way the end product can be marketed and used** by food manufacturers and consumers.

Benefits

- ➔ Reduces the industry's production of edible food waste (in excess of 7,000 tonnes per year)
- ➔ Creates a shelf stable product that can be sold when demand for fresh mushrooms falls
- ➔ Aligns with existing mushroom marketing - tasty, healthy, easy - and offers a product with 10x the nutrition of fresh mushrooms (by weight)
- ➔ Unlocks a myriad of other products in a timeline that works best for the growers and market forces
- ➔ Process has already been utilised by other fruit and vegetable growers to move up the value chain (see p.57).
- ➔ Low cost toll manufacturing is readily available in Australia

Supplements

Analysis of approximately 100 fruit and vegetable powders on the retail market indicates that prices range from \$30-\$1,200/kg, with a **median price of \$97/kg.**

Expected annual growth in the supplements market is 7.2%. As one powder manufacturer stated, "*Commodity foods makes cents, supplements make dollars*".

The biggest opportunities exist in addressing specific needs associated with lifestyle. Examples include protein supplements for muscle development, weight loss, and specific nutrients or bioactive compounds that have been shown to address human disease or disease risk factors.

Low meat consumption and flexitarianism

Global meat-alternative sales are expected to surpass \$200 billion dollars in the next 10 years. Almost half of Australians are aiming to eat less meat.

Large multinationals see opportunity in this space: Mars Australia recently invested in small companies transforming imported mushroom stems into "meat alternatives" here in Australia.

The mushroom is a highly valued, nutrient dense product that is versatile from a HVF product development perspective.

Product price point categories

Mushroom powder

How does it work?

Process in brief

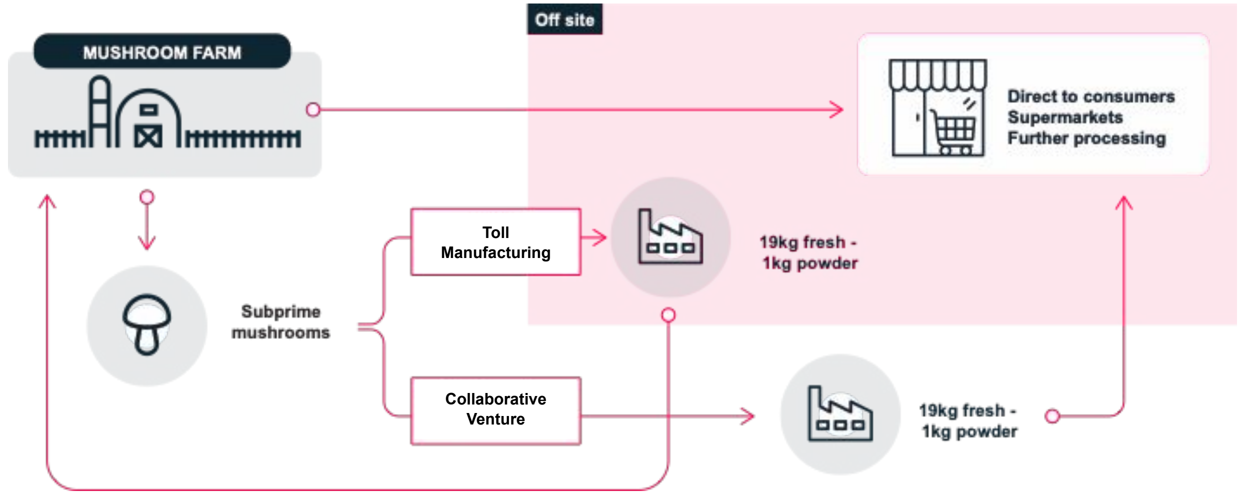
“Subprime” mushrooms, including a portion of double cut stems, are collected during harvesting.

Low temperature drying and powdering equipment **converts subprime mushrooms to powder at a ratio of approximately 19 kg of fresh mushrooms to 1 kg powder.**

There are at least two activities that can assist the grower to participate in the opportunity:

➔ Powder can be processed via a **toll manufacturing** agreement and either returned to the mushroom grower for B2B and/or B2C sales, or distributed as a product within the toll manufacturer’s existing brand and supply chain (no CapEx required).

➔ Growers may seek to invest in processing equipment and end-to-end capability building through a **collaborative venture** with other mushroom growers, food manufacturers or other parties (CapEx required).



- Co-investment in necessary equipment with nearby mushroom growers and other “high value” fruit and vegetable growers (e.g. sweet potato and broccoli) can reduce the costs of CapEx, improve equipment utilisation, and increase product diversity.
- For a larger investment, growers could share revenues (‘buy a slice’) generated from required commercial activities further downstream; that is, additional investment funds product development, branding and marketing, distribution, etc.

Mushroom powder

Changes to the process

Currently, producers that supply subprime mushrooms to HVF manufacturers are either paying for their removal or receiving commodity prices for an input “waste material”. The potential to increase revenue on subprime mushroom sales is limited.

Growers can aim to own a portion of the end product revenue by investing in manufacturing and commercialisation of mushroom powder products. This can be facilitated by activities like toll manufacturing and partnerships/collaborative ventures.

Options	Potential Changes	Risks and challenges
Processing through toll manufacturing	➔ Refrigerated storage at the mushroom facility for stems and subprime mushrooms until processed ➔ Double cutting is likely to be required, as no efficient and effective technology or method was identified to clean stems ➔ Transportation to food processing facility - rather than normal disposal method (i.e. mix with SMS). ➔ If powder is returned to the grower - management, storage and distribution of new products will be required ➔ Investment in branding & packaging required as well as relationships with Retailers or manufacturers ➔ Establishment of new B2B and B2C relationships for a finished product.	➔ The “first mover” in this space faces initial challenges and potential financial losses; appetite for this risk may be low (although >5 potential partners who are willing to work with the mushroom industry have been identified) ➔ Double cutting stems decreases harvesting efficiency and increases labour cost ➔ Improper storage means mushroom stems have a shelf life of 2-4 days. ➔ Upfront costs are necessary to “buy production” in order to refine product positioning and marketing potential ➔ Product may be commoditised unless supplied directly to end customer or a solid partnership agreement with manufacturer can be established. ➔ Cooperation with manufacturers may expose mushroom growers to competition risks during product development stage
Production through partnership or collaborative venture	➔ As above. ➔ Investment in new processing equipment and industry-wide cooperation for processing ➔ Coordination of edible mushroom waste and powder pricing between the industry participants. ➔ Training labour force on use and management of new powderisation equipment. ➔ At least one industry participant will need to house the powderisation equipment at their facility	➔ As above. ➔ Pay-off for investment in processing capability is dependent on scale of production - which is perhaps not always reliable with subprime mushrooms ➔ Increased regulatory hurdles for producing a finished food product. ➔ Relationship management presents challenges when coordinating production between competitors in the Australian mushroom industry and dealing with changes to the agreement

Grower views and business case analysis

We have tried to make HVF products but don't have access to the required distribution channels.

- Grower

Partnership can provide the required access to B2C and B2B customers. Consider an online direct to consumer strategy and experienced experts to guide the strategy and execution.

We made really great products but couldn't get the marketing right.

- Grower

Great products are determined by target consumers. Confirm that there is unmet consumer need or market demand. Consider engaging entities with a track record in successfully branding and marketing similar HVF products.

We don't want to cannibalise the fresh market.

- Grower

Expanding demand for mushrooms amongst the growing vegetarian and flexitarian markets will ensure that opportunities expand for growers. Successful HVF products should be made primarily from subprime mushrooms that do not have a robust fresh market.

We just supply stems and low grade mushrooms for next to nothing. Even at our price, we are in danger of being undercut in price.

- Grower

The only means to earn more on subprime mushrooms is to increase risk exposure, own more components of the value chain and/or partner with groups that can lend expertise in these areas and own the brand.

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Distribution and product choice

Processing mushrooms into a powder enables a **wide range of product possibilities**. Powders can be further processed into snacks, bulk powders, and **most financially attractive of all, supplements**. The ultimate product choice is dependent on the selected distribution channel (B2B vs B2C) and thus the margins that can be captured by the mushroom grower.

	Pros	Cons	Product choice
B2B	→ Facilitates retail distribution, shelf space and product development → Lowers marketing costs → Free product development - “Building on the back of others” network	→ Difficulty convincing large players to use the product → Risk of commoditising the input mushroom → Tighter margins and likely eliminates the viability of low price point snack foods requiring further processing	**Toll manufacturing** → Only viable to pursue high price point products because of inevitable margins captured by manufacturer and purchaser **Collaborative venture** → Incorporation of manufacturing partner expands possible product offerings
B2C	→ Value back to the grower, both financially and in terms of product awareness → Can manage production timeline based on fluctuations in fresh market demand and price → An opportunity to create a brand and build value in the brand	→ Increased CapEx and OpEx to run manufacturing, packaging, branding distribution and sales → Time and resources diverted from core business → Increased regulatory hurdles selling finished food products to consumers → Challenges dealing with retailers	**Toll manufacturing** → Viable for medium-high price categories, but high level of risk → Likely that existing distribution channels will need to be leveraged **Collaborative venture** → The low price products (i.e. processed snack foods) are now financially viable when growers own the means of production

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Mushroom powder

Viability by the numbers

This analysis is based upon interviews with food manufacturing experts and business owners, research on CapEx for powderisation equipment, and input from the mushroom industry.The objective was to understand **the minimum price** the mushroom grower would need to earn **to achieve payback** and **justify changes to current practices.**

Toll manufacturing

- ➔ Viability depends on grower's existing operations, toll manufacturing agreement, choice of powder product and market
- ➔ Less financial risk as toll manufacturing can be done cheaply and allows grower time to better understand market demand for the product
- ➔ Less price control of the final product (i.e. less upside)

Collaborative venture

- ➔ Viability depends on production agreement between growers and powder product chosen
- ➔ B2C sales in a collaborative venture is the most viable option within this entire solution - must utilise effective partnerships to facilitate path towards this business case.
- ➔ Once viable, smaller growers could sell their edible waste to powder producers

Processing through toll manufacturing

Break-even powder sale price for toll manufacturing, $/kg	**$18.75**
Production Cost, $/kg powder	$4.50
Break-even powder sale price received by grower, $/kg	**$14.25**

Production through collaborative venture or partnership*

The price points below represent the minimum price a mushroom grower would need to receive **per kg of powder** in order to achieve a payback in less than 5 years - this assumes an investment into production of approximately $100k

100t Mushrooms / week	Price Point per kg	$18.4
50t Mushrooms / week	Price Point per kg	$20.4
20t Mushrooms / week	Price Point per kg	$24.3
10t Mushrooms / week	Price Point per kg	$36.5

**Assumes the grower allocates 100% of their stems to powder production and investment into the collaborative venture is $95k + $50k OpEx p.a.*

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Business model review, case study, and proof of concept trial:

Natural Evolution Foods

The project team collected over 100 kg of subprime mushrooms from SjW mushrooms and transported them to Natural Evolution Foods for processing into mushroom powder. Potential business and collaboration models with Natural Evolution Foods were explored as part of this solution.

Mushroom powder

Business model review

Commercialising a HVF requires a plan to deal with the following essential tasks:

- Supply and preparation of raw input ingredient
- Processing and product development
- Packaging
- Certification, regulation and labelling
- Distribution
- Branding and marketing

Mushroom growers seeking to explore HVFs will either need to acquire or develop the skills and experience in these areas or find appropriate partners.

There are a number of food processing companies and food entrepreneurs interested in exploring HVF opportunities using mushrooms. As an example, Natural Evolution Foods has extensive experience utilising waste products to bring high value foods to market using various distribution models.

Selecting a partner to trial

The project team selected Natural Evolution Foods as an example company; they began as banana growers, and diversified into the processing of banana waste into powders. Natural Evolution Foods have developed internal expertise in areas in which growers are traditionally less experienced - branding, marketing, and innovative distribution models. Their journey provides a roadmap for mushroom growers to consider, and they may also represent a potential partner. Natural Evolution Foods, along with other Australian businesses, are available to talk about toll manufacturing or a collaborative venture agreement.

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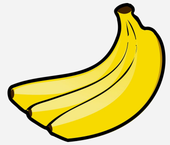
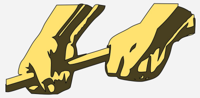
Natural Evolution Foods: A case study for innovative mushroom growers

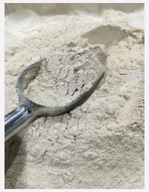
Journey up the value chain

Ten years ago, Rob Watkins owned and operated a banana farm in far north Queensland that discarded tonnes of off-colour, damaged, unripe, but mostly green bananas to be eaten by local cattle and wallabies. Today, Rob runs Natural Evolution Foods, a supplement and HVF business that retails green banana flour (at around $55/kg) into supermarkets and direct to customer via online sales.

- **Identify the problem -** Local cattle and wallabies ate the discarded bananas. It occurred to Rob that if the animals saw value in the product, there must be value for others.
- **Refine the powderisation technique -** Initially a manual process, the powderisation technique undertook several years of refinement.
- **Prove nutritional content relative to fresh product -** Rob funded his own nutritional analysis of the product to validate its worth.
- **The grower needs to be their own advocate in advancing the story of waste reduction -** Natural Evolution Foods have promoted their sustainability story and received press coverage across Australia in newspapers, magazines, and on national television.
- **Solve remaining technical challenges to produce at scale -** They established a market for the product, at a price point that was viable, and then went back to the production process to reduce costs and solve technical challenges to make the process easier.
- **Own the means of production to capture full returns of HVF product -** Natural Evolution Foods eventually expanded their production capabilities through the installation of a full scale powderisation facility, and have plans to expand to Victoria and NSW.

2009

300,000 t/year of banana waste = 5-30% of total production

2010

Rob Watkins begins manually powdering banana flour

2011

Powder contains resistant starches - supported by CSIRO report

2012

Peeling machinery for 300 kg of bananas/ week

2017

Powderisation factory constructed

2019

100 tonnes of banana flour / year

Diversified product range

Mushroom powder

Proof of concept trial

Trial

SjW Mushrooms in Queensland donated 112 kg of subprime mushrooms for a powderisation trial. Approximately 90% were double cut stems and 10% were off-grade mushrooms.

The subprime mushrooms were transported by refrigerated truck to Natural Evolution Foods' production facility and appropriately stored. Six days later, the subprime mushrooms were transformed into powder in a process that took a little more than a couple of hours.

Key Insights

- ➔ Drying and powderisation of the mushrooms produced an excellent result (texture and smell), and presented little or no difficulty for the production process
- ➔ It is technically feasible to create a mushroom powder without losing the nutritional benefits of fresh mushrooms
- ➔ Processing produces a product with enhanced nutritional values - a nutrient dense alternative mushroom format (i.e. supplement)
- ➔ Powder is high in fibre, beta glucan, protein, polyunsaturated fats, copper & selenium minerals
- ➔ Need to determine realistic serving (sensory), product specifications and positioning

High returns on subprime mushrooms **is key to the viability** of this solution. High returns are **only possible** if the nutritional benefits of the fresh product are not lost during processing.

Nutritional Information	Fresh *Agaricus bisporus* mushrooms		Mushroom Powder	
	Average Quantity per 100g	Percentage Daily Intake	Average Quantity per 100g	Percentage Daily Intake
Energy	86kJ (20kcal)	1%	1,210kJ	
Protein, total	2.3g	5%	21.9g	47.6%
Fat, total - saturated - trans - polyunsaturated - monounsaturated	0.4g 0.1 3.5mg 0.2g 0g	<1% <1%	2.2g 0.5g 200mg 1.5g 0g	
Carbohydrate - sugars	0.3g 0g	<1% 0%	29.5g 1g	
Dietary fibre, total - Resistant starch	2.7g 0.4g	9%	34.8g NA	116%
Sodium	9mg	<1%	110mg	
Riboflavin (B2)	0.37mg	22%	2.5mg	
Folate	22µg DFE	11%	160,000µg DFE	
Vitamin D (UV enhanced)	24µg	280%	NA	
Vitamin D (std raw)	2µg	20%	0.5µg	
Copper	0.37mg	12%	1.3mg	42.2%
Selenium	16µg	23%	110µg	158%
Polyphenols	64mg GAE	-	120mg/kg GAE	
Beta-glucan	NA	-	19.2%	

Recommendation and next steps

Recommendation **Proceed**

For risk averse growers, beginning with small scale toll manufacturing production while building out partners within the value chain is a reliable path forward. Risk tolerant growers should pursue collaborative ventures with partners identified during this project or others with similar capabilities.

Mushroom powder is recommended as a financially viable solution for industry to generate revenue if the grower can earn in excess of $18.75/kg of mushroom powder through toll manufacturing or between $18.4 - $36.5/kg (depending on production scale) for production through a collaborative venture. Feedback from experts and food manufacturers indicates this price per kg of powder is achievable.

Suggested next steps are:

1. Align interested mushroom growers within a region to form an alliance with shared commitment, investment and risk appetite.
2. Determine venture model and hence appropriate partner capability requirements.
3. Engage in product development within alliance capabilities and establish consumer price points.
4. Develop brand and marketing strategies.

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Exotic mushrooms from SMS

Reusing the compost component of SMS as the primary substrate for the cultivation of oyster mushrooms

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Solution 5

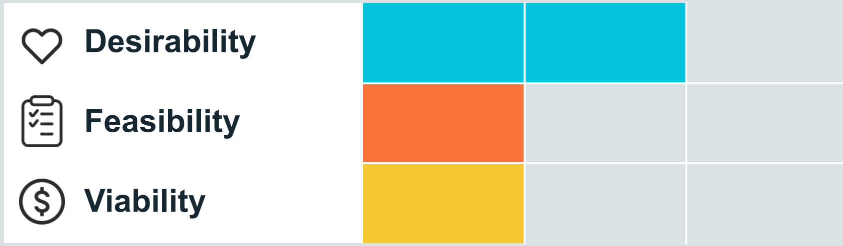
Exotic mushrooms from SMS

SMS from *Agaricus bisporus* production, fortified with a cellulose source, can be used as a growing substrate in the production of *Pleurotus ostreatus* (oyster) mushrooms.

Mushroom growers can diversify their fresh mushroom product offerings into a growing sector without substantial changes to their current operations and at minimal additional cost.

Interviews with current growers of exotic mushrooms, review of international academic research, and input from *Agaricus* mushroom growers all informed a small field trial in Victoria and the recommendations of this solution.

Business Case in Brief



Cost to implement

- <$5,000 CapEx/OpEx
- Loss of current SMS revenue

Viability — **Not viable**

- An inability to generate bioefficiency above supplementation levels stopped further exploration of price and the payback period necessary in a full viability analysis.

Recommendation — **Do not proceed**

- Technical feasibility was unable to be proven under trial conditions. Oyster mushrooms could not be grown from “fresh SMS”, precluding immediate industry adoption.
- It is likely that there are more economical and productive methods for growing exotic mushrooms than using SMS as the substrate.

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Exotic mushrooms from SMS

How does it work?

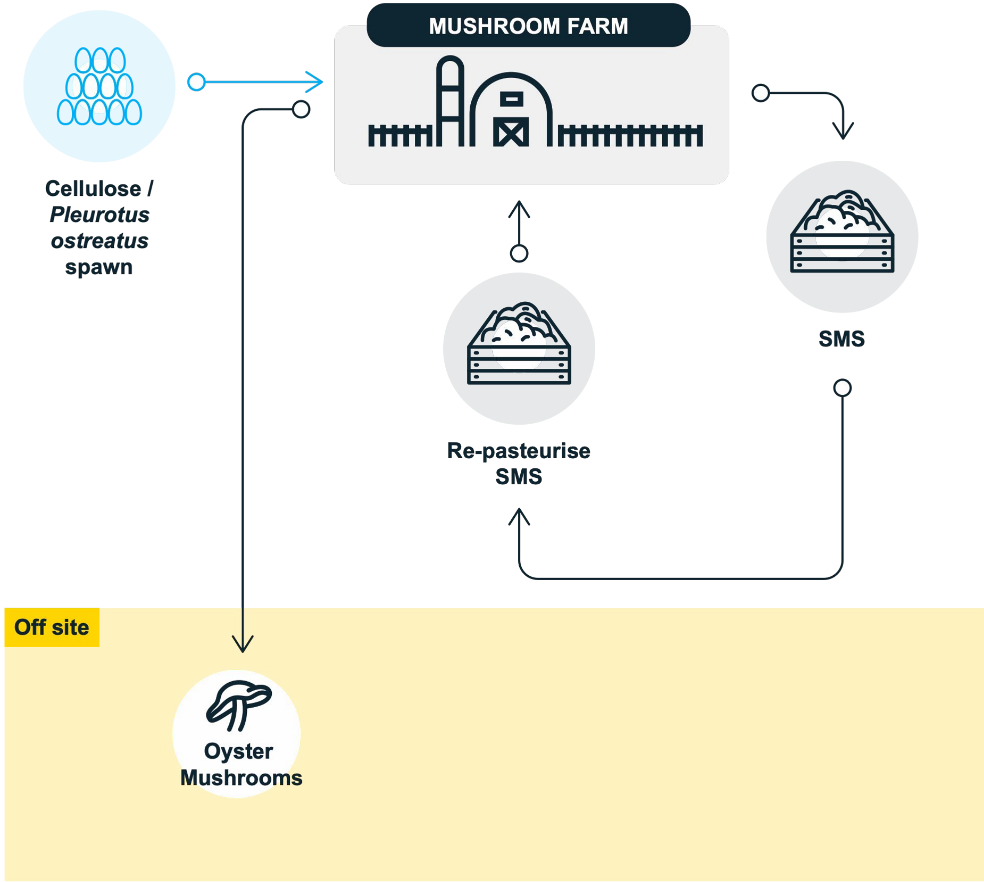
Process in brief

→ *Agaricus bisporus* SMS is emptied from the growing room then naturally or mechanically weathered to reduce EC levels below 2.0 mS.
- SMS is required to be stored on-site and either pushed into small piles to aid natural weathering, or mechanically "flooded" to wash out the salts from the SMS.
- Natural weathering of SMS requires semi-frequent turning to aid the process.

→ The SMS is pasteurised, supplemented with cellulose, has *Pleurotus* spawn added, then is transferred into aerated and sealed bags.
- The exact type of cellulose depends on availability, but a cellulose supplement with a large surface area (such as newspaper) is likely to decrease spawn colonisation time in the recycled substrate.
- Spare capacity in a growing room or Phase 2 tunnel is required for the pasteurisation.

→ Optimal results for growing oyster mushrooms will be obtained by increasing temperatures during incubation. Ideally, there would be a dedicated growing space with these conditions available for exotics.

→ Oyster mushrooms are harvested and then sold through normal distribution channels.



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Business case in brief

The project team consulted experts from industry and reviewed academic literature to identify two key observations:

1. Australian grown *Agaricus bisporus* SMS **roughly matches the growing requirements** of *Pleurotus ostreatus* (oyster mushrooms);
2. Growing oyster mushrooms on used SMS is **most viable for small commercial growers** that are seeking new revenue streams and growers that are **currently earning no revenue or paying to have their SMS taken off-farm**.

Rationale	Challenge	Viability Assessment
➔ Growers with lower profit margins that are unable to achieve economies of scale can diversify into growing exotics such as oyster mushrooms. ➔ There is opportunity for more innovation as there are no current industrial suppliers of substrate for exotics in Australia. ➔ Supermarkets are currently seeking increased supply of exotic mushrooms for Australian grown produce. Imported exotics are mostly available in Asian grocery stores and restaurants. ➔ The largest grower of exotics in Australia currently lacks the necessary resources to expand scale of production. ➔ As the price of wheaten straw has risen, oyster mushroom growers have resorted to using alternative waste streams as substrates. This has produced inconsistent mushroom quality.	➔ If unable to use "fresh SMS", very few (if any) growers currently have access to weathered SMS, and it is difficult to set aside sufficient land space for weathering/desalination of large quantities of SMS. ➔ Desalination of SMS is likely to take at least two years. ➔ Growing conditions of *Agaricus* mushroom farms are not necessarily compatible with *Pleurotus* growth - separate growing rooms may be required. ➔ Many suitable cellulose supplements, such as wheaten straw and cottonseed hulls, are either too expensive or not readily available. ➔ The industry is still expanding *Agaricus* production capability. Production of exotics diverts resources from primary operations.	**Growing oyster mushrooms on SMS is only viable when the cellulose supplementation price is more than the SMS sale price.** ➔ Oyster mushrooms sell for approximately 3x the price of *Agaricus bisporus*, and vary little in price throughout the year. ➔ Harvesting and management of exotics is more expensive than *Agaricus* farming, with lower yields (*although exotic growers are reluctant to share cost information*). ➔ Current oyster mushroom growing substrate price is more than the highest sale price of SMS (i.e. $17/t of SMS).

Field Trial

A field trial was undertaken to test the technical feasibility of reusing SMS as a substrate for the growth of oyster mushrooms. Proof of technical feasibility is essential for the viability and implementation of this solution in the industry.

Overview of field trial

The trial was modelled on a study conducted by Wageningen University (Netherlands), which found that *Pleurotus* could grow on 100% recycled SMS, although yields decreased by approximately 30% and mycelia colonisation was 50% slower.

Following feedback from industry experts, a cellulose supplement was prescribed to counteract this expected decrease in yield and slow mycelium growth.

Stage 1 - Sample A

Stage 1 - Sample B

Stage 1 - Sample C

Experimental Procedure

1. SMS was provided by Parwan Valley Mushrooms: Sample A was fresh SMS, Sample B was SMS weathered outside for 1 year and Sample C was SMS weathered outside for 5 years. All spent substrate was re-pasteurised prior to use in the trial.
2. The trial was conducted in Melbourne with a local horticulturist and oversight provided by Tim Adlington from Parwan Valley Mushrooms and AMGA.
3. The trial was conducted in two stages::
    a. Stage 1: oyster spawn was applied at a ratio of 10% of total weight (higher than applied by industry) to 10% cellulose supplement with A, B and C sample preparations, to produce indicative baseline results. Following initial positive results with Sample B, a Stage 2 trial was initiated.
    b. Stage 2: Spawn was added at 1% total weight to 5 kg bags for each of the SMS samples (A, B, C) and prepared with addition of 10%, 20% or 30% of a kitty litter cellulose supplement, to produce 9 samples. For each sample, mycelia uptake was measured by visual comparison of photos of each log (taken twice weekly with a fixed-position camera).
4. Fruiting occurred in the fruiting chamber under semi-automatic conditions, and a slight reduction in relative humidity (down to ~85%) and a temperature of approximately 15 deg C. Fresh air exchange occurred twice daily.
5. Mushroom “wet weights” were to be recorded as the SMS had already been pasteurised. This was not a true measurement of biological efficiency but was still a useful measure to quantify the efficiency of the trials.

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Results of field trial

Results

The bioefficiency of the process could not be determined because fruiting could not be efficiently achieved at commercial spawn rates. Thus, the technical feasibility of growing oyster mushrooms on recycled SMS could not be confirmed.

Sample A - fresh SMS:

➔ No spawn growth occurred in the substrate at 1% spawn rate.

Sample B - SMS weathered 1 year:

➔ In the Stage 1 trial, fruiting of the mycelium occurred for the 10% spawn rate (*Figure - upper right panel)* - inoculation to pinning took 35 days.

➔ At the 1% spawn rate, slow but consistent growth over 6 weeks was observed, however for all supplement levels (10, 20, 30%) coverage was insufficient for the fruiting process to commence (*Figure - lower and upper left panels).*

➔ These results mirror the growth challenges reported in the aforementioned Wageningen University study.

➔ Since fruiting did not occur in the 1% spawn rate samples, the effect of recycled SMS on yield quality and bioefficiency could not be determined.

Sample C - SMS weathered 5 years:

➔ Sample C with 1% spawn rate showed patchy spawn growth and a lack of appropriate coverage by the mycelium for fruiting.

Sample B with 1% spawn rate / 10% cellulose

Sample B with 10% spawn rate / 10% cellulose

1% spawn rate samples

Recommendation and next steps

Recommendation ⊗ **Do not proceed**

Technical feasibility could not be proven under trial conditions for a spectrum of fresh and leached SMS samples. Therefore, this solution is not recommended to proceed.

The rationale and business case for growth of exotic mushrooms on waste SMS is sound, particularly for small growers currently earning no revenue or paying to have their SMS taken off-farm. Further investigation and trials to prove feasibility could be undertaken by these grower groups.

SMS (fresh or leached) may not be the most suitable substrate for the growth of exotic mushrooms. For growers that wish to continue exploring the feasibility of this solution, this risk should be balanced against other options for the use of SMS.

For those growers with intent, next steps are:

1. Rerun trials with fresh SMS after manually washing out the salts, at spawn rates less than 10% of total weight, and utilising fully optimised growing conditions.
2. Substitute kitty litter with different cellulose supplements that have greater surface area (e.g. shredded newspaper), to reduce overall density in bags.
3. Increase supplementation levels to 50% if still economically viable given current prices.
4. Consult with project team to discuss in-depth trial procedures and supporting academic literature.

6

Insect bioconversion

Feeding SMS and mushroom stems to black soldier fly larvae for bioconversion into animal feed and soil additives

Solution 6

Insect bioconversion

Mushroom waste (stems and SMS) can be processed by black soldier fly larvae housed within a mobile insect farming unit located on-farm. Outputs would be grown larvae for potential sale as animal feedstock (which would first require rendering to reduce fat content) and frass (excreta of insects) for sale as fertiliser.

Insect bioconversion has the capability to use two waste streams with minimal disruption to current production systems. Further input is not required from the mushroom grower, as the technology provider manages all maintenance and harvesting.

A critical assessment of current technology providers was conducted as part of this project, with increased focus on the applicability and commercial readiness of their business models to the mushroom industry.

Business Case in Brief

- Desirability
- Feasibility
- Viability

Cost to implement

➔ $100k CapEx + $150 per tonne of waste as a processing fee

Viability ⊗ **Not viable**

➔ Without an established market for selling outputs, or a commitment from insect bioconversion operations to guarantee a minimum value per tonne of waste to growers, this solution has limited viability.

Recommendation ⊗ **Do not proceed**

➔ Current business model of insect bioconversion operations does not offer enough confirmed benefit to growers.

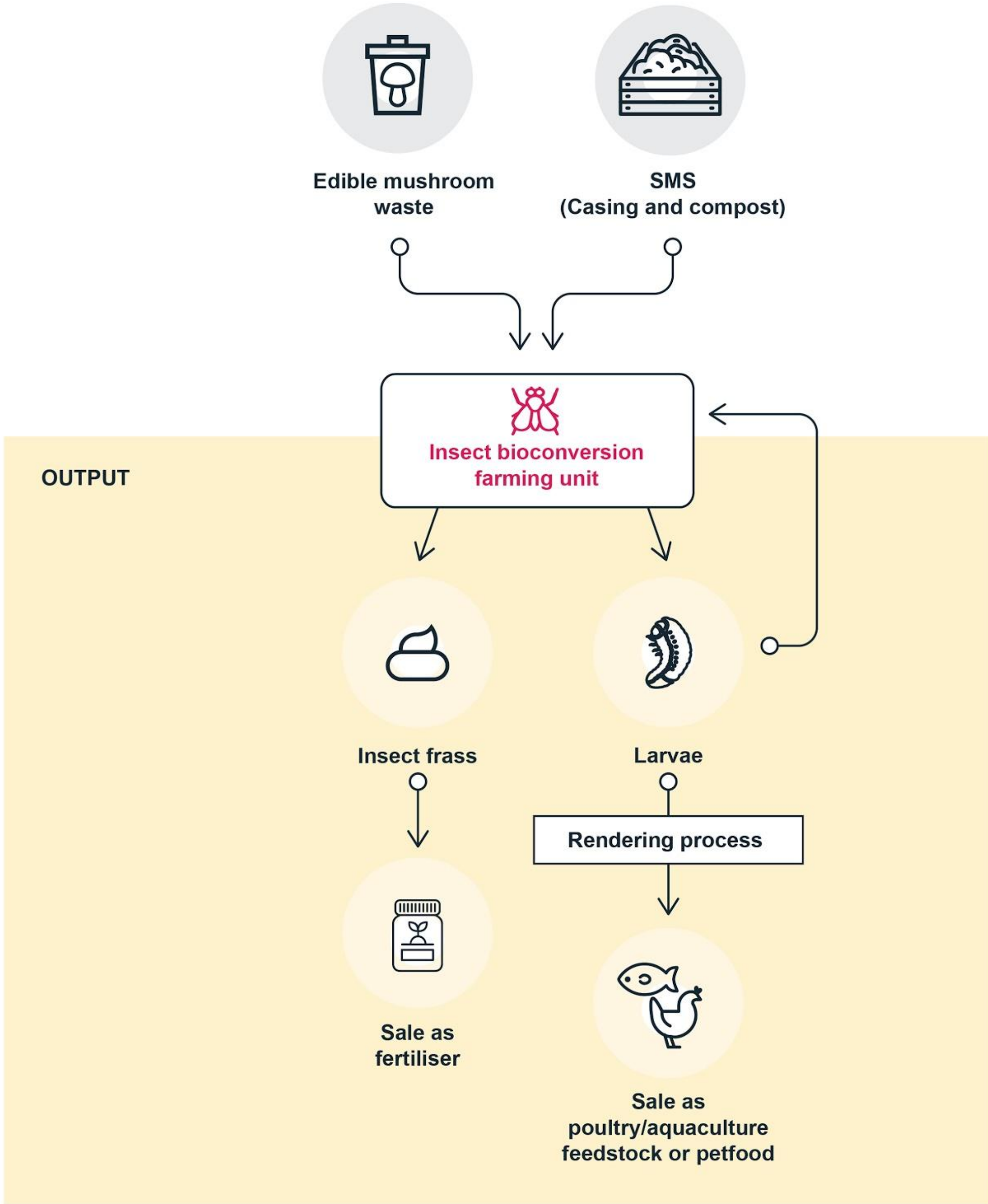
➔ Requires demonstration of contracted demand for insect larvae and frass products, providing more certainty of a workable business model.

Insect bioconversion

How does it work?

Potential changes to the process

- ➔ Mobile insect farming units are constructed to order and delivered to the mushroom farm.
- ➔ SMS and edible mushroom waste are loaded into the sealed, modular unit.
- ➔ These waste inputs are processed on-site through fully automated insect farming units.
- ➔ Within the unit, black soldier fly larvae consume the mushroom waste as feedstock. This is an aerobic process, with the waste being constantly turned, making it difficult for pathogens and bacteria to live within the unit.
- ➔ The larvae consume multiple times their body weight in waste each day and are bioconverted into insect protein and manure (frass) on a daily basis.
- ➔ After approximately 20 days, the larvae have grown considerably and are either harvested for rendering and use as poultry or aquaculture feedstock, use as pet food, or returned to the breeding cycle as adult insects to continue processing mushroom waste.
- ➔ The frass can be sold as a nutrient-rich soil conditioner/fertiliser.



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Business case in brief

For the technologies assessed, there is **upfront CapEx** for the modular unit and a **continuing "waste disposal fee"** for the processing of the waste. This solution is viable for mushroom growers **only if sufficiently high prices for the sale of insect larvae and frass** are achieved and that **revenue is shared with the mushroom growers.**

	Viability overview	Challenges	Assessment
Sale of insect larvae	➔ Quoted larvae sale price from the technology owner is $1500-1700/t. ➔ Initial trial indicated that conversion ratio of SMS is 6:1, so 167 kg of larvae are produced per tonne of SMS, equal to approximately $250/tonne of SMS. ➔ Initial trial indicated that conversion ratio of mushroom stems is 4:1, so 250 kg of larvae are produced per tonne of stems, equal to approximately $375/tonne of stems.	➔ There is currently no established market for selling insect larvae as an additive for pet food, or as poultry or aquaculture feedstock. ➔ No current capability in Australia to render larvae to reduce fat content. ➔ Even when the rendering process becomes possible, the potential for breaking into the feedstock market is unknown. The sale price is unknown, but could presumably be estimated based on competing feeds and their nutritional profiles.	**A fee for a waste disposal service is not viable for mushroom growers. The only model that is likely to be viable is an arrangement where a sizable percentage of the revenue from rendered larvae and frass sales is returned to the farm.** ● If the approximate service fee for processing the waste is $150/tonne, then larvae sales could produce an additional $160/tonne. ● A proportion of profits from frass and larvae sales would need to be returned to the farm to offset the purchase cost of the farming unit ($100k) within a 3-5 year payback period. Given the uncertainty in the markets and sales value for these outputs, a minimum value per tonne of waste returned to the mushroom farm would be the preferred option. **Possible alternative options include**: ● Frass is returned to the mushroom grower for use as a compost additive. ● The mushroom grower receives carbon credits for disposing of their waste via insect farming. ● The partnership could be undertaken as a joint venture.
Sale of insect frass	➔ Quoted frass sale price from the equipment owner is $110-120/t. ➔ Technology providers do sell some frass output to cottage farmers and have been in discussion with horticulture suppliers. ➔ Conversion rate of SMS and stems to frass is unknown.	➔ There is currently no established market for selling insect frass as a soil, compost, or fertiliser additive. ➔ The potential commercial sale price of insect frass is unknown.	

Recommendation and next steps

Recommendation ⊗ **Do not proceed**

Insect bioconversion of mushroom waste is not an economically viable option for disposal of waste from the Australian mushroom industry. A service fee charged per tonne of waste and capital expenditure on the farming unit is unlikely to be a viable model for the industry at current SMS sale prices.

The potential to offset this cost by growers participating in profit sharing from sales of the output products of bioconversion (frass and larvae) is encouraging. However, there is no reliable market for these end products at present.

For those growers with intent, next steps are:

1. Vet different business models with technology owners - potential for joint revenue-sharing arrangements for insect bioconversion of mushroom waste.
2. Monitor development in markets for rendered larvae and frass.
3. To provide more accurate information on potential sale prices, arrange testing to determine:
   - ➔ Conversion ratios of SMS and stems
   - ➔ Nutritional content of insect frass

7 Recycling CO_2

Replacing the existing CO_2 supplementation of greenhouses and algae farms with the CO_2 emitted during cultivation of mushrooms

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Solution 7

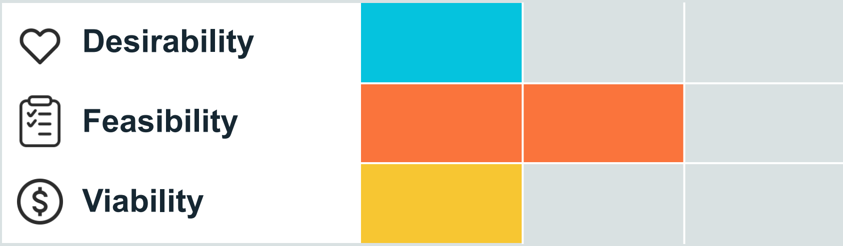
Recycling CO_2

Excess CO_2 from the mushroom farm is captured during the growing process for immediate transfer or storage and transportation to greenhouses and algae farms.

CO_2 from the mushroom farm is utilised at greenhouses and algae farms for a fee, while allowing both businesses to reduce their carbon footprint.

A global search of available academic research and consultations with greenhouse and algae farm experts was conducted; these informed the high level financial model and recommendations for this solution.

Business Case in Brief



Cost to implement

➔ $60 per tonne of Phase 1 compost used during the mushroom growing cycle

Viability — **Not viable**

➔ For utility gas prices lower than $22/GJ, recycling CO_2 into greenhouses is not financially viable.

Recommendation — **Do not proceed**

➔ Technically feasible but difficult to create a viable business that is sufficiently beneficial for mushroom farmers to warrant investment in necessary equipment.

➔ CO_2 from mushroom farms is not a sufficiently desirable input for greenhouses and algae farms to justify investment in new equipment and changes to current processes of CO_2 supplementation.

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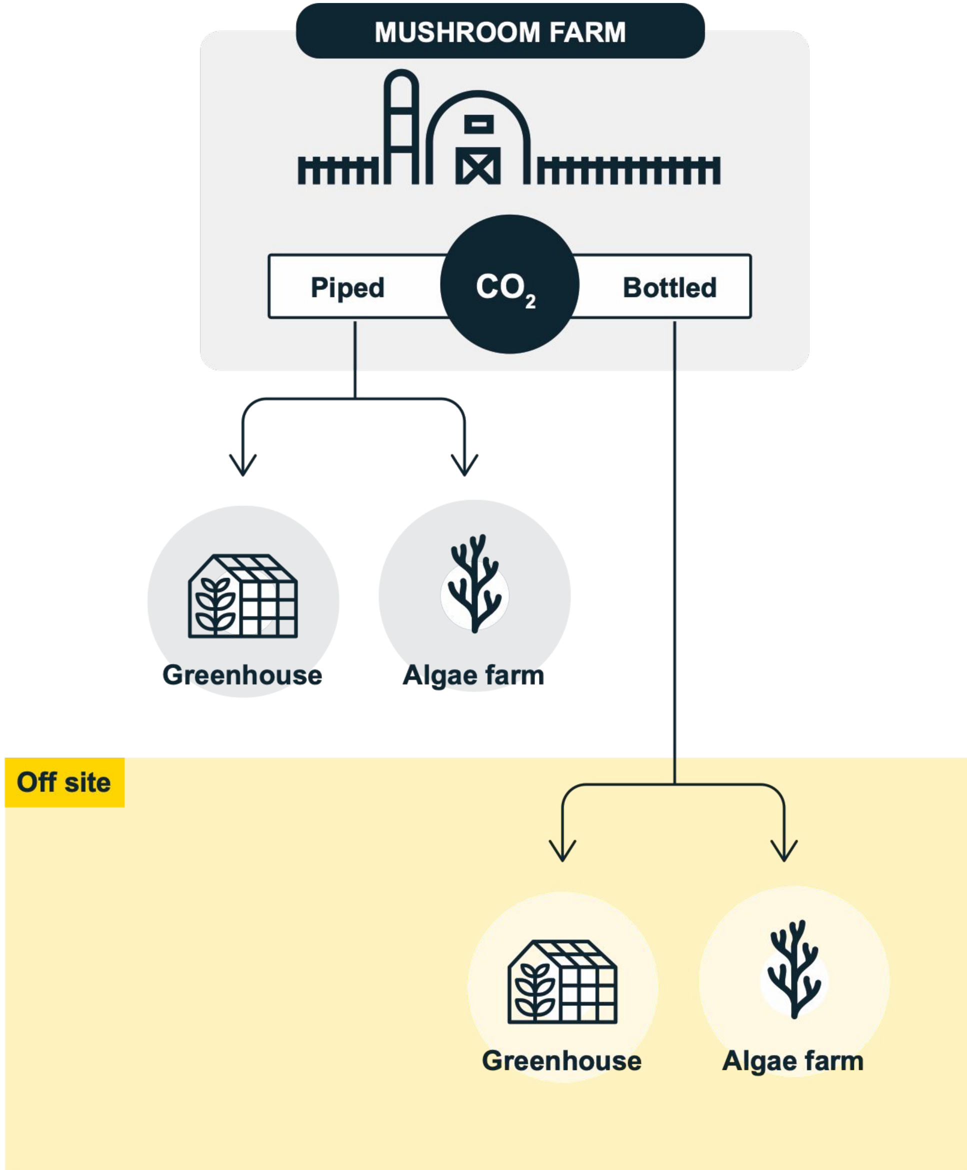
Recycling CO_2

How does it work?

Potential changes to the process

- ➔ Growing process of mushrooms remains unchanged, with 7 air exchanges per hour to manage CO_2 levels in the rooms when the mushrooms are actively growing.
- ➔ A carbon capture system is installed into current ventilation systems to capture CO_2 from exhaust vents released from growing rooms.
- ➔ If a greenhouse or algae farm is nearby, captured CO_2 is transported there via pipeline.
- ➔ If these sites are more distant, CO_2 is compressed into cylinders for storage and transport.
- ➔ The supplied CO_2 is integrated into the greenhouse or algae farm through existing CO_2 supplementation equipment.



CO_2

Recycling CO_2

Business case in brief

With current technology and equipment, recycling CO_2 into greenhouses and algae farms **is technically feasible** but **is not urgently desirable** for those operations. There is currently **no pressing need for alternative sources of CO_2 supplementation** for greenhouses or algae farms.

The project team worked to understand the needs of both industries, assess feasibility overlaps, and ultimately, identify hurdles to implementation and misalignments between the waste of the mushroom farm and the needs of the end customer.

Rationale	Feasibility overlap	Challenges
➔ For every tonne of Phase 1 compost used during the mushroom growing process, approximately 580-590 kg of CO_2 is released into the atmosphere.	➔ Air expelled from a mushroom growing room contains 1800 ppm CO_2 - tomatoes for instance, can increase yield with only 1500 ppm CO_2. ➔ Assuming 20 g CO_2/m^2 bed/hr produced during growth cycles, and maximum plant CO_2 uptake rate at 7 g/m^2/hr, a 500 m^2 bed mushroom farm would be able to support a 1429 m^2 greenhouse operation.	➔ Most CO_2 released during the mushroom production process is during the Phase 1 composting process but it is unsuitable for greenhouse operations because of the ammonia and volatile hydrocarbons in the waste air. ➔ Supplemental CO_2 should be pure or of very highly quality. Noxious gases such as carbon monoxide, ozone, nitrogen oxides and ethylene may damage the plants, as will sulphur impurities.
➔ CO_2 enrichment of greenhouses and algae farms in Australia depends on the use of fossil fuels - creating future challenges around regulation and rising fuel prices.	➔ Various CO_2 capture, cleanup, compression, storage, transportation, handling, delivery technologies and commercial systems are available to decrease algae farm and horticultural reliance on fossil fuels.	➔ The greenhouse CO_2 enrichment system is normally included in a typical hydronic heating system (i.e. even with supplemented CO_2, the greenhouse will still need heating). ➔ Currently, CO_2 emissions are not being metered at mushroom farms and greenhouses, and there are no regulations in place (or in sight) for excess emissions or credits for emission reductions.
➔ CO_2 is a limiting factor in both greenhouse and algae cultivation.	➔ CO_2 is actively expelled from mushroom growing rooms in order to keep CO_2 levels at 1300-1800 ppm.	➔ In the current market and environment, the value placed on nitrogen and phosphorus is much higher than for carbon, and the preference is to provide an overarching solution for C, N and P supplementation. ➔ Temperature and light take precedence in the construction of greenhouses and in plant growth.

Feedback from industry, academia and experts

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The project team **consulted with greenhouse and algae farm experts, private enterprises and researchers** across the world to more fully comprehend potential feasibility and viability synergies between the two industries.

Greenhouse experts

CO_2 uptake rates by plants depend heavily on prevailing temperature and light levels

Supply needs to be reliable and constant, and the quality of CO_2 needs to be very high without noxious gases that will damage plants

Commercial greenhouse production requires efficiency and controllability of technologies that do not unduly add additional labour

Researchers

Alternatives for CO_2 enrichment were explored by the greenhouse industry but interest was lost when natural gas prices dropped

Many industries produce CO_2 but storage and transport possibilities, match in quantity, and the price of CO_2 make the business case challenging

For greenhouses, liquified CO_2 is still more likely to be economically viable than CO_2 transfer from mushroom farms

Algae farms

The requirement for CO_2 is on a project-by-project basis - for some farms, CO_2 is less of a restriction

Sequestering CO_2 from a coal-fired power plant was successfully trialled, but lacked commercial viability after the carbon tax repeal

It is important to understand the drivers of the carbon usage and the ability to incorporate nitrogen and oxygen as well

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Viability by the numbers

Utility gas prices would need to be substantially higher than $22/GJ for this solution to be financially viable to the end users of the CO_2 and the mushroom growers.

It is likely that the end users of the CO_2 would need to subsidise the integration costs and pay a fee per tonne of CO_2 for this solution to be viable to the mushroom farmers.

Future trends that could increase viability

- ➔ Increases in gas prices.
- ➔ Reintroduction of carbon credits, penalties on carbon emissions, or subsidies to decrease carbon emissions.
- ➔ Advancement in technology readiness level of CO_2 capture and storage that bring down costs.
- ➔ Location rather than grower type is a more important consideration. However, big growers that have high CO_2 output, or those that already have or are looking into greenhouse or algae farming ventures, may find it easier to justify the investment.
- ➔ The use of the SMS, edible mushroom waste, washdown water and excess heat from mushroom farms at greenhouses and algae farms could increase the viability of their integration.

Viability assessment

Utility gas generation of CO_2	
Price to produce 1 tonne of CO_2	**$141.09**
Total CO_2 cost - 1 hectare greenhouse	**$80k**
Supplementation with liquified CO_2	
Price to produce 1 tonne of CO_2	**$170**
Total CO_2 cost - 1 hectare greenhouse	**$96.5k**
Projected cost of recycled CO_2 (direct transfer)	
Price to produce 1 tonne CO_2	**$264**
Total CO_2 cost - 1 hectare greenhouse	**$150k**

Assumptions:

- CO_2 in a 1 hectare greenhouse is raised to 1800 ppm with a standard 70 cubic metre per hour generator.
- Retail gas price = $12/GJ.
- CO_2 is maintained at this level 24 hours/day x 365 days/year.
- Recycled CO_2 cost assumes CapEx and OpEx on per tonne of CO_2 basis.

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Recommendation and next steps

Recommendation ⊗ **Do not proceed**

Recycling CO_2 for use in greenhouse or algae farms is not a viable revenue-gaining option for disposal of mushroom waste.

This solution is technically feasible but difficult to create a viable business that is sufficiently beneficial for mushroom growers to warrant investment in the necessary equipment.

At current utility energy prices, CO_2 is not a sufficiently desirable input for greenhouses and algae farms to change their process of CO_2 supplementation.

For those growers with intent, next steps are:

1 Connect with project team's experts in horticulture and algae farm industries to assess feasibility and desirability for your location and needs.

2 **Feasibility**

- ➔ Assess integration as an option only if the greenhouse is in close proximity to the mushroom farm and/or the horticultural grower is looking to build a new location.
- ➔ Focus specifically on greenfield sites where large scale heating is unnecessary.
- ➔ Match horticulture products to the 1800 ppm CO_2 currently expelled from mushroom growing rooms.

3 **Viability**

- ➔ Engage with greenhouse and algae farm industry if gas prices rise above $22/GJ or if the carbon tax is reintroduced.

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Edible shelf life extender

Edible coating applied to fresh mushrooms to extend shelf life and reduce costs and spoilage

Solution 8

Edible shelf life extender

A water-soluble & edible coating based on silk-protein that has been shown to increase shelf life, reduce waste, and decrease operational and storage costs of various fresh fruits and vegetables.

The coating creates an invisible barrier that regulates the exchange of oxygen, water vapour and slows microbial growth. The objective of this work is to determine the effect of the coating on Agaricus mushrooms.

The team reviewed the current scientific progress in shelf life extending technologies and processes, and identified case studies of successful adoption across various industries. A world-first trial with the US-based technology owner, Cambridge Crops was conducted & potential commercial pathways utilising this technology were explored.

Business Case in Brief

Desirability

Feasibility

Viability

Cost to implement

- ➔ Projected cost to utilise the edible coating is $0.10 per kg of fresh mushrooms.

Viability Viable

- ➔ Viability is supported through 3 circumstances in which growers can increase revenues from their product 1. Increased price to purchasers 2. Operational cost savings 3. Expand sales opportunities for P+3 or P+4 mushrooms

Recommendation **Inconclusive**

- ➔ Promising feasibility, but application to current supply chains, customer demands, regulation and optimal formulation of the product require further investigation.
- ➔ Work with technology owners to further refine product specs to mushroom industry needs
- ➔ Regulatory hurdles represent an existing barrier for immediate adoption

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Why extend the shelf life?

Despite scientific efforts over several decades, **there has been limited progress in increasing the shelf life of fresh *Agaricus bisporus* mushrooms.** The project team investigated several new and exciting discoveries in an effort to maximise the opportunities in this space.

Rationale

- ➔ Over a third of the world's food is either wasted or lost - 1.3 billion tonnes of food per year
- ➔ With the world's population expected to reach 10 billion people by 2050, shelf life extending technologies will be necessary to ensure that food growers can meet the demands of the 21st century
- ➔ Shelf life extending technologies help to reduce the need for wax and chemical additives to food
- ➔ These technologies will also limit the need for single use plastics to increase shelf life - possibly leapfrogging the need for investments in biodegradable and compostable plastics and films
- ➔ Certain applications can reduce the need for cold storage, saving energy and resources for the growers and consumers.

*https://thespoon.tech/market-map-food-waste-innovation-in-2019-version-1-1/

Before identifying a technology or process, the project team researched and categorised global efforts to extend the shelf life of mushrooms, this included all four of the *Preservation and Packaging - Top Companies Addressing Food Waste in 2019** (image at right - Appendix viii).

PRESERVATION & PACKAGING

Previous Efforts	Results
Modified Atmosphere Packaging	Little consensus on conditions and benefits, susceptible to temperature abuse
Modified humidity packaging	Reduced humidity results in more weight loss
Washing - used commercially to reduce browning and improve food safety	Inconclusive as it can make some mushrooms more susceptible to bacterial blotch and increased enzymatic browning, and in others it whitens and reduces food safety risks
Irradiation to prevent bacterial blotch	Benefits found in research studies - although cost, insufficient penetration into packed punnets and consumer acceptance may be issues
Pre-harvest irrigation with $CaCl_2$	Benefits demonstrated in laboratory research
Various active agents targeting enzymatic browning or microbial blotching	Limited to laboratory research. Chemical-based solutions may raise health and ecological concerns
New packaging materials - e.g. Sira-Flex Resolve by Sirane (UK)	Packaging already optimised for its purposes. Consumers are seeking less packaging

Edible coatings - How do they work?

Edible coatings are emerging as a promising post-harvest treatment for the horticultural industry. The coatings **form a barrier to gases and moisture** and **can also serve as a carrier for additional active agents** such as antimicrobials and enzyme inhibitors.

In the fight against food spoilage and waste, edible coatings have emerged as an eco-friendly, sustainable technology that requires minimal processing and handling.

Mushrooms are rapidly perishable produce because of their high water content, respiration rate and lack of cuticle. Edible coatings help to mitigate these challenges by forming an invisible barrier on the produce, helping to retain moisture and slow respiration rate.

Cambridge Crops

Earlier this year, Cambridge Crops was identified by Bill Gates as one of the top companies working in this space, receiving millions of dollars in investment from top venture capital firms in the United States. Cambridge Crops utilises a silk fibroin (the protein from silk cocoons) as an edible coating.

The company has already demonstrated success in perishable food preservation, with applications in whole produce (e.g. avocados), ready to eat food, meat and seafood. **The coating slows respiration, extends firmness, prevents oxidation and dehydration, and prevents microbial growth.**

The company is still in the process of gaining FDA approval in the USA (approximately 12 months away). However, the mushroom industry could lead efforts to establish regulatory approval in Australia.

Key technology capabilities

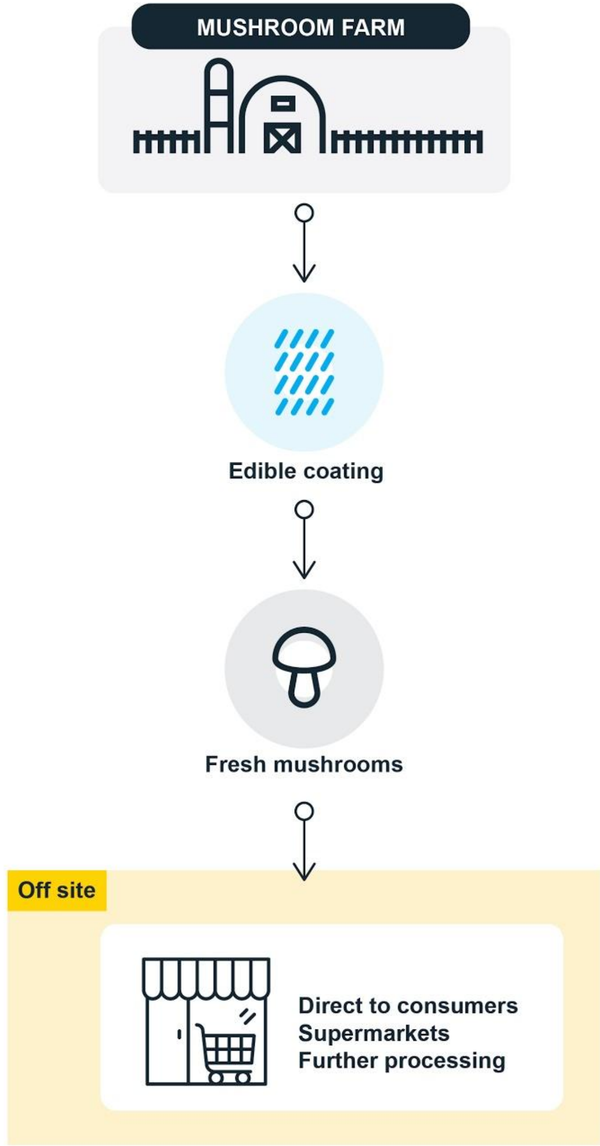
- ➔ Odourless, flavourless and transparent layer that is less than 0.01mm thick when applied.
- ➔ Does not require an added plasticiser to achieve desirable malleability.
- ➔ Forms a selective barrier between a perishable item and the external environment, reducing water and oxygen permeability.
- ➔ Allows functional versatility through incorporation of additional agents.
- ➔ Extends shelf life - reduces or even eliminates the need for conventional cold chain management employed for a particular perishable product.
- ➔ Allows the product to withstand a greater degree of deviations or fluctuations in temperature, moisture, mechanical stress and light exposure.
- ➔ Effective in preserving both climacteric produce (which ripens through ethylene production and increased cell respiration, e.g. apples, bananas and tomatoes) and non-climacteric produce (e.g. berries and grapes).

Edible shelf life extender

Changes to the process

The following table describes the process by which a technology like Cambridge Crops' could be used in the Australian mushroom industry, how this technology would change the process, and any potential risks those changes would pose to the business.

Process in brief	Risks
➔ Product is powdered and mixed with water to create a shelf life extending solution. ➔ Either immediately before or during harvesting, the proprietary solution is applied via spray or bath ➔ Creates an invisible, edible coating on the outside of the mushrooms with no change to taste, smell and texture ➔ Coating material can be incorporated into the pre-harvest irrigation/rinse system and sprayed on mushrooms ➔ If mushrooms are sliced, coating is applied after slicing ➔ The coating must be allowed to dry on the mushrooms before further packaging and transportation. ➔ Sold through normal distribution channels with the same temperature requirements	➔ Incorporates a novel but still developing technology into a process that requires commercial scale and capabilities. ➔ If cost savings cannot be captured, price increases must be passed along to the customer - "Is the customer willing to pay more for this?". ➔ Any price increases will need to account for the possibility of slower harvesting times due to the application of the solution. ➔ Production becomes dependent on reliably sourcing the powderised silk protein input.



Viability by the numbers

Edible coating companies represent an early stage investment opportunity with massive growth potential, and exclusive use within the Australian mushroom industry could help insulate domestic growers from future international competition.

Overall assessment

There are several key determinants underpinning the viability of this solution for the Australian mushroom industry:

1. Producers pass along the cost of the edible coating to the customer + margin. Only viable if supermarkets and/or end consumers are willing to pay more for a mushroom with increased shelf life.
2. The use of coating results in operational cost savings for the mushroom industry.
3. Increased shelf life expands export opportunities. Exclusive partnership agreements could also limit the threat posed by future fresh imports.

Key issues to address affecting viability

1. Regulatory approvals in US and AU
2. Stakeholder acceptance of coating. (this includes consumers and retailers as the main groups)
3. Technology access and licensing details (to be negotiated with owner)

While further testing would be required to guarantee their validity, the project team created a high-level model of potential operational cost savings

High level assessment of cost savings

Mushroom average sale price received by grower, $/kg	$4.50
Labour cost, % of mushroom sale price	33%
Saturday labour cost vs Monday-Friday	1.5x
Sunday & public holiday labour cost vs Monday-Friday	2x
With coating: labour cost saving, $/kg	$0.20
With coating: plastic and energy saving, $/kg	$0.06
Coating price, $/kg of mushrooms coated	$0.10
Net saving for growers, $/kg of mushrooms sold	**$0.16**

Assumptions

1. The coating limits the need for refrigerated storage throughout the value chain
2. Limits the amount of harvesting and transport on weekends at penalty rates.
3. Reduces the need for plastic packaging - benefitting the bottomline, the environment, and generating a positive consumer marketing story.
4. Equal numbers of mushrooms are harvested each day of the week.
5. Coating (Mon-Fri) delays Saturday and Sunday harvesting to Monday
6. Use of the coating results in no changes in mushroom average selling price or transport costs.
7. No new capital cost is required.
8. The only new operating cost is the cost (price) of the coating material. No extra labour is required for mixing or application.

Mushroom shelf life trial:

Cambridge Crops

The project team and Cambridge Crops conducted the the first trial in the world utilising and edible shelf life extender technology and agaricus bisporus mushrooms

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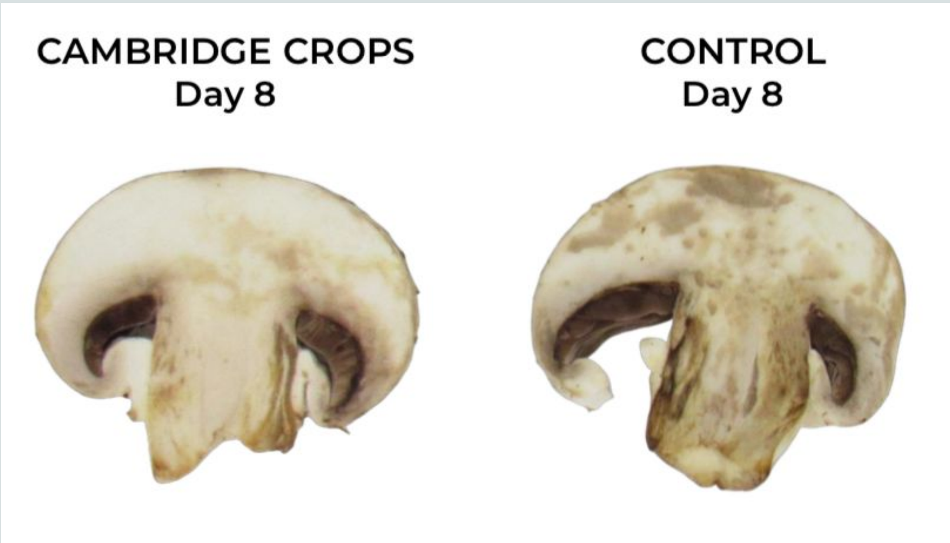
Trial overview

Designing a field trial - Considerations & rationale

- ➔ After consultation with industry and current shelf life extending technologies and processes in the mushroom industry, the project team selected mushrooms sliced and whole White Button and Swiss Brown mushrooms
- ➔ Harvesting "grades" provided by Australian supermarkets were utilised to determine the reliability and freshness characteristics of both the control and test group of mushrooms
- ➔ Due to time and logistical constraints, the trial was conducted in the United States at Cambridge Crops' lab utilising American grown mushrooms



Sliced White Button Mushroom Category

Trial protocol

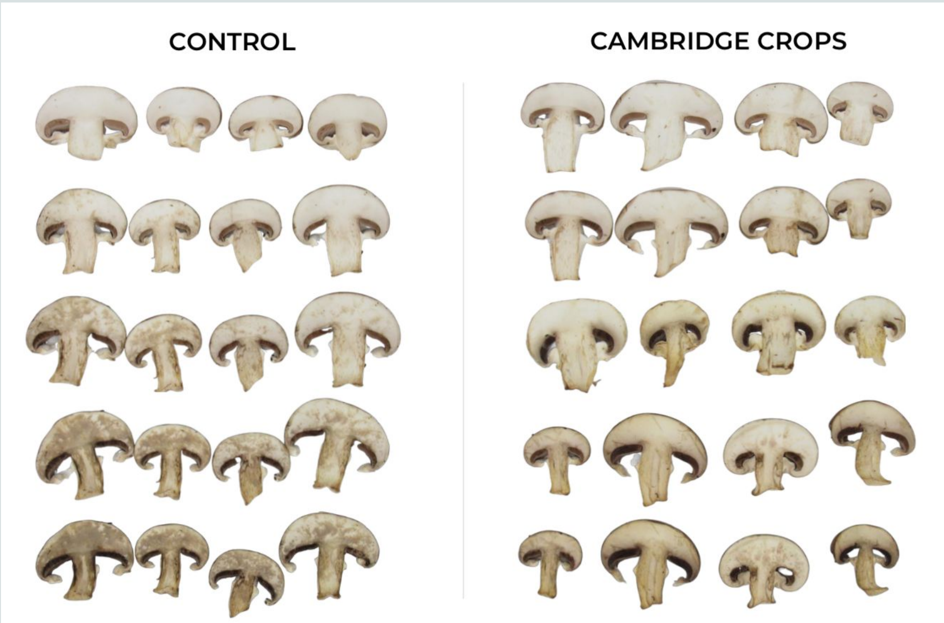
1. Delivery of mushrooms 2 days after harvesting (P+2) from Pennsylvania, USA to Cambridge Crops' lab in Cambridge, Massachusetts USA
2. In total, Whole White Button Mushrooms (5lb), Whole Cremini (Brown Swiss) Mushrooms (5lb), Sliced White Button Mushrooms (5lb), Sliced Cremini (Brown Swiss) Mushrooms (5lb) were sourced for the trial
3. Whole and sliced mushrooms were brushed clean and placed at 2C until processed.
4. Mushrooms were coated 1 group at a time (24 samples per group), dried until there is no drip (making sure not overdry)
5. Pieces were placed into styrofoam trays, imaged, and weighed while on the tray (weight per tray).
6. Wrapped with plastic overwrap and stored at 4C fridge
7. Qualitative image assessments and mass loss per tray were conducted throughout the duration of the trail, providing assessment on days Pick + 6 (P+6), Pick + 8 (P+8), Pick + 10 (P+10), and Pick + 13 (P+13)

Edible shelf life extender

Results Snapshot

- ➔ Overall, Cambridge Crops demonstrated an ability to slow the spoilage breakdown in whole and sliced Agaricus bisporus
- ➔ Efficacy was most notable in sliced swiss brown, where Cambridge Crops improved discoloration, hood splitting and overall rot
- ➔ In addition, Cambridge Crops improved overall marketability in three of the four varieties tested: sliced Swiss brown (33% increase in marketable samples at day 8), sliced white (13% at day 8), and whole white (5% at day 8)
- ➔ Scientifically there is evidence of a positive effect. Further work needs to be done to tailor the formulation and application to maximise the preservation effect.

Sample of Sliced Swiss Brown Results



An assessment of the technology's ability to reduce the spoilage of agaricus bisporus mushrooms was based on one **quantitative factor (mass retention)** and one **qualitative factor (marketability)**

Mass retention of test group vs. control at conclusion of testing

Sliced White Button	**-25%**
Whole White Button	**+4%**
Sliced Swiss Brown	**+3%**
Whole Swiss Brown	**+6%**

Marketability of mushrooms at P+10

Sliced White Button	Marketability*	**+13%**
Whole White Button	Marketability*	**+5%**
Sliced Swiss Brown	Marketability*	**+33%**
Whole Swiss Brown	Marketability*	**+5%**

**Mushrooms deemed as marketable were classified as either Grade A or Grad B*

Recommendation and next steps

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Recommendation **Inconclusive**

While edible shelf life extenders are an exciting opportunity and the products assessed and trialed during this project yielded positive results, the pathway to significant operational cost savings or new revenue is undetermined.

More time is necessary on the part of the technology owners in order to progress necessary regulatory approval and product development to meet the exact requirements of the industry at scale

Edible shelf life extenders may be a product best suited for the customers - (i.e. applied by the supermarket)

For those growers with intent, next steps are:

1. Further collaboration with technology owners to refine the formulation, test new application methods, and define supply chain integration
2. Engage with current customers in order to assess the desirability of a plastic free, edible shelf life extender
3. Gather regulatory advice on status of candidate technology and others
4. Continue to explore other companies and products in this space as consumers will continue to seek reductions in plastic packaging

Path to Phase 4

This report synthesises numerous insights, technology reviews, field trials, site visits, expert opinions and desktop research into a set of potential solutions. Their suitability for application in the Australian mushroom industry was assessed. Four solutions are recommended for further exploration and industry adoption.

This final section of the report is a review of the next steps for each of the recommended solutions. Finally, we offer six important insights for the Australian mushroom industry to help guide the next steps in this innovation journey.

Australian Mushroom Industry Future

Identification of the trends and insights below was instrumental to the selection of the **four solutions recommended for continued development** by this report. In the Appendix (Appendix ix), there is a list of additional concepts that could potentially be explored. These concepts align with these trends and the scope of this project, but they were not fully developed during Phase 3.

Mushroom R&D spending is declining globally.

➔ The most direct result of this is a decreased likelihood that technology and processes will emerge that can drastically reduce costs to the business (i.e. there is very little effort globally to explore replacement inputs such as wheaten straw and peat casing).

Adding value to waste takes a back seat to other daily operations.

➔ There are currently very few incentives for mushroom growers to change their waste disposal practices. The goal of this project has been to focus on the waste challenges grounded in the current industry experience.

Australian mushroom growers are global leaders in the price per tonne of waste.

➔ Australia is one of the few, if only, developed nations that earns revenue on the vast majority of mushroom waste. In order to achieve even higher returns, the focus should be on high risk-reward opportunities that initially might only be able to handle a small portion of the industry's waste.

Dealing with large quantities of waste is inherently expensive.

➔ If the mushroom industry wants to find solutions (beyond recycling) that increase operational cost savings or revenues for their large quantities of waste, they must be prepared to invest in capital intensive equipment to meet this objective.

Environmental issues shift in and out of focus for state and federal governments.

➔ There is a dependable, long term trend of increased legislation and improved customer awareness regarding environmental issues in developed nations. Continued improvement in environmental and sustainability performance is good for business.

The price of raw input materials are continually driven by scarcity and becoming more expensive.

➔ This means that mushroom production waste streams will be worth more and costs to the business are projected to increase.

Solutions: Next steps

Xinova and the project team's participation in each of the solutions is highly specific to the next steps needed to advance their development. The team is able and willing to participate in any of the broader project next steps listed below or project-specific next steps located in the tables on the following slides:

- ➔ Participate and lead pilot efforts with new equipment or processes assessed during the project.
- ➔ Foster and develop relationships with key partners. Our experience in understanding your business as well as technology suppliers enables us to fast track discussions and translate key requirements.
- ➔ Some growers may wish to pursue specific advice for their unique situation. We are well positioned to tailor our advice through various financial and business models and our network of technology experts.

Solutions: Next steps

Solution 1
Recycling SMS
Recycling SMS back into the production process as either casing or compost

Desirability

Feasibility

Viability

→ Commit to developing this operational capability as a competitive advantage.

→ Growers proceed to site-specific trials at their own facilities utilising expertise gathered during trials conducted as part of this project:

- Recycling SMS as casing - engage advocate grower to create 3-4 small piles of SMS - turn regularly, and assess EC in one year.
- Recycling casing as casing - conduct a trial using manually separated casing to confirm results from academic literature before engaging with casing separator manufacturers.
- Recycling compost as compost - conduct an additional industrial trial of recycling compost for compost to confirm results at a larger scale and for Phase 1 of the composting process.

Solution 2
Pelletiser System
Investment in capital equipment for non-thermal dewatering of SMS for on-site energy or off-site sales into energy and fertiliser markets

Desirability

Feasibility

Viability

Dewatered SMS

→ Producers can work with the project team to organise an auger at their facility, and to match the equipment and drying chemical to the substrate and needs of the business.

→ Consider partnership with players or affiliated businesses to spread the cost of capital and maximise its utilisation.

→ Apply for alternative funding from ARENA and Bioenergy Australia to subsidise CapEx (this can be facilitated by the project team).

On-site energy

→ Engage biomass boiler equipment providers with results of testing conducted as part of this project.

→ Project team can provide full plan cost model and adapt dimensions depending on needs of the business and available co-input (if possible).

Off-site sales

→ Test pelletised SMS with sourced co-input for calorific value and elemental composition. The project team can make introductions to energy off-take and pellet fertiliser companies in the local area.

→ Map suitable co-inputs available in the region of the production facility.

Solutions: Next steps

Solution 4
Mushroom powder

Drying and powderisation of edible mushroom waste into a shelf-stable powder for the high value food (HVF) market

Desirability
Feasibility
Viability

- Align interested mushroom growers within a region to form an alliance with shared commitment, investment and risk appetite.
- Determine venture model and hence appropriate partner capability requirements
- Engage in product development within alliance capabilities and establish consumer price points.
- Develop brand and marketing strategies.

Solution 8
Edible shelf life extender

Edible coating applied to fresh mushrooms to extend shelf life and reduce costs and spoilage

Desirability
Feasibility
Viability

- Further collaboration with technology owners to refine the formulation, test new application methods, and define supply chain integration
- Engage with current customers in order to assess the desirability of a plastic free, edible shelf life extender
- Continue to explore other companies and products in this space as consumers will continue to seek reductions in plastics in their packaging

Appendices

Project approach - Converging on solutions

Initial Search

Considerations

- Geography
- SIAP guide rails
- Payback periods
- Regulations and markets
- Technology readiness

Approach

- Understand market demand
- Diverse market readiness
- Align with intent

Pest management
Crop production
Food for animals and fish
Nanocapsules and biopesticides
Bioremediation
Green composting
Pelletising
Valorisation of compost
Anaerobic digester (AD)
Horizontal integration
HPP
TVP
Mushroom crisp/puff
Mushroom soup
Mushroom burger
Mushroom extract
Enhance probiotic performance
Building materials
SMS packaging
Mushroom leather
Peat for industrial purposes
Paper and breath freshener
Reuse compost
Reuse casing
Decrease fermentation times of alcohol
Lignocellulosic enzyme extraction

Ideation Workshop

Considerations

- Partnering
- Previous experience
- IP

Approach

- Highlight solution areas
- Incorporate SIAP feedback
- Focus on product potential

Biorescue
Funguschain
Anaerobic digester
Exotic Mushrooms
Horizontal integration
Reuse casing
Reuse compost
SMS packaging
TVP
HPP
Mushroom puffs
Mushroom jerky
Mushroom powder

Legend:
Process
Product
Technology

Solution Areas

Mycelium Materials and Co-Products	Energy and Fertilisers	High Value Foods	Recycling waste for further production

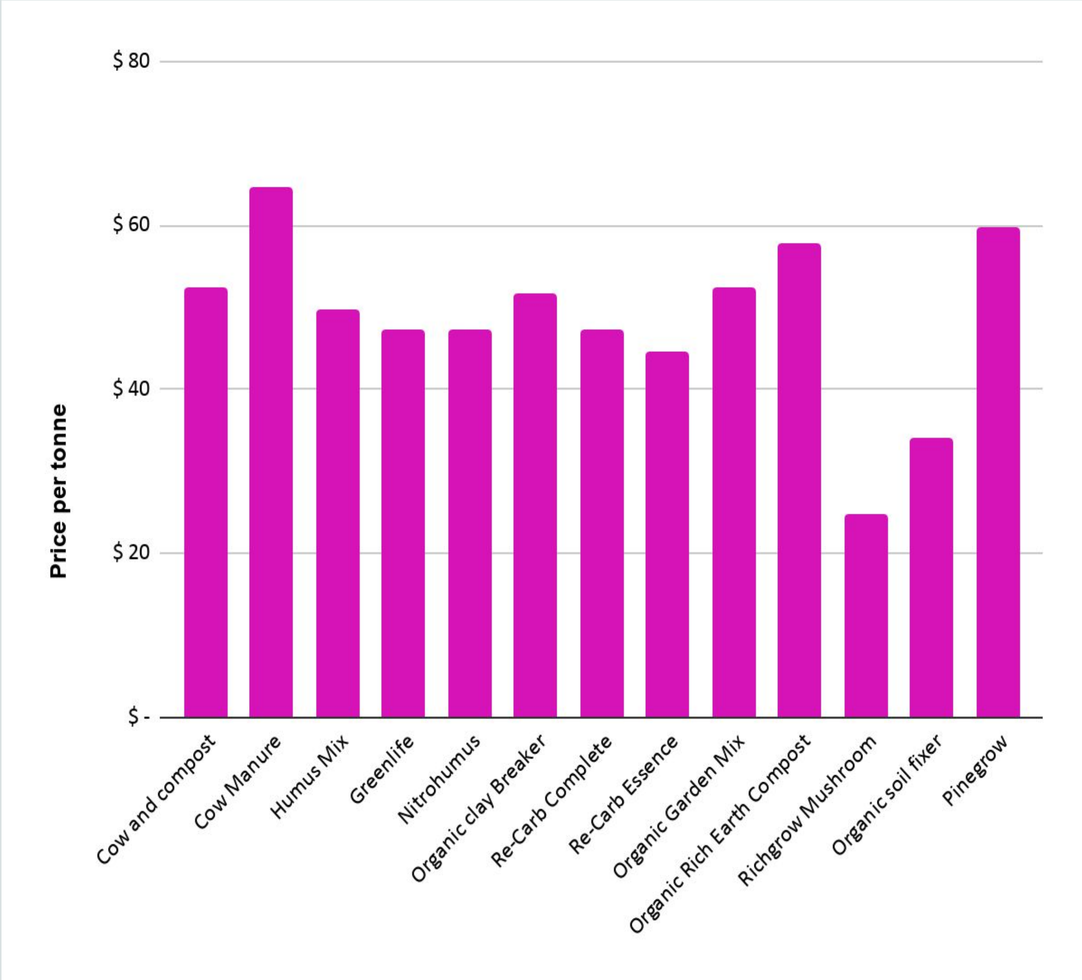
Pelletiser System

Dewatering for off-site sales

After consultation with experts in the pelletised fertiliser industry the project team developed the following insights to inform the Step 1 business case:

1. “SMS is soil amendment that is sold at compost price” - should be earning 2-3x current prices
2. A locked-in price for dewatered SMS before investment would de-risk this step and the rest of the pelletisation process
3. Mushrooms use only a small portion of the many nutrients available within the growing substrate
4. Many of the introduced nutrients are available within the SMS post harvesting
5. SMS with its high trace lement and major cation element content should be considered as a high value soil amendment, not just a compost
6. Marketing of this product needs to be reassessed in order to ensure higher prices
7. The contained nutrient, humic and organic content provides increased benefits from its application into various horticultural markets
8. The biggest barrier to earning a higher price on SMS is moisture content - most soil amendments and fertilisers are sold at <25% moisture

Below is a survey of the estimated bulk input prices for competing products in the soil amendment market



On-site energy with free co-input + 1:1 Govt incentive

Pelletiser for on-site energy from SMS aligns with government grant funding selection criteria. On-site energy with a free co-input and 1:1 government grant is financially viable for large growers at current and decreased gas prices and smaller growers at gas prices 2x greater than current levels.

ARENA (Australian Renewable Energy Agency) Advancing Renewables Program (ARP): Development, demonstration and pre-commercial deployment projects. Grants between $100,000 and $50 million.

Pros

- ➔ Grant funding (not equity or debt)
- ➔ Up to 50% of capital cost (equipment & installation)
- ➔ "First movers" likely to be rewarded
- ➔ For larger growers, government grant could facilitate larger scale pelletiser facilities, and in turn, be utilised as industry pilot plants for smaller growers

Cons

- ➔ "Development, demonstration and pre-commercial deployment projects." For first (novel) deployment only: no obvious source of grant funding for subsequent, replicated deployments. (Clean Energy Finance Corp has equity or debt funding)
- ➔ ARENA requires applicants to share knowledge with the renewable energy industry and other key stakeholders, such as the general public.

On-site energy generation, SMC + co-input + govt subsidy

Farm size, tonnes of mushrooms per week	Dry fert sale price, $/t	New CapEx, $	Utility gas price ($/GJ) to achieve 5 year payback
25	$41.20	$1,209k	$29.50
50	$26.00	$1,209k	$12.40
100	$3.30	$1,209k	$0.00

Assumptions

1. Same equipment, same capital, installation, maintenance costs as Option 2 and 3, installed once "Option 1" investment has been paid off
2. Pelletiser drying chemical cost: $0.
3. Brown coal dust is delivered to mushroom farm at no cost.
4. Spent mushroom compost: 65% moisture, net calorific value 4.1 MJ/kg (based on measurement).
5. Add 0.2 tonnes of brown coal dust (net calorific value 8.4 MJ/kg) to each tonne of SMC.
6. Dryer/granulator runs 60 hours/week and processes ALL available SMC, boiler/generator runs 24/7
7. Combined heat & power (CHP) system produces all required steam plus ⅓ of required electrical energy

Off-site sales with co-input

Path to Viability

Below are the results of the elemental analysis of the pellets (without a co-input) conducted for purposes of creating a high value organic fertiliser.

Sample Number (19088-1) – HRL Technology Group

Pellets		Pellets		
Elements	**%**	**Oxides**	**(sample) %**	**(Ash) %**
Si	**1.1**	SiO_2	2.3	38.3
Al	**0.08**	Al_2O_3	0.15	2.4
Fe	**0.06**	$Fe2O_3$	0.08	1.4
Ti	**0.01**	TiO_2	0.01	0.16
K	**0.46**	K_2O	0.55	9.1
Mg	**0.12**	MgO	0.20	3.4
Na	**0.08**	Na_2O	0.10	1.7
Ca	**0.86**	CaO	1.2	19.8
S	**0.10**	SO_3	0.24	3.9
P	**0.12**	P_2O_5	0.27	4.5
Ba	**<0.01**	BaO	<0.01	0.04
Sr	**0.01**	SrO	0.01	0.12
Cu	**0.01**	CuO	0.01	0.24
Mn	**0.01**	MnO	0.02	0.27
Cr	**<0.01**	Cr_2O_3	<0.01	0.01
Zn	**0.01**	ZnO	0.01	0.12
V	**<0.01**	V_2O_5	<0.01	<0.01
Co	**<0.01**	Co_2O_4	<0.01	<0.01
Ni	**<0.01**	NiO	<0.01	<0.01

SMS as a Fertiliser

The nutrient availability of SMS (table at left) is quite low compared to typical nutrient availability of fertilisers as depicted in **Appendix v.**

To create a high yielding fertiliser blend out of the SMS, further nutrients need to be blended into the SMS mix prior to sale. Fertiliser blending is complex and challenging, and the following factors should be considered:

1. **Moisture content** – Typically fertilisers are blended while dry (<15% H_2O).
2. **Region** - fertilisers must be matched to their region's soil deficiencies and plant needs. In general, however, Australian soils are deficient in phosphorus - making it a "high potential" co-input for SMS as a fertiliser
3. **Hygroscopic materials, adsorbents and absorbents** – Typical high nutrient fertilisers are hygroscopic (tend to absorb moisture from the air). If you mix these types of fertilisers into a wet substrate (like SMS) they will equilibriate and absorb moisture from the wet substrate. This absorption forms a slurry or cake that cannot be used.
4. **pH –** Typically, similar pH fertilisers should be blended with one another to prevent neutralisation of pH (i.e. mix high pH with high pH materials; low pH with low pH materials and neutral pH with neutral pH materials)
5. **Mechanical blending –** It is typical that fertilisers are blended by hand or mechanically through screw mixers, ribbon blenders and or cone mixers.
6. **Size –** Size of granules matter. In the fertiliser industry, granules are typically 2-6mm in size and can easily pass through a mechanical spreader. For composts, this material must be spreadable by hand or mechanical rakes.

Marketed Fertiliser Nutritional Content

List of Fertilisers	Nutrient content
Single Superphosphate	9% Phosphorus; 11% sulphur
Double Superphosphate	18 % Phosphorus; 10% sulphur
Triple Superphosphate	18 % Phosphorus; 10% sulphur
Urea	45-50% Nitrogen
Ammonium Sulphate	21% Nitrogen
Muriate of Potash (MOP)	50% Potassium
Sulphate of Potash (SOP)	40% Potassium
Di-ammonium Phosphate (DAP)	20% Phosphorous
Mono-ammonium Phosphate (MAP)	22% Phosphorous
Nitrophoska / Rustica	12% Nitrogen, 5% Phosphorus, 14% Potassium, 8% Sulphur, 3% Calcium, 1% Magnesium + Trace Elements
Processed Poultry Manure	1% Potassium, 0.5% Phosphorus, 1% to 1.5% Nitrogen
Phosphate Rock	20% Phosphorous, 20% Calcium
Amorphous Silica	30-55% Amorphous silica, 10% Calcium 5% Magnesium
Alfalfa meal	3-5% Nitrogen
Ammonium Sulphate	21% Nitrogen
Blood Meal	10-12% Nitrogen
Bone Meal	15-22% Calcium; 20-30% Phosphorous + Trace Elements
Boron	15-20% Boron
Chelated Iron	5-10% Iron - EDDHA
Corn Gluten	10% Nitrogen
Epsom Salts	10% Magnesium, 10-12% Sulphur
Fish Products	5% Nitrogen, 1% Phosphorus and 1% Potassium
Greensand / Glauconite	5-7% Potassium
Guano	20% Nitrogen + Trace Elements
Humates	35% Humic Acids
Kelp Products	1.5-4% Nitrogen, 10% Phosphorus,
Wood ashes	5-10% Potassium, 1-2% Phosphorus
Gypsum	20-25% Calcium, 15-28% Sulphur
Lime	>90% Calcium – used as pH buffer
Sulphur	>20% Sulphur – used as a pH buffer

Anaerobic digester

Equipment to facilitate change

AD technology is advancing and increases in the bio-efficiency of ADs would greatly expand their viability for the Australian mushroom industry. Currently, **three passive digester types** exist, in which inputs are fed into the digester and the effluent (AD sludge) flows out the other end of the process with **minimal intervention or energy.** The **total solids content of the co-input** will likely determine the digester type required.

Covered anaerobic pond

A deep impoundment, essentially free of dissolved oxygen, that promotes anaerobic conditions. The process typically takes place in deep earthen basins. Ponds are used as anaerobic pretreatment systems. Anaerobic lagoons are not aerated, heated, or mixed.

Recommended total solids content : 1-3%

Mix digester

Complete Mix digesters produce biogas from a variety of organic wastes that have a total solid content of 3-10%. To enhance production, the waste is heated and mixed to maintain a high level of bacteria. An impermeable material covers the top of the vessel to keep the biogas from escaping. Components include a mix tank, a digester tank, effluent storage structure and biogas utilisation system.

Recommended total solids content: 3-11%

Plug and flow digester

An engineered, heated, rectangular tank that treats feedstocks with 11–20% solids. Feedstocks are introduced to the digester as a "plug". As the plug moves through the digester, it is acted upon by anaerobes and biogas is produced. Feedstocks with less than 11% solids content do not perform well in plug flow digesters due to the lack of fibre.

Recommended total solids content : 11-20%

Viability assessment

Viability assessment		Challenges
1. SMS only for on-site energy and sale of digestate	**Viable -** if sale price of digestate is >$10/t, AD has capacity >0.68 t/hr, current SMS sale price is <$1/t and gas prices are >$11.99GJ/t	→ Only viable at highest CapEx thresholds → Without significant government subsidy, CapEx likely excludes smaller players in the industry - unlikely to break the expected 5 year payback period. → Sale of anaerobic digestate "sludge" is widely publicised as the fix for financial viability, but Australia currently lacks a commercial market for digestate, and this would be particularly challenging if using wastewater.
2. SMS and co-input for on-site energy	**Viable** - if energy prices are >$11.99GJ/t, current SMS sale price is <$1/t, and AD has capacity >0.68t/hr	→ Only viable at highest CapEx threshold and if current gas prices increase. → SMS (with or without casing) and co-input will need to reach **net calorific value of 6-7 MJ/kg** of input to be viable. → Very few co-inputs can provide this energy value at scale (see p.44).
3. SMS and co-input for on-site energy and sale of digestate	**Viable -** if AD has capacity >.68t/h, gas is >11.99GJ/t and SMS <$20/t **|** If scale of digester is >.34/t/h, gas is >$11.99GJ/t and SMS <$1/t	→ The uncertain market, consistency and value of SMS plus co-input as a fertiliser, as well as the costs and land requirements involved in monitoring, stabilising, storing and QA testing of digestate. → The restrictions imposed by regulations for handling, storage and application of co-digested wastewater (for instance) and the prospect of managing co-digestate for sale as a fertiliser may make anaerobic co-digestion unattractive as an SMS disposal solution.

$ in: net CapEx, $/t mushrooms/year	$ out: net saving, $/t mushrooms produced		
	$12/GJ, SMS $10/t	$12/GJ, SMS $0/t	$15/GJ, SMS $0/t
$50	-$7.0	-$5.0	-$5.0
$100	$2.0	$14.0	$17.0
$150	$11.0	**$32.0**	**$37.0**
$50	-$6.0	-$5.0	-$5.0
$100	$4.0	$10.0	$15.0
$150	$19.0	**$30.0**	**$41.0**
$50	-$5.0	-$4.0	-$3.0
$100	$16.0	**$22.0**	**$27.0**
$150	**$41.0**	**$53.0**	**$63.0**

Available technology - a global search

As part of this search, the project team engaged and assessed each of the four companies listed in the *Preservation and Packaging - Top Companies Addressing Food Waste in 2019**. After an assessment of all four, the team **initiated a trial and business case assessment with Cambridge Crops.** Below is an overview of our engagement with other companies in this space.

Company	What they do?	Why they don't fit?
StixFresh	All-natural coating on a sticker made up of specially sourced wax and other natural ingredients, that creates a protective layer around the produce. Slows down the ripening process and can extend the freshness of many fruits by up to 14 days	➔ Currently only tested on fruits and vegetable with a "peel" ➔ Requires a change to how the product is presented (i.e. one sticker on each mushroom) ➔ Designed to impede bacterial and fungal growth, so does not address respiration issues inherent to the mushroom ageing process ➔ Technology yet to be proven effective without needing to be applied directly to the product - i.e. can it be applied to the punnet before the mushrooms are packaged?
Evertron	Makers of a modified refrigerator, known as the Freshtron.Panels on the top and bottom emit 50,000 waves per second, drastically increasing the shelf life of fruits and vegetables and halting the ripening process	➔ Expensive piece of hardware that is not particularly scalable to the size of commercial mushroom farms ➔ Technology is best suited for trucking companies and supermarkets ➔ Produce loses the added value once it leaves the Freshtron refrigerator, making it difficult for the mushroom grower to increase sale price ➔ Evertron is yet to demonstrate the technology is able to slow the ripening process in the growing rooms at a commercial scale, but could be big opportunities for the mushroom industry to reduce labour costs and control harvesting times
Apeel Sciences	Makers of an edible coating made of lipids and glycerolipids intended to mimic the peel, or skin, of fruits and vegetables. Their coating can already be found on avocados at Costco in the USA	➔ Coating requires substantial alterations and customisation to the selected fruit or vegetable ➔ Product is best suited to produce that already has a skin or peel ➔ Apeel Sciences charge a paid service to apply their technology to new industries. Essentially charging once for the development and again for the product itself

*https://thespoon.tech/market-map-food-waste-innovation-in-2019-version-1-1/

Potential next steps

Our recommendations contain a set of solutions for dealing with the mushroom waste challenge. Beyond what we were able to focus on during this project, there are excellent opportunities to advance the mushroom industry:

- **Mycelium packaging**. This solution area was eliminated at the end of Phase 3. This solution area potentially requires a greater tolerance to risk, but it has the potential to tap into rapidly growing markets such as eco-packaging and eco-building products. A project in this area would repeat our steps in Phase 3 and would build upon the research and trial information collected during the recycling of SMS for exotics included in this report.
- **Automation and digitisation**. With labour representing such a high proportion of costs, automation and digitisation should be seen as a significant opportunity. A project in automation would analyse business processes, identify areas where automation would unlock value, and identify technologies for (a) adoption, (b) adaptation to make them suitable, or (c) invention where they do not yet exist but the business case supports it.
- **Consumer behaviours**. Behavioural sciences and consumer technologies such as mobile connectivity and augmented reality are coming together to assist in growing markets and improving consumer experience. These could be used effectively in reducing consumer food waste, improving consumption experience and understanding changing attitudes to food, including sustainability conversations. A project in this area would develop and pilot a consumer experience aligned with industry goals such as market expansion.
- **Chitosan extraction.** This is a valuable health supplement produced from chitin, a polymer found abundantly in the cells of crustaceans and *Agaricus* mushrooms. Further investigation would need to be conducted to analyse the business case technical feasibility of producing chitosan from edible mushroom waste. Mushroom powder may be an interesting pathway to chitosan production, and chitosan could also be utilised as a dewatering agent in a pelletisation process. These would both require further investigation in a method similar to Phase 3 of this project.
- **Chlorine salt replacement.** Salt build-up was consistently identified as a hurdle during each part of this project when exploring new uses for SMS. Further work could investigate other materials that could replace chlorine salts (e.g. citric acid or probiotics) and could be used to limit the development of brown blotch.