Repurposing Grape Marc in Marlborough: The Way Forward

From Assessment of Options to Next Steps

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Summary

Five options for repurposing grape marc in Marlborough have been investigated in the techno-enviro-economic analyses presented in two reports[1] and at two fora[2]. The two fora were attended by wine industry representatives. A number of the participants attending the second forum have agreed to establish a Working Group. A first meeting is planned, to which representatives of the major peak bodies and wine industry groups will be invited. The Working Group will determine the option or options to take to Stage II development.

This study was initiated by the Marlborough District Council and is funded in part by them and by the Waste Minimisation Fund. The motivation to consider alternatives for repurposing grape marc has a number of contributing factors; (i), the quantity of grape marc is large, estimated in 2019 at 46,000 tonnes from 305,467 tonnes of pressed grapes, which produce an estimated 218 million litres of wine; (ii), the vineyard area is expanding rapidly, from 25,135 ha (2017) to 27,808 ha (2020). (iii), earlier attempts to compost grape marc led to prosecution of some operators for poor environmental outcomes; (iv), direct land-spreading of raw grape marc has arisen as the preferred activity but is not without environmental risk; (v), both direct land-spreading and composting require land and necessitate take-back arrangements with winegrowers; and (vi), neither composting nor direct land-spreading offer the opportunity to value add.

All five options investigated here avoid that risk. They are:

- best-practice composting;
- drying to make dried grape marc for sale;
- combustion to generate steam to make electricity;
- gasification to produce electricity in gas engines and excess heat; and,
- pyrolysis to produce biochar/charcoal and excess heat.

Some calculations are also included for comparison with direct land-spreading of raw grape marc. A number of these options have viable commercialisation pathways that balance positive environmental outcomes with volume reduction of grape marc and profitability. They all require capital investment. This report summarises the options and presents the next steps towards commercialisation. The Working Group will further assess and refine these options.

Approach

The study provides a techno-enviro-economic comparison. The techno- part details the processing steps, their size and complexity, the utility requirements, the discharges to the environment and the product volumes. Figures from this techno-analysis are crucial for the enviro- and economic analyses. Environmental analysis is focussed on the carbon footprint from discharges to air, including the emissions associated with construction, transport, facility operation and end-of-life. In some, carbon is sequestered, but in others it returns to the atmosphere through further decomposition. Discharges to water are assumed to be properly collected and sent for trade-waste treatment; long-term stockpile management is treated as equivalent to landfill management. Economic analysis investigates the viability of each process over a 25 year period, where initial capital cost and the annual operating and maintenance cost must be recouped with sufficient revenue to reduce the net present value to zero. The cost of capital is set at 5%. It should be noted that the economic analyses presented here are distinct from business cases. An economic analysis is a systematic exercise in identifying and analysing alternatives whilst a business case would need to be conducted to determine whether a particular course of action should be taken by a legal entity.

[1] The two reports on repurposing grape marc, Research Report & Project Synopsis Report are publically available on the Marlborough District Council website.
[2] February 21 and May 22, 2020

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1. The Goal of Repurposing

Grape marc is the residue that remains after the juice has been pressed from the grapes. It is both a resource and a problem. Repurposing is necessary, otherwise it becomes stranded in stockpiles which require storage and risk poor environmental outcomes. Over recent years, the repurposing activities in Marlborough have included the above agricultural stockpiling, small-scale composting, and direct land-spreading of raw grape marc. The dominant activity among these is now direct land-spreading of raw grape marc. Large scale composting was attempted earlier but resulted in practitioners being charged for non-compliance to environmental standards. Other ventures such as drying to make dried grape marc for sale and anaerobic digestion for biogas are currently being investigated but are not yet commercial. High value extraction of polyphenols is also undertaken commercially in Marlborough. This latter activity, while in itself does not reduce the volume of residue needing repurposing, is an essential part of a bio-refining industry around grape marc: a thorough analysis of value-adding opportunities by bio-refining is given in Chapter 2 of the Research Report.

The emphasis of this work is to investigate alternatives to current land-spreading and agricultural stockpiling, and complement the existing ventures, with an objective of repurposing 100% of the grape marc every year. Repurposing has the following additional functions:

- it maximises environmental benefit and minimises environmental risk;
- it adds value to the grape marc and provides a foundation for other processes to utilise by-products and add further value (i.e., the bio-refining concept);
- it provides co-benefits to Marlborough and other businesses; and,
- it maximises regional and wine industry reputation.

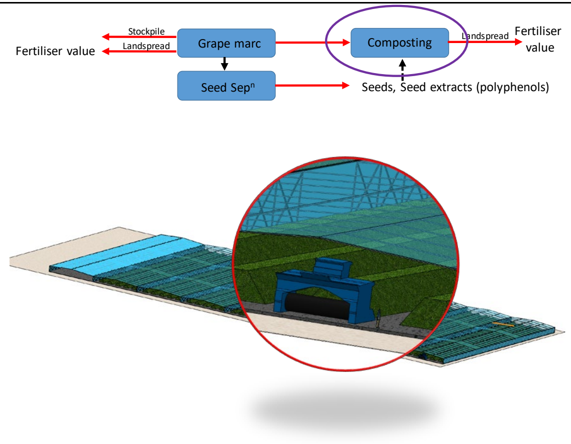
Another driver for change is the increasing transparency of environmental outcomes. An example is the rise of hyperspectral sensing, which is a relatively new technology that can detect spurious emissions from stockpiles and land. These methods are now transitioning from the research to the commercial arena, which means that air emissions of methane and nitrous oxide, which were once very difficult to detect, will be increasingly easy to pinpoint to their origin. As a case in point, New Zealand will assume mission control of the MethaneSAT satellite after its launch in 2023, which has the specific objective of measuring global methane emissions. It is also widely accepted that, in the past, otherwise invisible gaseous emissions have been under-estimated from agricultural sources and landfills. In future, it is expected that the New Zealand Emission Trading Scheme, in compliance with expected international obligations, will make producers accountable for these emissions. Therefore, the strategic decision with repurposing grape marc needs to balance both emissions profiles and risk with changing consumer preference for products with net-good environment outcomes.

2. Options Investigated

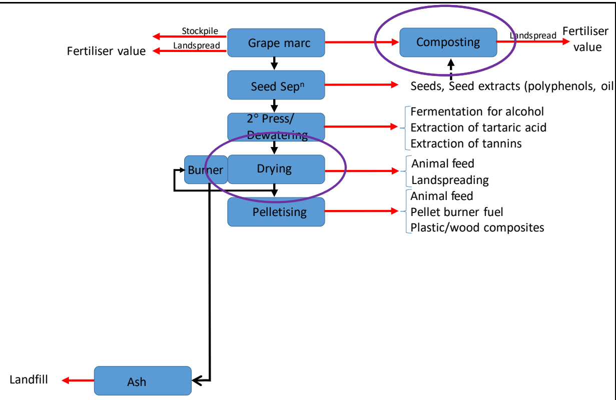
The current activities in Marlborough are listed in Figure 1(a). The alternative repurposing options all in involve drying, which is shown in Figure 1(b). The red arrows show the product streams. Clearly, including drying within the suite of activities greatly increases the opportunity to add value. These are discussed in detail in Chapter 2 of the Research Report.

Figures 1(c) includes the further three thermal processes: combustion to produce steam to make electricity in steam turbines, gasification for electricity in gas engines with excess heat, and pyrolysis to make charcoal which has a variety of product uses. Figure 1(d) shows the emissions associated with each of the repurposing options.

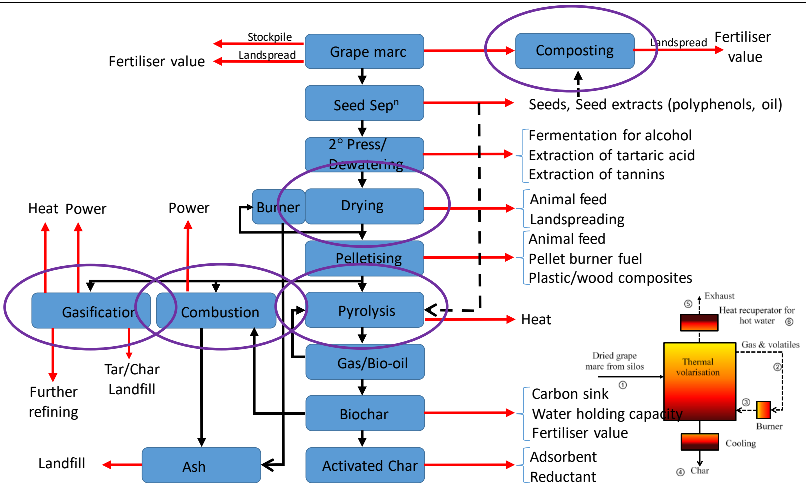
The study uses a basis of 70,000 tonnes of grape marc produced annually, which is more than the current production of *ca.* 46,000 tonnes, but represents a potential future amount with continued growth of the wine sector in the region.



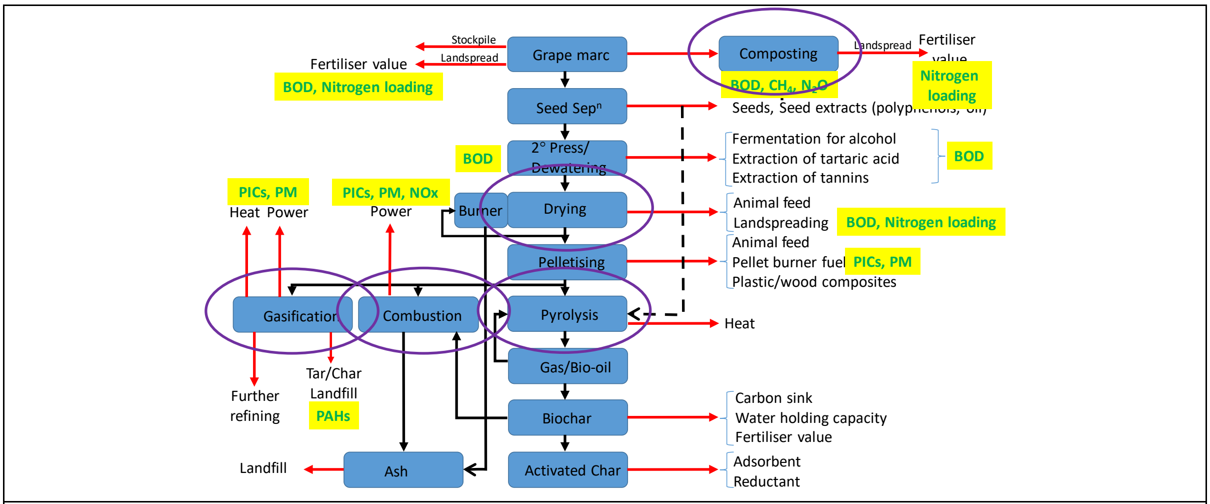
(a) Current activities in Marlborough.



(b) Adding drying to current activities, which provides opportunity to new value-add products.



(c) Adding drying and combustion, drying and gasification, and drying and pyrolysis, which provides both opportunity to new value-add products and reduce the volume of residue.



(d) Emissions associated with the activities. Abbreviations: products of incomplete combustion (PICs), biological oxygen demand (BOD), particulate matter (PM), nitrous oxide (N_2O), methane (CH_4), and polycyclic aromatic hydrocarbons (PAHs).

Figure 1. Schematic of the repurposing options investigated.

For each repurposing option, up to six scenarios were investigated, for which the detailed design assumptions and calculations are given in the Research Report. For this summary, a subset of the scenarios were selected and are shown in Table 1.

Table 1. Scenarios of the process configurations for grape marc repurposing. The numbers refer to the scenario of each option. See the Research Report for full details.

Scenarios	Explanation
Direct Land-spreading	Direct land-spreading repurposes the raw grape marc. It has no plant and therefore no capital costs but incurs an operating cost. At a regional level, it returns its fertiliser nutrient value to land in the same way as compost. The potential liability is BOD overload of soil, forming methane, nitrous oxide and leaching to waterways, the cost of which is not able to be estimated.
Best-practice Composting	Best-practice composting incurs capital costs, e.g., prepared land, leachate collection, cover to avoid rain events, and O&M costs for windrow turning. Compost is then land-spread to return its fertiliser nutrient value. Liabilities result from the in-built reliance on takeback agreements, and poor management of the composting operation, resulting in a rise in methane emissions.
Drying 3	Drying, involves mechanical dewatering, from 67% moisture to 50% moisture, prior to thermal drying. Some solids are lost in the pressate, which carries a high BOD, the treatment of which is costed as trade-waste. The result is that drying requires less energy, and so more dried grape marc is produced. Drying extends over 337 days.
Combustion 3	Combustion of dried grape marc from D3 is used to produce electricity over 337 days. No useful heat is produced. The residue ash is landfilled. At a regional level, the industrial fertiliser are required to replace the nutrients to the soil.
Gasification 3	Gasification of the dried grape marc from D3 is used to produce electricity and heat over 337 days of operation. The residue tar, char and captured particular matter is landfilled. The landfilled char contains sequestered carbon. At a regional level, no nutrients are returned to productive land and so industrial fertilisers are required.
Gasification 6	Gasification of the dried grape marc from D3 is used to produce electricity and heat over 337 days, but where the excess heat from gasification is recycled to the drying plant (i.e., this becomes a more integrated process) to reduce the fraction of dried grape marc that needs to be combusted in order to supply the heat for drying. The result is more dried grape marc entering the gasification plant, which produces more electricity.
Pyrolysis 3	Pyrolysis of the dried grape marc from D3 is used to produce biochar and heat over 337 days. The biochar contains sequestered carbon and retains some fertiliser nutrient value. Biochar can be sold for a range of uses. At a regional level, the missing fertiliser nutrient value not returned to soil must be replaced by industrial fertilisers.
Pyrolysis 6	Pyrolysis of the dried grape marc from D3 is used to produce biochar and heat over 337 days, but where the excess heat from pyrolysis is recycled to the drying plant (i.e., this becomes a more integrated process) to reduce the fraction of dried grape marc that needs to be combusted in order to supply the heat for drying. The result is that drying requires less energy, and so more dried grape marc is produced, and consequently more biochar is produced.

3. Comparisons

The options can be compared in a number of ways as highlighted in Sections 3.1 to 3.6. They are collated in section 3.7.

3.1 Reducing the tonnage

One of the major goals of repurposing is to redirect the raw grape marc into products or energy so that the tonnage of grape marc is reduced to zero. The tonnages produced from each scenario are shown in Table 2. The thermal options all involve drying, which is cheaper if the grape marc is first mechanically pressed to lower the moisture content from 67% down to 50%.; this produces a liquid with a high BOD (*ca.* 85 g/L) which is processed as trade-waste. The ash and gasification char produced in the thermal processes are sent to landfill.

Table 2. Tonnage reductions of the various options for repurposing grape marc. The most effective processes at reducing tonnage are given stars.

Options for Comparison	Physical Product	Product Tonnage	Liquid Tradewaste	Landfill ash/char
Direct land-spreading	Raw grape marc	70,000	-	-
Best-practice composting	Compost	22,960	-	-
Drying 3	Dried grape marc	20,717	24,566	181
Combustion 3	1 None	-	24,556	704
Gasification 3	2 None	-	24,566	2,176
Pyrolysis 6	3 Charcoal/biochar	7,689	24,566	181

3.2 Carbon footprint

Life cycle assessment (LCA) methodology has been used to calculate the carbon footprint, as detailed in the Research Report. The figures in Table 3 give the amount of equivalent carbon dioxide released for each activity compared to simple aerobic decay of grape marc, i.e., the hypothetical natural cycle where all organic carbon returns to the atmosphere as CO_2. Best practice composting approaches the hypothetical aerobic decomposition of biomass, but necessarily includes emissions associated with the building of the site and the use of trucks and the windrow turning vehicles. Making biochar, then putting it into soil, sequesters carbon to the extent that the emissions are 225 kg of CO_2 less per tonne of raw grape marc than would be emitted by hypothetical aerobic decay. This is a significant environmental outcome. If instead, the charcoal is sold as heating fuel or as an adsorbent, the benefit of carbon sequestration is lost. The right hand column shows the offsetting effect where grape marc is used instead of coal (e.g., to produce heat for a dairy spray dryer, or heat for a hospital or a school). In this case, because the factory, hospital or school, already uses a fossil fuel, the conversion to biomass means that an offset of the fossil fuel emissions can be claimed.

Table 3. Carbon footprint of the various options for repurposing grape marc. The most effective processes at reducing carbon footprint are given stars.

Process	Carbon footprint	Carbon footprint with offsetting of coal
	kg CO_2e/(tonne raw GM)	
Composting	20	20
Combustion 3	62	-161 4
Gasification 3	-12	-253 2
Pyrolysis 6	3 -225 [24[a]]	-256 1

[a] This bracketed figure is the carbon footprint when charcoal is sold as heating fuel, or as an adsorbent, rather than added to soil as biochar.

3.3 Risk and liability

Mitigating risk and liability are an important part of any business strategy. However, quantifying them is often difficult. Here, there is a clear need for more research into the risks of direct land-spreading of raw grape marc. This is because of the significant difference in land-spreading rate allowable under the Marlborough Environment Plan and the limit recommended by AgResearch in a 2012 report to the Marlborough District Council. The MEP limit on spreading raw grape marc, set at 200 kg nitrogen per hectare per year (200 kg N/ha/yr), equates to 42.6 tonnes of raw grape marc per hectare per year (42.6 t raw GM/ha/yr), which media reports show is being applied commercially. This figure is higher than the AgResearch recommendation that the limit not exceed 3 dry matter tonnes per hectare per year (3 t DM/ha/yr), which equates to 9 tonne of raw grape marc per hectare per year (9 t raw GM/ha/yr). (Raw grape marc has 67% moisture off the presses.) AgResearch warned that exceeding this limit risks biological oxygen demand (BOD) overload of the soil, with poor environmental and soil health consequences. Monitoring of sites currently being land-spread is recommended.

Composting, which produces a cured and stable product, does not have this BOD overload risk. The financial incentive to make compost rests with its lower tonnage and that, once cured, it is able to be stored. However, the benefit does not extend to reduced acreage for spreading, because composting only slightly reduces the nitrogen content. In fact, under the MEP, the maximum spreading rate of compost equates to 14.3 tonnes per hectare per year (to deliver 200 kg N/ha/yr). Notably, the current MEP nitrogen limit is also above the maximum recommended by AgResearch at 150 kg N/ha/yr.

Both activities necessitate land and so most likely require take-back agreements with winegrowers. If not, then stranded stockpiles result. Similarly, as producing dried grape marc results in similar tonnages to composting, not being able to sell the dried grape marc results in stranded warehouses of dried product. These are potential liabilities for winegrowers, pressors, composters and drier operators. The costs of stockpiling or storage are estimated to be equivalent to those of landfilling, \$135/t minus GST, as this is the known cost of proper management including site preparation, leachate collection, and methane collection and flaring. Agricultural stockpiles are permitted under the MEP, but without frequent turning, as done in best-practice composting, these will become anoxic with associated excessive but invisible methane emissions.

Thermal processing removes the environmental problems of poor practise in handling biological stockpiles. Combustion and gasification remove all biomass, leaving only well-understood streams, a liquid stream processed as trade-waste and ash and gasification char, which are all accommodated within the design and costed into plant operation. Biochar has a much reduced tonnage compared to compost or drying but, if unsold, may also carry a liability issue for plant operators and winegrowers. However, the default activity of land-spreading biochar carries enormous environmental advantage, which mitigates the risk.

Table 4. Comparison of risk and liability of the various options for repurposing grape marc. The most effective options at reducing risk and liability are coloured green and the least are blue.

Option / Risk and liability	Direct Land-spreading	Best-practice Composting 4	Drying 3	Combustion 3 1	Gasification 3 2	Pyrolysis 6 3
Carbon footprint of activity [with offsets]	Unknown	Small +ve	Medium +ve	Medium +ve [Large –ve]	Small –ve [Large –ve]	Large –ve [Large –ve]
Risk of unsold or non-repurposed product, i.e., stranded	Large	Moderate	Moderate	None	None	Small
Deferred cost of fertiliser replacement	None	None	Medium	Medium	Medium	Small
Risk of leaching	Yes	No	No	No	No	No
Risk of BOD overload of soil	Yes	No	No	No	No	No
Potential for additional GHG release	Yes	Yes	No	No	No	No

3.4 Process economic analysis

Each option is compared in Table 5 with respect to capital cost, plant operating and maintenance cost and the required revenue for the venture to be profitable over 25 years (see Research Report and Project Synopsis Report for more details). The gasification plant is the most technically complex and therefore the most expensive. Drying on its own is $5.1M and is included within the plant costs for the other thermal processing options.

Table 5. Process economic analysis for the various options for repurposing grape marc.

Option	Capital Cost	Operating & Maintenance Cost	Revenue[a] required to reduce NPV to zero over 25 years, $/yr
Direct Landspreading	-	@$10/t, $0.7M @$20/t, $1.4M @$30/t, $2.1M	$0.7M $1.4M $2.1M
Composting	$14.22M	$1.51M	$2.08M
Drying 3	$5.10M	$2.56M	$2.76M
Combustion 3 (incl. D3)	$31.27M	$3.90M	$5.15M[a]
Gasification 3 (incl. D3)	$76.73M	$3.78M	$6.85M[a]
Gasification 6 (incl. D3)	$90.72M	$4.24M	$7.87M[a]
Pyrolysis 3 (incl. D3)	$23.44M	$3.57M	$4.51M[a]
Pyrolysis 6 (incl. D3)	$27.93M	$3.93M	$5.05M[a]

[a]Required revenue includes the embodied costs of the drying plant.

3.5 Sources of revenue

Achieving the required revenue for profitability is a challenge for some of the options. For example, there is a shortfall in revenue of $5.94M/yr for gasification (to produce electricity in gas engines and excess heat for sale). On the other hand, drying on its own (to produce dried grape marc for sale as heating pellets) is predicted to range from profitable, yielding $1.21M/yr, to a small shortfall of $0.17M/yr.

All of these options are compared to direct land-spreading, which has costs somewhere between $10-$30/tonne of raw grape marc (involving trucking, spreading and ploughing). For 70,000 tonnes/yr of raw grape marc, the cost of the direct land-spreading is given in the first column, but this is ameliorated by its intrinsic fertiliser value, which results in a net range, from returning value of $0.47M/yr to costing $0.93M/yr. Given that the likely cost of land-spreading is nearer $30/tonne when all associated activities are included and that raw grape marc has *per se* no sale value, the activity is a net annual cost to winegrowers. In comparison, composting has a net cost of between $1.21-1.39M/yr and combustion (to make steam to generate electricity) has a net cost of $2.97M/yr. However, all thermal options that do not return grape marc to soil also carry the deferred cost of fertiliser, which landowners have to source separately. In a business, this deferred cost would not be borne by the electricity generator, but is recognised here as a net cost to the region.

Three scenarios of revenue generation are shown for pyrolysis to charcoal/biochar. (Note: the solid product of pyrolysis is charcoal which, when returned to soil, is called **biochar**. If used as heating fuel or as an adsorbent, it is called **charcoal**.) These scenarios reflect the range of uses of charcoal/biochar. They range from a net cost for biochar when added into soil to sequester carbon, at $3.86-3.93M/yr, to very profitable when used as an industrial adsorbent, at $6.87M/yr.

In summary, some options appear profitable while others have a shortfall. However, these figures need to be balanced by the potential benefits of environmental outcome, risk and reliability, and future expectations of fiscal and market drivers to improve environmental outcomes.

A more extensive discussion of these sources of revenue is contained in the Research Report and Project Synopsis Report.

Table 6. Sources of revenue for the various options for repurposing grape marc. The most profitable process options are given stars.

Option	Revenue[a] required to reduce NPV to zero over 25 years, $/yr	Revenue able to be earned, or intrinsic fertiliser value	Further costs	Net Revenue required to reduce NPV to zero over 25 years, $/yr	Deferred Cost
Direct Landspreading	$0.7M to $2.1M For spreading	$1.17M Fertiliser value	None	-$0.47M to $0.93M ★3	
Composting	$2.08M	$1.17M Fertiliser value	$0.23 to $0.69M For spreading	$1.21M to $1.39M	
Drying 3	$2.76M	$2.59M to $4.66M Dried GM heating pellets	None	-$1.90M to $0.17M ★2	$1.17M fertiliser
Drying 3 + Combustion 3	$5.15M	$2.18M Electricity	None	$2.97M	$1.17M fertiliser
Drying 3 + Gasification 6	$7.87M	$1.93M Electricity & heat	None	$5.94M	$1.17M fertiliser
Drying 3 + Pyrolysis 3 for Biochar	$4.51M	$0.71M Process heat & Fertiliser	$0.06M to $0.17M For spreading	$3.86M to $3.97M	$0.67M fertiliser
Drying 3 + Pyrolysis 6 for char heating pellets	$5.05M	$2.31M to $5.19M Char heating pellets	None	-$0.14M to $2.74M ★4	$1.17M fertiliser
Drying 3 + Pyrolysis 6 for Activ. Char	$5.05M[a]	$11.53M	None	-$6.48M[a] ★1	$1.17M fertiliser

3.6 Cost of emitting carbon in the NZ Emissions Trading Scheme

Environmental emissions are not currently monetised in agriculture or primary processing, except through the compliance cost of plant design needed to achieve the required stack concentrations and discharge allowances. However, in future, these are most likely to be monetised, driven by international accords and realised through the NZETS and other mechanisms. Indeed, the 2019 NZ Tax Working group led by Sir Michael Cullen stated that future environmental change will become fiscally driven.

This work determines carbon footprint against the global warming potential (GWP) impact category using Life Cycle Assessment methodology. This is just one aspect of sustainability. Nevertheless, if agricultural and primary processing emissions are included in the NZETS, at the current value of a New Zealand Unit ($26.50/ t CO_2e), Table 7 (upper) shows the cost or value. For example, composting is a net emitter so would cost $0.04M/yr, while putting biochar into soil is a net sequestration and so has a value of $0.42M/yr. The real value comes when grape marc replaces coal in an existing coal-fired plant, ranging from $0.30-$0.47M/yr across the options. Examples are dairy factories which use coal to generate heat for their spray driers, or hospitals or schools that may use coal for their heating. This is only a first mover opportunity because, once the coal has been replaced, offsetting is not possible.

The value of a New Zealand Unit is also expected to rise in line with international expectations. Future analysis of these will be part of any business case risk analysis. Table 7 (lower) highlights how costs or value change if the NZU rises to $100/t CO_2e.

Table 7. Cost or value of the carbon footprint for the various options for grape marc repurposing if entry is permitted within the NZ Emission Trading Scheme, at either the current value of a New Zealand Unit, \$26.50/t CO_2e, or at \$100/t CO_2e. Cost is positive and value is negative.

Process	Carbon footprint*	Environmental cost if in ETS @\$26.50/NZU	Carbon footprint* with offsetting of coal	Environmental cost if in ETS @\$26.50/NZU
		kg CO_2e/(tonne raw GM)		
Composting[a]	20	\$0.04M	20	\$0.04M
Combustion 3[b]	62	\$0.12M	-161	-\$0.30M
Gasification 3[c]	-12	-\$0.02M	-253	-\$0.47M
Pyrolysis 6[d]	-225	-\$0.42M	-256	-\$0.48M

Process	Carbon footprint*	Environmental cost if in ETS @\$100/NZU	Carbon footprint* with offsetting of coal	Environmental cost if in ETS @\$100/NZU
		kg CO_2e/(tonne raw GM)		
Composting[a]	20	\$0.14M	20	\$0.14M
Combustion 3[b]	62	\$0.43M	-161	-\$1.13M
Gasification 3[c]	-12	-\$0.08M	-253	-\$1.77M
Pyrolysis 6[d]	-225	-\$1.57M	-256	-\$1.79M

3.7 Choosing the best option

Choosing the best option is a matter of weighing the benefits against the costs. Table 8 collates the results of this analysis, alongside the rating stars previously used. Some options have a net shortfall in annual revenue needed to achieve profitability. Here, if winegrowers support the shortfall, every \$10 per tonne of support will raise \$0.7M towards the required revenue. To balance this with added earnings, Marlborough produces some 220M litres of wine per annum with current grape marc production. For the basis used in this work (a future figure) of 70,000 tonnes of grape marc, the wine yield will be *ca.* 330M litres. Therefore, every extra 1¢/L earned represents an additional \$3.3M. Therefore, apart from gasification which delivers similar outcomes to combustion but is more expensive, all other options are viable. The advantages and disadvantages of each are discussed below, alongside the next steps needed to develop them further.

Direct land-spreading. Its **advantages** are: it does not require any capital investment in infrastructure; it returns fertiliser value to the soil; and, it has fixed costs associated with spreading. Its **disadvantages** are: it has high tonnage, 70,000 tonnes; it does not provide opportunity to add value; it requires land which is the responsibility of winegrowers to find as grape marc has no sale value; it risks poor environmental outcomes due to the current levels of application (see Section 3.3); and, due to the previous two points winegrowers remain custodians of the environmental outcomes. **Clearly, as the next step, more research is required to establish the sustainability of the current practice**.

Best-practice composting. Its **advantages** are: it is a simple, well understood process; it produces a stable product with much reduced tonnage, 22,960 tonnes; its stability ensures that once made, risk is much reduced for negative environmental outcomes; and, it returns most of its fertiliser value to the soil. Its **disadvantages** are: it requires capital investment (prepared impermeable land, leachate collection, and covered windrows, etc.); it requires land which means that, for business assurance, composters will most likely require take-back agreements from winegrowers; and, it provides little opportunity to add further value. **As the next step, a demonstration best-practice composting facility can be set up**. Experienced composting companies can do this.

Table 8. Comparison of options for repurposing grape marc. The stars indicate the ranking against the various categories.

Option	Net Revenue required to reduce NPV to zero over 25 years, $/yr	Deferred Cost of fertiliser not returned to soil	Carbon footprint [kg CO2e/t raw GM]	Coal offset carbon footprint [kg CO2e/t raw GM]	Ranking: Env. risk and liability	Ranking: Tonnage reduction
Direct Landspreading	-$0.47M to $0.93M ★3	★1	?	?		
Composting	$1.21M to $1.39M	★2	20 ★3	20 ★4	★4	
Drying 3	-$1.90M to $0.17M ★2	$1.17M				★4
Combustion 3 (incl. D3)	$2.97M	$1.17M	62	-161 ★3	★1	★1
Gasification 6 (incl. D3)	$5.94M	$1.17M	-12 ★2	-253 ★2	★2	★2
Pyrolysis 3 (incl. D3) Biochar	$3.86M to $3.97M	$0.67M ★3	-225 ★1	-256 ★1		
Pyrolysis 6 (incl. D3) Pellets	-$0.14M to $2.74M ★4	$1.17M	24 ★4	24 ★5	★3	★3
Pyrolysis 6 (incl. D3) Activated Char	-$6.48M[a] ★1	$1.17M	24	24		

Drying to make dried grape marc for sale. Its **advantages** are: drying reduces the tonnage, it produces a storable product, it is marginally profitable, and as heating fuel can offset coal in boilers and furnaces, e.g., dairy factories. It is also a precursor to the other thermal processing options and provides additional side stream opportunities to add value (see Fig. 1(b)). Its **disadvantages** are: it requires capital investment (a burner, drying plant, and emissions control); it costs are too high to allow land-spreading for dried grape marc to be a viable commercial activity; it requires a market that can absorb the quantity, 20,717 tonnes, which may require rail or road transport to Canterbury; and, by being sold, it will not return fertiliser value to soil which represents a deferred cost to the region. **The most promising avenue to achieve profitability and a positive environmental outcome is as heating fuel to offset coal. As the next step, further research is required to determine the firing behaviour, e.g., slagging, and compare its performance to that of *P. radiata* pellets.** Some work will also be require to determine whether biomass replacement of coal requires retrofitting of furnaces. Note: the preliminary design used in the techno-analysis of this project included all the necessary mitigation technologies, but they need to be proven.

Combustion to generate steam for electricity generation. Its **advantages** are: it completely removes the tonnage, hence transfers custodianship of the environmental outcomes from winegrowers to the electricity generator; it can be done in Marlborough and so avoids additional transport; but, if the dried marc is transported to a combustion plant within the South Island (e.g., a dairy factory) then by offsetting coal, it can achieve a significant mutually beneficial environmental outcome. This indeed, is similar to the dried grape marc above, but here the engineering design includes the unit operations of the furnace, heat recovery boiler and steam turbine, and so its cost structure is representative of the delivered cost at the dairy plant. Its **disadvantages** are: it requires capital investment; electricity generation is not profitable without wine industry support (e.g., a levy); offsets for electricity production at scale are outside Marlborough and so involve road or rail transport; and without offsets, the carbon footprint is a net emitter, about three times more than best-practice composting. **The most promising avenue for combustion is to develop a relationship with a major industrial user, such as a dairy plant, to offset coal in their cogeneration plant. As the next step, further research is required to determine the firing behaviour, e.g., slagging.** Note: the preliminary design used in the techno-analysis of this project included all the necessary mitigation technologies, but they need to be proven.

Pyrolysis for charcoal/biochar. Three version of this option are presented which go from very profitable to costly. Pyrolysis, as shown in Figure 1(c), allows the opportunity for the most side stream products. This approach progresses the wine industry towards the wider bio-refining concept, where many opportunities for value adding become integrated. See the Research Report for further discussion. **The most advantageous approach with biochar/charcoal may be a combination of the three versions, to achieve both a favourable overall carbon footprint and achieve profitability**. They are described below.

Biochar for soil addition. Its **advantages** are: it provides by far the best environmental outcome with carbon sequestered permanently into the soil. This net draw-down of atmospheric carbon can be used to balance net emissions in other parts of the winemaking process, and it is also likely to have the largest sustainability benefit by adding value to the wine product in environmentally sensitive markets. Its **disadvantage is**: it requires capital investment; on its own, it is not profitable without wine industry support (e.g., a levy). **As a next step, a pilot/demonstration plant should be built to scale and optimise production and research, through soil trials, should be conducted to determine the environmental benefit beyond sequestration of which there are many, e.g., water holding capacity which improves drought resistance, and soil health through a number of mechanisms**. See the Research Report for a more complete discussion.

Charcoal heating pellets. Its **advantages** are: it is marginally profitable; it has a coal-equivalent heating value with lower ash and sulphur contents than most coals; charcoal burns much hotter and cleaner than wood; charcoal is less susceptible to moisture which affects the burning performance of wood; and, it can be used to offset the coal from an existing coal user, e.g., a dairy plant or a hospital, which is a mutually beneficial to both industries. Lastly, because the tonnage is smaller, there are more likely to be Marlborough based users, e.g., hospitals and schools, which avoids long-distance transport. Its **disadvantages** are: it requires capital investment; by being sold, it will not return fertiliser value to soil which represented a deferred cost to the region; and, also by being sold, the sequestration value is lost and the carbon footprint is similar to that for best-practice composting. **As a next step, a pilot/demonstration plant should be built as above, and further trials to establish the combustion and metallurgical reductant (another potential product) performance of charcoal.** This information is essential to future clients.

Activated charcoal. Its **advantages** are: it is highly profitable even as a relative low-grade activated char. Its main **disadvantage** is, in addition to those for heating pellets, that it is the least explored. Activation requires another processing step, which has not been studied in the present project. **Therefore, the next step is research to establish the extent of activation, the role of its inherent ash content, and its adsorbency to common and selected pollutants**. If this is favourable a pilot-scale activation unit operation should be built.

In all options, next steps involve refining the techno-enviro-economic analysis.

4. The Way Forward

The techno-enviro-economic analysis of the options for repurposing grape marc have established the processing complexity needed, the opportunity in terms of the environmental outcome, where that may be important to sustainability planning, and the process economics with respect to the capital and operating costs of the processing facilities. Only gasification rules itself out because its cost is much higher than combustion which delivers similar outcomes. All other options have advantages and disadvantages. What is now needed is the industry to convene and discuss the options through the lens of their strategic goals and those of the region of Marlborough. With consensus and commitment to a way forward, then the necessary stakeholder relationships can be formed. Further research, development and business analysis proceed from there.

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