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Rethinking Waste Streams

New alternatives for the Australian processing tomato industry

A report for

By Andre Henry

2018 Nuffield Scholar

December 2019

Nuffield Australia Project No 1820

Supported by Australian Processing Tomato Growers and the inaugural Nuffield Australia Alumni Scholarship, which in 2018 was entitled the “Max Jelbart Scholarship”

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Executive Summary

The utilisation of waste streams in all forms of production, not just agriculture, has seen renewed focus of late with two driving aims. These are to reduce input costs, such as energy associated with production; as well as reducing the environmental cost of operations with many parts of the world now applying a price to carbon emissions.

This report investigates the potential technology that exists to make use of the tomato vine waste produced each season by the Australian processing tomato industry. The aim is to provide alternatives for consideration that may be suitable on an industry or individual grower scale.

The report defines the key challenges to the use of waste tomato vine as a material or energy resource as:

- Relatively low calorific energy value per ton of dry vine mass (14.8Gj/ton)
- The vines physical characteristics post-harvest

The technologies investigated have been considered in a context of how they might operate in Australia. Many technologies found in Europe were found to be highly effective in operating there, but unsuitable as an Australian alternative for technical and economic reasons.

A new concept of distributed ammonia production via the gasification of the waste tomato vine is proposed as a possible industry solution. It meets a present demand for nitrogen-based fertilisers in tomato production and creates a high value product from a low value waste stream. The financial potential for such a system at this early stage appears positive, and a description of how an industry application could potentially operate in Australia is outlined.

It is hoped that this report offers a potentially new direction for the processing tomato industry which could see growers increase returns; unattached to their primary fruit production. The technology may also offer a path to industry energy independence as well as significant carbon emissions reductions.

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Foreword

My path to Nuffield has been an unconventional one. I was actively involved in our family's operations growing up on our family farm at Appin South; before leaving to study Environmental Engineering at Monash in 2008.

On completing my degree, I took a different route to most of my friends in engineering. I joined Hanson, a concrete and quarry company owned by the multinational Heidelberg Cement Group. I was employed within a management development program of the company and exposed to a wide variety of business units; from logistics to quarries and concrete. I was encouraged to investigate and understand the performance and profit drivers within each. It was during this time that I was introduced to the concept of vertical integration; where a retail "business" serves as the major customer for the primary production business that supplies it; thereby protecting the primary production businesses margin. I believed this concept may work for our family farm; and left Hanson in 2014. I have since been building a retail business; that uses our primary production through a range of value-added retail products. At the same time, I am also constantly looking at ways we can improve our farm operations. It was during one such period of investigation that I started to become interested in the waste streams of our production.

Each season, tomato growers are producing enormous volumes of vine biomass that has next to no digestible value to livestock, is a disease risk if left in the paddock, and in a less than environmentally ideal situation the majority of growers are burning it. My brother and I have already patented a building material to utilise it. We are conducting technical testing to prove and commercialise it as a product. However, developing a new product, as well as a market for it, takes time; especially to a point where it will utilise the volume available.

My aim with a Nuffield Scholarship was to see what technology may be out in the world to either utilise tomato vine as a value-added product, or as an alternative energy source right now.

Acknowledgments

The first people I'd like to thank and acknowledge for this incredible opportunity are my investors – The Australian Processing Tomato Growers and Nuffield Australia's Max Jelbart Scholarship. It is an immense honour and a privilege to be supported by not just your industry but also the alumni of Nuffield itself. I did not have the pleasure of meeting 1991 Max Jelbart OAM. However, by reading his report and meeting his sons, my perception is that he was a man ahead of his time. He foresaw a period where dairy producers would need to look more closely into the markets they service; and explore the potential the industry had to leverage higher value from their production by moving away from the commoditised marketplace. He was also a man that contributed greatly to the Nuffield organisation itself, his community, and his family. I hope that my own thoughts and findings will have the same positive impact within my own family and industry as well.

I'd like to thank Scholar Jim Geltch for reaching out to my parents several years ago with an email about a Nuffield day. It was a day of visiting farms near Rutherglen, chatting with other scholars and an eye-opening experience. I feel like it's often very difficult to get an honest reaction from many in the agriculture sector. The forthright discussions of what individuals believed they had done well; and owning where they believed they had failed or made a mistake was incredible. I left with my mind buzzing, and for the next two years I thought of what topic that not only presented an opportunity for our industry but engaged me as an individual. That one email has opened me up to a world I never knew existed; one of enormous opportunities, possibilities, and a keen desire to question why. Not just my own topic, but question my businesses direction as a whole, as well as my own contribution and place within the world itself.

Thank you to my fellow scholars of 2018. Such a diverse group of people created a great melting pot of ideas and backgrounds. I'd like to especially thank the members of my Global Focus Program group – Stuart, Dylan, Steve, Jean, Rob and Simon; truly a pleasure to have seen some parts of the world I never would have envisaged, each made infinitely better by the company of each of you.

To the numerous farms, research and university organisations as well as equipment designers and manufacturers I visited in the UK, Netherlands, Germany and the USA thank you. Your insights, suggestions and openness to think over the problem, and potential opportunity I described we have in Australia were eye opening. My investigations certainly lead me down a path of thinking and technology that I could never have expected, or even found, without the discussions I shared during my visits.

Lastly, I'd like to say perhaps the biggest thanks to my own family- Dad (Tony), Mum (Rowena) and brother (Jas). None of the experiences I've had over the last year would have been in any way possible without your incredible help and support. Whether it be fulfilling online orders, loading pallets for distributors or restocking Cherelle, Amy and co for the markets you've done it all and more, often covering for my mistakes and oversights at the same time. Not to mention getting everything done on the farm, as well as two other full-time jobs.

This opportunity may have been awarded to me as an individual, but the true thanks and appreciation should lie with each of you.

Abbreviations

ACCC- Australian Competition and Consumer Commission

AFI- Australian Farm Institute

APTG- Australian Processing Tomato Grower’s

APTRC- Australian Processing Tomato Research Council

ARENA- Australian Renewable Energy Agency

ATM- Atmospheres of pressure

AUD- Australian Dollars

BTU- British Thermal Units

CAP- Common Agricultural Policy

CH4- Methane

CHP- Combined Heat and Power

CHyP- Continuous Hydrogen Production

CO- Carbon Monoxide

CO2- Carbon Dioxide

CO2e- Carbon Dioxide equivalent emissions

€- Euros

EU- European Union

GJ- Gigajoule

HA- Hectare

H2- Hydrogen

HCL- Hydrochloric acid

HIA – Horticulture Innovation Australia

HWH- Kilowatt Hours

N- Nitrogen

NDA- Non-disclosure agreement

NH3- Ammonia

Nm3- Normal cubic metres (volume at 1 atm)

PSA- Pressure Swing Absorption

£- English Pounds

UAN- Urea Ammonium Nitrate

UK- United Kingdom

UOM- University of Minnesota

USA- United States of America

USD- US Dollars

WTO- World Trade Organisation

Objectives

The objective of this study is to find systems or technology that can be applied on a grower or industry scale to utilise the waste vine from the processing tomato industry. To either reduce the cost of production or create another source of grower revenue. These objectives can be in the form of:

- A material or other value-added product.
- An alternative energy source applicable for on farm use, i.e.: electrical or diesel replacement for irrigation pumping.
- A way to mitigate another cost within the processing tomato growing system, i.e.: fertiliser.

The technology will need to be viable within an Australian context from both an economic and practical standpoint.

Introduction

The Australian processing tomato industry is very small by world standards, and highly concentrated. Approximately 200,000 to 250,000 tons of fruit is grown per year by ten private growers, and two larger scale corporate operations. Domestic consumption of processed tomato products remains relatively high by world standards at around 23.5kg per person per year; and with Australia's continued population growth the market as a whole is on a growth trajectory.

Contrasting this data with the level of domestic versus imported production however paints a darker picture. In a little over ten years imported production has grown its market share from around 40% to almost 70%. Refer to Figure 1 and 2 below.

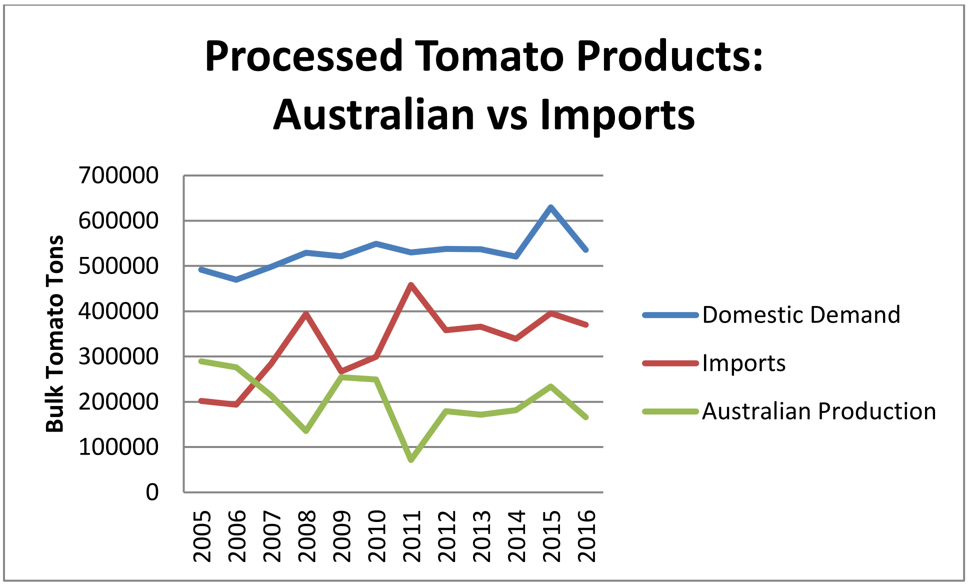


Figure 1: Domestic demand, Australian and imported production tons (APTRC, 2017)

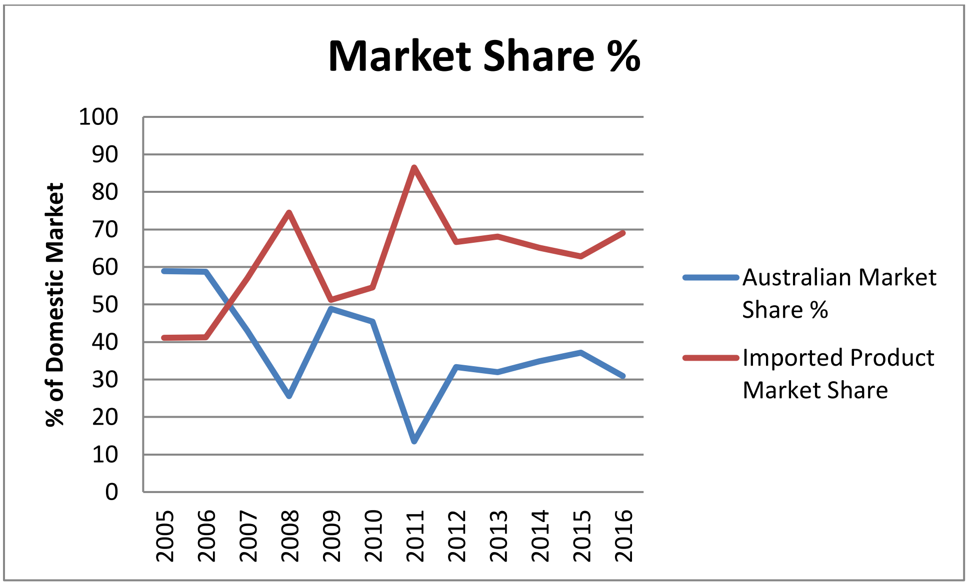


Figure 2: Market share imports vs Australian Production (APTRC, 2017)

This picture describes the challenge the two major Australian tomato processors – Kagome and SPC – are facing. This pricing challenge is then also seen by growers at the farm gate. The industry is competing for retail and commercial sales alongside heavily subsidised Italian growers; unregulated and low-cost producers such as China; as well as the efficiencies of scale seen from California. Tomato paste and canned products commonly have shelf lives of up to two years; and as such can be traded globally as bulk commodities with no immediate regard to perishability.

In the retail sector, the impact the subsidisation of processed Italian tomatoes plays on the domestic market is enormous. It has been allowed to continue as the language surrounding payments to Italian growers is such that the European Union (EU) CAP subsidies are de-coupled or not linked with their production. Meaning they have been defined as "having no market distorting effect" (La Doria 2016). The real-world reality for Australian Processing Tomato Growers (APTG)'s however can be spelled out in one statement:

APTG's average yields are 80-100% higher than Italian tomato producers; APTG's are paid 25-30% less per ton (Tomato News, 2018), and yet Italian cans are still being "sold" wholesale to Australian retailers at prices 20-30% lower prices.

It is clear better government policy and further Australian Competition and Consumer Commission (ACCC), and potentially World Trade Organisation (WTO), action is required to ensure a "free" domestic market is re-established. It is clear that stronger representation is required within government to comprehend the implications of free trade deals with the EU. Those in government may be making decisions on the correct assumption that Australian growers will be able to out compete European growers on a free and equal market. The problem lies in the fact that the EU has shown no inclination in allowing such a free market to exist; and also place a far greater value on their own food production and value of agriculture than that seen here in Australia.

There also needs to be a greater level of scrutiny placed upon the supply chains and purchasing decisions of the major retailers in Australia's domestic market. The regulatory burden placed on Australian growers in supplying fruit for their grocery products doesn't seem to apply to their imported products where wage standards, chemical usage and land stewardship are somehow no longer considerations if a product is being manufactured or grown offshore.

Hence, with Australian processors facing effectively a fixed to shrinking market share; as well as rising production costs themselves, particularly in energy, the industry will struggle to return to growth and prosperity by simply producing more fruit.

The industry needs to create more value and profitability from the production already being achieved, and concurrently reduce the fixed costs of this production wherever possible. A very new direction is required.

Chapter 1: Opportunity

1.1 Defining the opportunity

The processing tomato industry can be summarised as high input and high output broadacre horticulture. All Australian growers adhere to and are audited against Freshcare standards for environmental protection and safe food production; but the input of resources into each growing season is inarguably far greater than that seen in enterprises such as broadacre grain cropping.

Whilst the importance of understanding biological processes of different farming systems is now receiving deserved attention, in a high input system such as tomatoes, the physics of an energy balance can also highlight areas of both waste and potential savings. Table 1 below highlights the major flows per ha in a direct seeded Australian tomato crop.

The specific details of in-paddock operations; pump and tractor fuel efficiency as well as fertiliser use may vary quite considerably by grower, but the figures quoted serve as an initial baseline. The calculation of energy from fertiliser use has been estimated using the Australian Farm Institute (AFI)'s figure of 24.3GJ/ton of urea produced. Whilst most growers are currently meeting this nitrogen demand through the use of Urea Ammonium Nitrate (UAN), at this time urea can serve as a figure for a coarse comparison of the energy needed to meet crop nitrogen demand.

Operation/ Input:	**Type of Energy used:**	**GJ Energy/ha:**	**Variation Potential:**
Starter Fertiliser	Natural Gas	0.2	+50%/-10%
Fertigation Nitrogen	Natural Gas	6.4	+100%/-10%
Field Operations (tractor passes, irrigation pumping, harvest)	Diesel Fuel	27.4	+/- 10%
Output/ Production:	**Form of Energy:**	**GJ Energy/ha:**	**Variation Potential:**
Tomatoes	Calorific energy	81	+80%/-30%
Tomato Vine	Calorific energy	148	+50%/-30%

Table 1: Energy inputs vs Output processing tomato system. Excludes chemical inputs and solar energy applied over the crops 135+ day growing period

The data highlights that as an industry the tomato vine represents the greatest energy leakage and potential opportunity with approximately 64% of the crops total energy output currently being unutilised.

Chapter 2: Value Adding

2.1 Value added materials or products

The ideal solution for the tomato vine would be to find a high value material use to maximise the return to growers. There are very few companies in the world working with, or developing products, that utilise crop residues as a raw material; especially at the grower or grower co-op accessible scale.

2.1.1 Cornboard Industries

Situated in North West Texas, Cornboard Industries utilises corn leaves to create pressed and glued fibre board. The material can be used as a bulk material sheet to replace wood, or in a myriad of other products.

Production Manager Jonny Gazas described how they pay surrounding corn farms $10USD per 500kg bale of corn stubble and remove 80% of the field total crop residue. They also attribute a baling cost of $10USD per bale for collection. This raw material is fed into a rotating trommel screen, with a fan at one end, to separate the corn leaves from stalks and corn cobs. This is done because the resin glue must be able to entirely coat the material to ensure sufficient bonding. The stalks and cobs being three dimensional shapes compress like hollow tubes without binding, unlike a flat leaf that maintains the pressed shape. As a result, only 35% of the raw corn stubble material supply ends up as cleaned feed for Cornboard processing.

This leaf material is then layered into bulk sheets and washed with the adhesive resin glue and pressed at up to 300PSI while at high temperature to create a uniform sheet. The materials edges are then trimmed smooth for final use.

Figure 3: Trimmed edge from board highlighting the density obtained during the pressing process (Cornboard)

Figure 4: Trials of different plant fibres, resins, pressures and temperatures (Cornboard)

The business is very well managed with distinct commercial strengths and smart decision making around the process. The company is owned by Lane Segerstrom who is directly involved in the equipment company, OEM, who manufacture the large-scale press used within the system. He has a deep understanding not only of pressed board manufacturing equipment, but also the commercial board market in which they intend to compete. The company recognises the enormous corn residue resource that exists across the USA post-harvest. However, they have a challenge in displacing wood-based feed stocks within the supply chain.

Cornboard Industries has also been very smart in marketing their material, producing small scale consumer products first to build public awareness and drive demand. “StalkIt” skateboards, skis and surfboards have given the business a public face which may help lead to a faster commercial uptake in the building material sector.

Figure 5: A completed "Stalkit" board with a core made from Cornboard, Jonny Gazas, Production Manager

In an Australian context, sadly the technology appears unsuitable. The tomato vine as a feedstock is essentially leaf free. The bulk of the plant’s leaves have dried off and disintegrated before, or just following harvest, leaving the hollow tubes of stem that Cornboard described, as unsuitable due to squishing. These could potentially be split longitudinally to allow them to compact flat, but this would add considerably to the processing cost.

It was also clear the high level of technical skill and experience required in the production system. Cornboard consistently pointed out minute additions or adjustments required while the system was running, in order to produce a consistent product from an inconsistent feedstock such as a crop residue. Hence, unless a tomato grower’s core business was to become a board manufacturer, it is unlikely to be a business that could be conducted alongside existing operations.

Unfortunately, the only other company that had manufactured materials from crop residues was fruit boxes from tomato vines by Solidus Solutions in the Netherlands. They initially worked in conjunction with Wageningen University to develop a product using tomato vine from the large glasshouse tomato industry in the Netherlands. In discussions with Area

Manager Jouke De Vries of Solidus Solutions, the project had been put on hold and they were not available to comment on any progress regarding the material (Solidus 2018).

The investigation of tomato vine as a possible cellulosic feedstock for large-scale applications such as paper mills was deemed to be outside the focus of this report. As described in the objectives, the focus is on technology that individual growers, or the industry, could implement to aid existing operations.

2.2 Biomass gasification

Referring to the initial energy demands of most APTG farming systems, irrigation pumping is a significant cost for growers, often in excess of $300AUD/ hectare (ha) depending on water usage needs. One technology that has been utilised around the world to power stationary engines is gasification. This involves the reacting of a fuel source, such as biomass at high temperatures in an environment of controlled air addition that prevents combustion.

This means that unlike standard combustion, or burning, the volatile and energy rich compounds such as CH4, H2 and CO are released as a gas from the cellulose feedstock leaving behind carbon char. This gas can then be filtered and upgraded for use in engines.

The first system visited was at Wampler’s Farm Sausages in Tennessee, USA. They are a premium pig slaughterhouse and sausage meat manufacturer, with the owner Ted Wampler Jr. looking to make his operation energy independent. The 500kw system was developed by Proton Power; a specialist equipment provider who manufacture large scale gasification systems, to produce electrical energy on a land footprint considerably smaller than that required for the solar farm they had already installed. The system has a number of very intelligent design adoptions to aid material flow and prevent system blockages.

Figure 6: End view of feed housing to reactor body. Note the faint V-outline on flat plate, the moving feed floor prevents bridging blockages when handling bulkier biomass (Wampler's Farm Sausages)

By accurately controlling the reaction temperature of gasification, the system produces a very consistent syngas that is then filtered and sent to an array of CAT engine powered generators. The consistent and highly controlled reaction temperatures have also led to the production of a high value carbon char by-product (Figure 7). This was highlighted by the owner's belief that whilst they installed the system to meet a power demand window that could not be satisfied by solar, the biochar may in fact be the primary product, with energy production being only a secondary benefit. The trials they've conducted to date, showed greatly improved biomass production as well as plant establishment in cottonwood trees when plot soil was treated using "Pro-C" bio-char.

Figure 7: Not all chars are created equal, highly controlled reactor temperature of the Wampler Farm system produces high grade biochar with significant soil health benefits

Wampler's Farm Sausage owners are also in the process of getting testing done to confirm the char is high-quality graphene. This would be a significant development, due to graphene's high manufacturing cost and the value that it may represent as an ingredient for insulators in the electronics industry.

A challenge described by Bryan Biss, a Project Engineer from Proton Power who installed the system, was slagging occurring within the reactors when they were using straw as a feedstock. This was due to the lower ash melting point of straw feed stocks; as a result, they have switched to a woodchip feed.

Without detailing the NDA protected economics of the Proton Power CHyP system which are quite positive, the scale of system required to make it economically and practically viable is beyond what would be achievable or required by APTG's. At present, growers have no external use for such large constant volumes of electrical power and would also struggle to meet the feed stock demand. Proton Power also offers a system that can produce upgradeable liquid fuels, such as diesel. However, unfortunately the scale of investment and the volume of biomass required being even larger than what the industry could possibly produce, also rules it out as a viable alternative, even at an industry level.

The search for smaller scale gasification plants in use on farms, led to a visit to Tom Lifely's twin CHP-50 installations in Herefordshire, UK. The system is quite similar to the Wampler arrangement but at a much smaller scale. It is made up of two containerised engines, each of 50kw output, with their own biomass gasifier reactors to produce the required wood-gas. The system has been designed to have both units drawing from the same raw wood supply stockpile. Tom runs a woodchip dryer using the waste heat generated during gasification to lower the moisture content of all fresh wood entering the system (Figure 8).

Figure 8: L: Tom Lifely showing wood chip dryer and screen; R: external to the shed showing the material feed augers entering and exiting the container modules

The owner detailed that the system generates an income in three key ways:

1. electrical power production (in excess of their farms use) sold back to the grid;
2. renewable Heat Incentive (RHI) payments; and
3. generation of Renewable Obligation Certificates (ROC).

The implementation of these payments/incentives saw a large uptake of the technology in the surrounding area, with the owner describing many projects being rushed to completion before the funding cut-off date. Most projects that were completed and installed have been modelled on a five-year payback period with a 20-year projected equipment life. The owner highlighted the importance of reducing system down time and maximising run hours to achieve these payback periods. His target run time is 8,000 hours per year for each engine to maximise the system's performance. Keeping a large inventory of spare parts on hand, servicing in house and accelerating the cleaning procedure with air cool down were all ways, not just to reduce the cost of breakdowns, but minimise the revenue loss whilst the engine was not running. It was highlighted that each of the above initiatives had made the process of energy production more labour intensive than expected, but had the equipment achieving closer to the level of economic outcome expected.

In an Australian context, sadly the breakdown of income versus cost for such a system is not viable. Without the incentives in place through RHI's and ROC's, running costs of the system exceed the income that could be achieved through electricity generation. Whilst the owner's biomass feedstock price of £50-£80 per ton and electrical feed in tariffs of £0.06 to £0.20/kwh are much higher than Australia when adjusted for currency value, in the relationship of one variable to the other, they are very similar in both countries. The costs and revenue in Table 2 highlight the difference between what could be expected in Australia versus the UK.

RHI: (£)	80,726	**Woodchip cost: (£)**	80,000
ROC: (£)	57,177	**Servicing: (£)**	10,000
PPA/ Feed In: (£)	33,388		
Total: (£)	171,292	**Total: (£)**	90,000
UK Outcome: (£)	81,292	**Aus Outcome: (£)**	-56,612

Table 2: UK circumstances vs Australian circumstance (Lifely, 2018)

As can be seen, when the above figures are converted to Australian Dollars, a UK operator would produce a profit of $151,203 AUD, whilst an Australian application of the same system would have the grower $105,298.32 AUD in deficit.

Whilst visiting other boiler and gasification technology providers, such as SpannerRe2 and Heizomat in Germany and Austria, one key issue was made abundantly clear. The lower ash melting point seen in straws and crop residues made them a difficult feedstock to use in CHP gasification systems due to slagging and the formation of acids in the syngas that wear out the system and engine downstream.

Alexander Baldauf from SpannerRe2 described it best:

"Anyone that can claim their system will run on straw biomass, they're talking rubbish. They can get it to run, for a week, and then it will be all blocked up with slag. The hydrochloric acid formed will also have greatly reduced the life of all components and you'll have a system that won't go." (Spanner 2018)

Chapter 3: Technology

3.1 Technology unsuitable for an Australian application

Following an investigation of gasification, a number of alternative energy technologies were also investigated and found unlikely to be feasible in an Australian context. As they were found to be unlikely suitable, the technologies will only be described in brief summary:

- Total combustion of the vine in a **high-pressure steam boiler**. This boiler would then feed a steam expander/ turbine to generate electrical power. Enormous scale required makes capital cost prohibitive without incentives and subsidies in place. Steam boilers are heavily engineered to handle the pressure of steam generation which contributes to capital cost. Steam generated electricity also only captures approximately 30% of the vine's total energy. (Langdon, 2018)
- **Rankine Cycle Systems** that use heat exchangers to "steam" a working fluid with a boiling point below that of water in a closed loop. This allows the use of lower temperature heat sources. It is a developing and improving technology, but at the present time the enormous cost to power output ratio makes them economically unviable. If not fitted with sophisticated control systems, they can also be highly technical to operate. (Viking Heat Engines, 2018)
- **Sterling heat engines** use the temperature differential over a cylinder to generate mechanical work. The technology is prohibitively expensive in terms of capital costs, and without a use for the waste heat overall energy conversion. Okofen boilers offer 1kw unit to fit on domestic pellet boilers for around €8k ($12,880AUD) (Okofen, 2018).
- **Thermoelectric Generators/ Peltier Modules** are electrical components that generate a current when they have a temperature differential between their opposing faces using the Seabeck effect. Unfortunately, their energy production is too small to be practical. II-VI Marlow produces a 100-watt system for $1,000USD ($1,460AUD) that operates at 4-6% total efficiency. They're likely only a viable solution in polar oil fields with no solar capability and abundant waste heat. If the cost of each unit's manufacture were to greatly decrease in the future it could become an interesting application for agriculture when large scale waste disposal (burning) is taking place on farm; with no moving parts one side of the device can simply be placed near a heat source such as a fire to start generating power. (II-VI Marlow, 2018).

All these technologies failed as alternatives for using the industries tomato vines on either simple technical basis, i.e.: raw energy conversion efficiency, or sheer capital cost relative to expected production. Two key problems were found in every option potential path to implementation in Australia:

3.1.1 Renewable incentive skewed capital cost vs energy conversion inefficiencies of older technology

It became increasingly apparent throughout the EU that government incentives within the market had not only skewed the capital cost of potential systems, but directly impacted the direction of research and development. The conflicting argument of up-front capital cost versus equipment efficiency was highlighted best when comparing the “Green Micro-turbine” System in the Netherlands with the “Village Industrial Power” unit developed in the USA.

The Green Micro-turbine is an exceptionally efficient piece of equipment with counter rotating turbine steam expanders producing 15kw of electrical energy from supplied steam at an efficiency of almost 40%. Its shortfall is the fact that its price tag is over €40,000 ($64,400AUD); which is just for the turbine and its control system. To generate power a steam boiler would also need to be purchased to feed the system to steam. The cost of such a system makes it unviable in Australia, despite its high efficiency (Green Turbine, 2018).

On the other end of the spectrum are systems such as that produced by Village Industrial Power in the USA.

Figure 9: VIP 10-40 Unit in the USA. Note the steam boiler body in green and feedstock hopper on left in black

Inventor Carl Bielenberg has developed a total unit with steam boiler running a single cylinder uniflow steam engine capable of producing 10kw of electrical power, from any combustible biomass. The units have been developed with the intent of providing village power and heating in places such as India and Kenya. The company aims to have them priced at $25,000USD ($36,500AUD) if manufactured in the USA, and as low as $15,000USD ($21,900AUD) if they're built in India. The technology is wonderfully suited to this application as it provides reliable base load power to areas of the world that have never had access to it, as well as heat for grain drying or fruit processing. (Bielenberg, 2018)

Unfortunately, in an Australian context it too would also be unviable for two reasons:

1. **Energy conversion efficiency of the system is too low:**

While Carl at Village Industrial Power has made significant strides in improving the efficiency of the uniflow engine, the system currently operates at approximately 6% total efficiency. Whilst the vine of the tomato industry is a waste product, it's collection from a row crop field has been estimated at $70AUD/ton (Kilter, 2017). Hence, with tomato vines calorific energy of 14.8GJ/ton only 0.83GJ or approximately 230KWH is actually converted to electrical power. Even utilising a domestic retail price of $0.20/KWH, this translates to an electrical value of approximately $46AUD which is considerably below the cost of the vines collection.

2. **Manual control is not possible with Australian wage standards:**

One of the reasons Village Industrial Power can produce units so cheaply is that almost all control systems are manual valves and taps. The feed hopper operates on a timed electrical auger, but all steam throttling and pressure control must be done manually. This is perfectly adequate in places such as India and Kenya where wage costs are low. The equipment is likely to be the centrepiece of a village and other activities such as grain drying may take place around it. However, as a "set and forget" power source for growers in Australia, the units would need considerable control system upgrades, pressure monitoring, flow control, temperature control, all of which would in turn add to the unit's initial capital cost.

3.1.2 No high value use for waste heat; lack of impetus to change current practices

A visit to Professor Tony Bridgewater, Director of the European Bioenergy Research Institute (EBRI), helped encapsulate the challenge of using biomass to power technology in an Australian context with three clear definitive statements:

- *"You have no value or need for the waste heat."*
- *"You have no financial cost pressure to discourage in paddock burning, or government incentives to do something else."*
- *"I can think of no technology in Europe that would suit the potential application that you describe."*

It would appear that using the tomato vine as a source of calorific energy to convert to thermal energy and finally electrical or engine power, is not going to be the way forward for APTG.

Chapter 4: Ammonia

4.1 Ammonia – a new way forward?

The investigations for potential use thus far highlight that tomato vine, whilst an abundant resource, has a low calorific energy which greatly reduces its value as a thermal energy source for power generation. This led to an investigation as to whether the vine resource could be harnessed in a different way to supplement the need for fossil fuel-based nitrogen fertilisers.

Distributed or localised ammonia production is a relatively new concept (Proton Ventures, 2018) with very few plants currently in operation but many planned to be rolled out in the coming years as increasing natural gas prices and rising transport costs of bulk materials make smaller production centres cost competitive.

Ammonia or NH3 is produced using the “Haber Process” developed by Fritz Haber in 1909 (Proton Ventures, 2018). The process can be simplified to the reaction of hydrogen H2 and Nitrogen N over a heated catalyst in a pressurised environment. In reality, the process is continuous with unreacted ingredients recycled back to the reactor until they are converted. The resulting ammonia gas is then compressed in tanks as a liquid.

To manufacture ammonia, two pure streams of nitrogen and hydrogen must first be produced. The production of nitrogen is relatively straightforward. Air is 79% nitrogen with ~21% oxygen. To separate the nitrogen from the surrounding oxygen, compressed air is pumped through a carbon bed sieve. The diffusion rate of oxygen into the sieve of carbon is much faster than nitrogen, hence the nitrogen molecules pass through, leaving the oxygen behind. This process is done in a cycle with two sieves operating concurrently; one pressurising and one de-pressurising constantly, to release the particles from the pore spaces of the carbon before the next pressurisation. Hence the name “Pressure Swing Absorption” or PSA (UOM, 2018) the process is best explained by Figure 10.

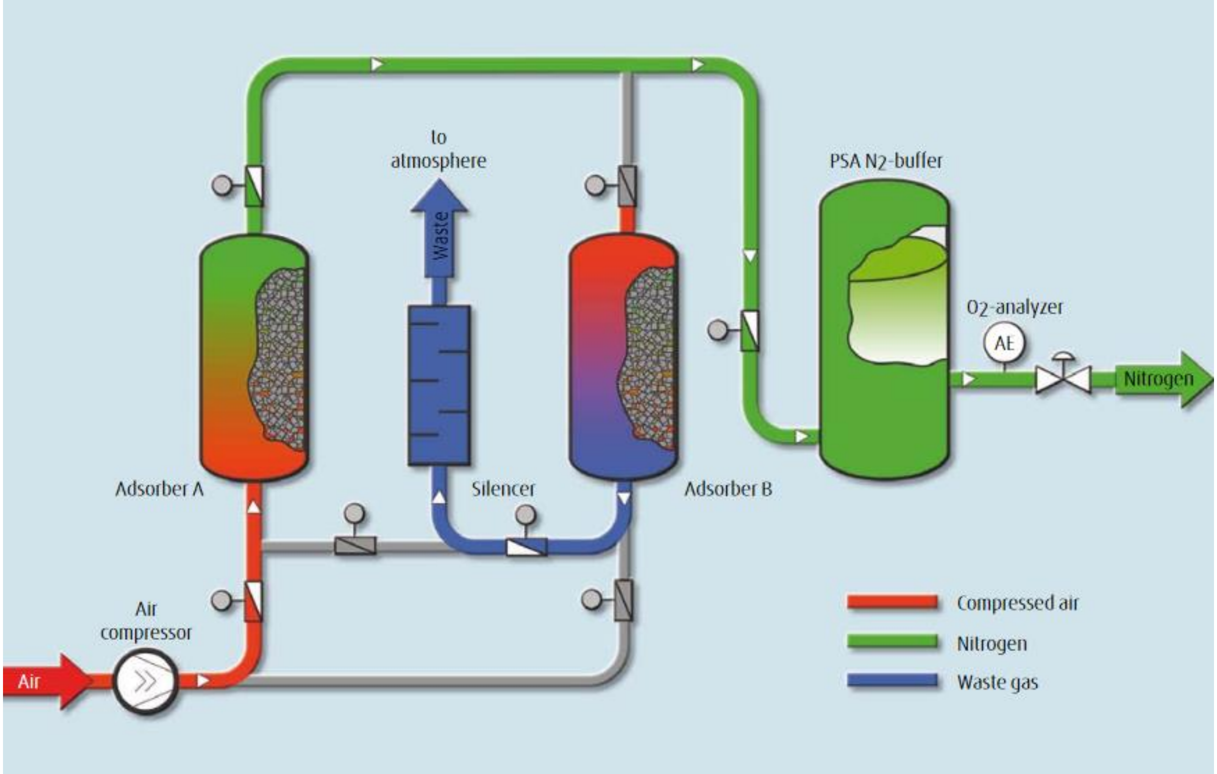


Figure 10: Nitrogen Pressure Swing Absorption (PSA). Parallel sieves alternate between pressure and de-pressurisation to produce pure nitrogen (Linde Group, 2019)

Nitrogen generators can run on any electrical power source and are generally regarded as low maintenance and low cost. (Proton Ventures, 2018).

The other component of NH3 is hydrogen. Unlike nitrogen, hydrogen can be very expensive to produce and has two common pathways for its production – electrolysis or water splitting using electrical current, or steam – methane reforming from a gas feedstock. Both of which historically have had their energy demand met by large fossil fuel supplies.

Electrolysis:

The production of hydrogen via the electrolysis of water involves the use of an anode and cathode of an inert material such as stainless steel being placed in water and a DC current passed through them (Figure 11). This drives the formation of oxygen bubbles at the anode and hydrogen bubbles at the cathode (UOM, 2018).

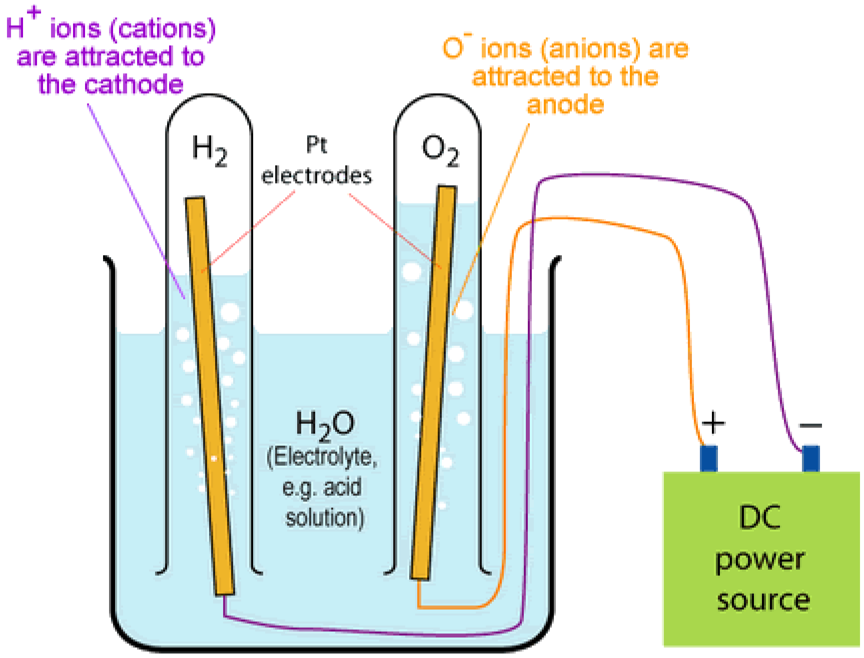


Figure 11: Bench top example of water electrolysis process. (Kullabs, 2019)

As expected, this is a very energy intensive process to supply the current necessary to split the hydrogen from its bond to oxygen in the water. Efficiencies can be improved with the use of catalysts but approximately 80% of the total energy consumed to manufacture ammonia is to produce the required hydrogen (UOM, 2018) Proton Ventures equates this number to 45-60Kwh of electrical power per kg of hydrogen.

The other, more common path to hydrogen production is steam methane reforming of natural gas. In a high temperature reactor, steam is reacted with methane (the largest component of natural gas) to create carbon monoxide and water (Proton Ventures, 2018):

$$\mathbf{CH_4 + H_2O \rightleftharpoons CO + 3\ H_2}$$

The carbon monoxide can then also be reacted with water to further increase the production of hydrogen:

$$\mathbf{CO + H_2O \rightleftharpoons CO_2 + H_2}$$

The technology is very established with natural gas, but companies such as Hygear in the USA have developed technology to handle the more varied composition of bio-digester biogas as well as syngas from the gasification of biomass (Hygear, 2018).

This gas path to the hydrogen needed for ammonia production may offer a potential use for the industries waste tomato vine.

4.2 Research stage – university installation

As with most new technology, the path to commercialisation will likely be

- research/ university implementation;

- pilot scale installation; and
- commercial implementation.

The University of Minnesota’s Renewable Energy Program in Morris, Minnesota, has developed a small-scale ammonia production plant utilising electricity generated on site by the campus’ wind turbine. They utilise this power through an electrolysis system to produce hydrogen; and operate a PSA nitrogen generator to produce the nitrogen components for ammonia production.

The system has been laid in distinct zones to separate each area of the process for safety but also to be able to trial different settings in each section of the plant with the aim of optimising energy performance. They aim to increase the systems performance from 12KWH per pound of ammonia produced down to 6KWH. The performance of the system in terms of the volume of ammonia produced per the volume of energy supplied was highlighted as the key critical parameter to commercial viability. The performance described above when combined with expected Australian electrical costs, either from the grid power supplied at \$0.20AUD/kwh or on-farm solar power supplied at \$0.045AUD/kwh, resulted in an estimated ammonia price of between \$1188AUD and \$5280AUD per ton.

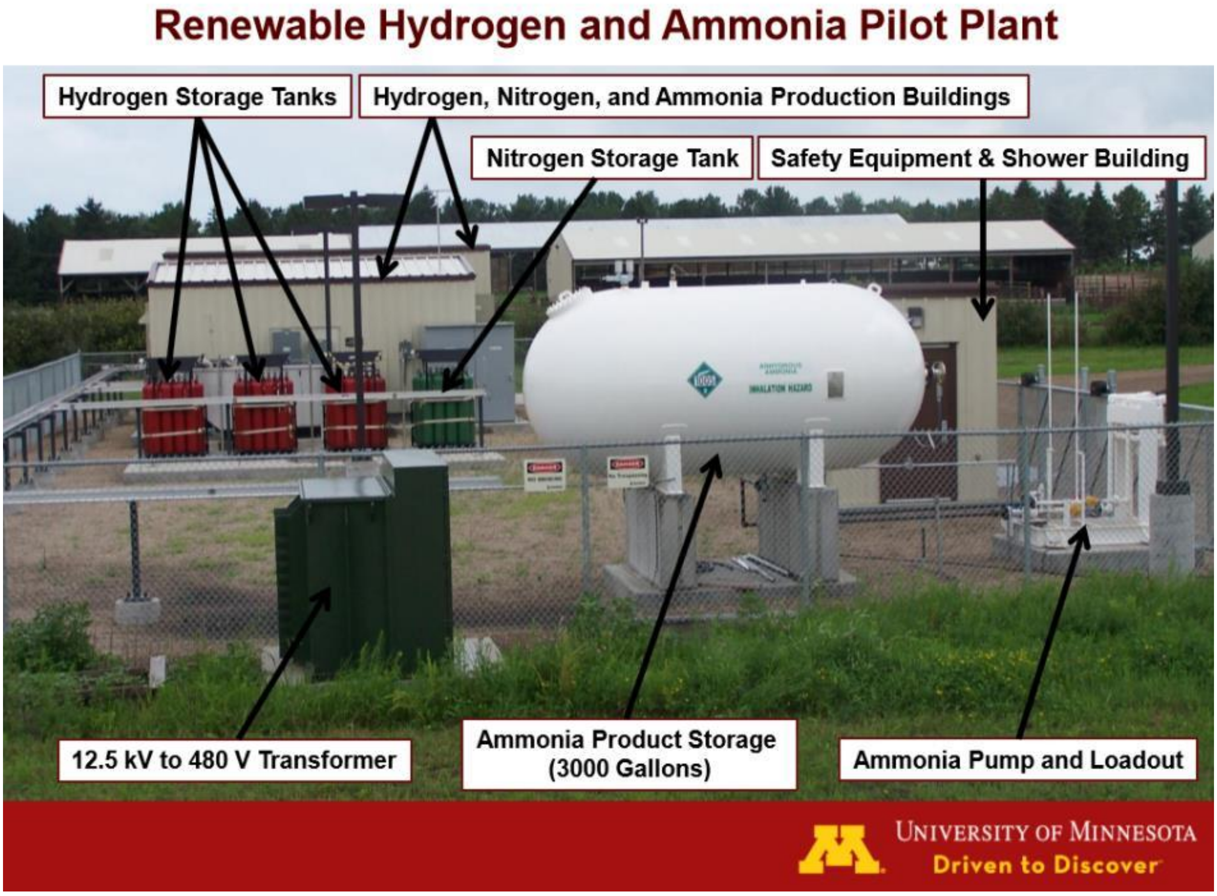


Figure 12: External layout and view of UOM ammonia pilot plant (UOM, 2018)

The university is continuing work to quantify energy leakages and where improvements might be made within the system. One area identified was in the reactor process where the nitrogen and hydrogen are combined. Currently, the system operates using a reaction and condensation-based system. This involves one side of the system being heated, whilst concurrently the other side requires chilling. In both instances this takes place at pressure to ensure both the effective reaction of nitrogen and hydrogen takes place, and the subsequent separation of ammonia is achieved. The team at UOM plan on switching this to an absorption-based model where an absorber containing Magnesium Chloride (MgCl2) blocks will absorb the ammonia from the stream. The absorption path offers a conversion ratio of 85% of reactants in a single pass through the reactor, whilst standard Haber-Bosch conditions operate at around 20% with the reactants continually recycled (UOM, 2018). This could reduce energy consumption from both reactor temperature control as well as amount of pressurised pumping. The pressure reduction is potentially significant, 200atm down to 20atm. In new systems this might represent not just an operating cost saving, but potentially a capital cost improvement as the pipework and pressure controls of future systems may only need a lower rating.

The University of Minnesota certainly appears to be at the forefront of renewable ammonia production and are great advocates for producers sharing and using their knowledge for commercial farming applications.

4.3 The pioneer stage – farm pilot installation

Jay Schmuecker’s family farm in Blairstown in Iowa is truly an eye-opening insight into what a carbon free, energy independent, farming system might look like. Developed as an honour project to his father Raphael Schmuecker, the system uses solar power from an 8kw panel array to generate hydrogen via electrolysis. This hydrogen is then compressed and stored in tanks for use as a fuel for the tractor. The Schmuecker family team have modified a 7810 John Deere tractor with a retrofitted V8 engine to run on hydrogen. The tractor produces 150hp and can be run at full load for four hours before the hydrogen tanks required refilling. The only exhaust from the tractor’s operation is water vapour.

Figure 13: Hydrogen converted tractor at the Schmuecker family farm in Iowa. Note the hydrogen tanks mounted longitudinally above the cab as well as the smaller ammonia tank mounted cross ways at the front

The smaller ammonia tank situated in front of the cab was originally conceived as a back up to the four larger hydrogen tanks; it was only later the potential of ammonia as an energy source and potential fertiliser was recognised. To put in the context of energy density, the small tank of ammonia mounted at the front across the tractor contains half the energy of the four larger hydrogen tanks mounted over the cab. The ammonia is also stored at a much lower pressure. The total systems operation can be best described by the schematic below.

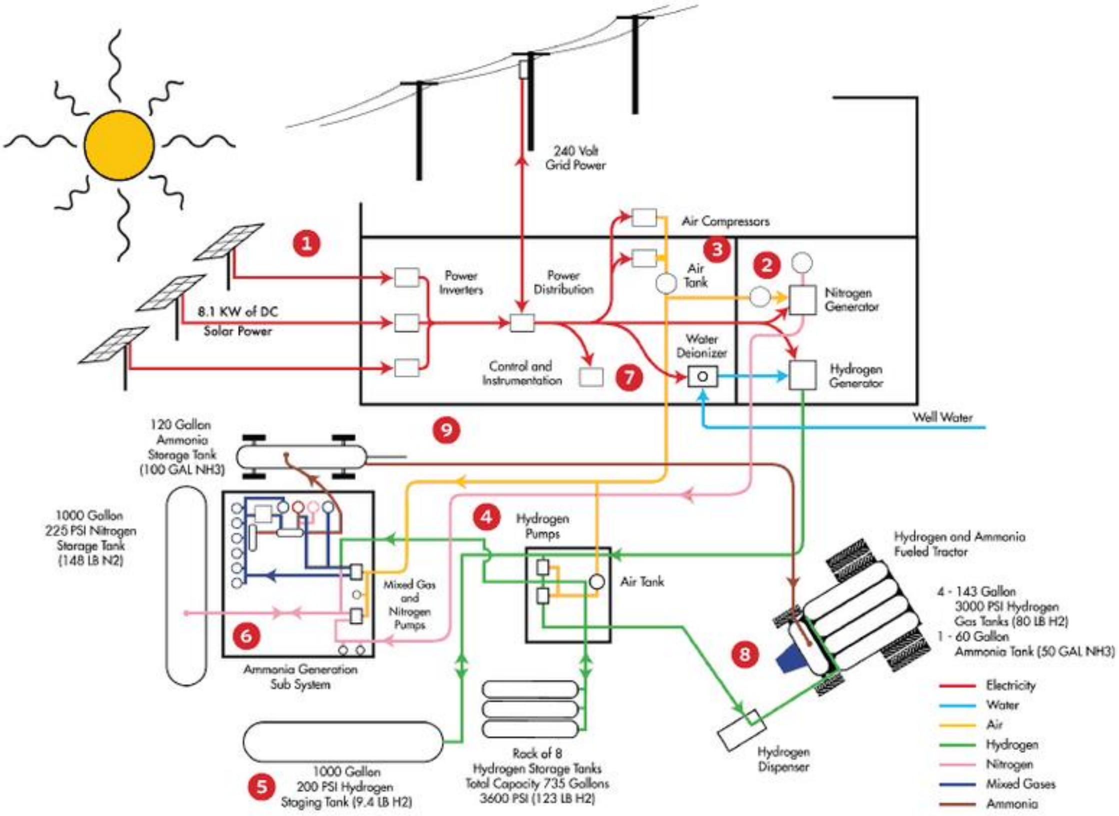


Figure 14: C-free hydrogen and ammonia production from solar power (Schmuecker, 2018)

Whilst the system installed by Jay and his family is only a pilot, it is able to service the fertiliser and tractor fuel needs for a typical bean/ corn rotation over 10% of the whole farm area, or approximately 30 acres; and perhaps more importantly, it provides an example and highlights that the technology is practically possible on a grower or industry scale.

As was found at the University of Minnesota, Jay Schmuecker and his team are wonderful advocates for the technology and have completed the project not with the aim of seeing an economic return but hope to change the direction of farming. Jay hopes to bring about a new era of energy independence for producers at the same time as having a positive impact on the environmental footprint of farming operations.

The broad challenge of rising input costs and falling real crop returns are the same in the USA as what growers are seeing in Australia. Our responsibilities as producers is to reduce the environmental impact, and this is one that's globally shared.

4.4 Commercial stage – production scale systems

To commit to the implementation of such a new technology in Australia, a commercial partner would need to be found that could construct an operating system that is not just on a research or pilot scale but may create a high value use for the industries tomato vine waste stream. An adaptable installation may also be able to accept waste streams from other agricultural industries.

A visit to the head office of Proton Ventures took place in the city of Rotterdam. It was highlighted during the visit, and in discussions with engineer Kevin Kardux, that the concept of distributed ammonia production is a relatively new one. The history of ammonia production has been to construct plants of enormous scale next to existing gas refining infrastructure, where the energy source is abundant and cheap. In recent years improvements in technology has allowed for the size of plants to be greatly reduced, without the overall reduction in process efficiency making them unviable. In an era with increasing localised energy sources such as stranded gas deposits and dispersed renewable energy options the technology offers a way to translate this energy into a valuable and transportable commodity.

Proton Ventures "Nfuel" systems can operate using hydrogen produced by either pathway- electrolysis of water, or steam methane reforming from natural gas. Both methods of production may be applicable and potentially economically viable in Australia, however the greater cost efficiency expected using the gas pathway suggests it could be most suitable.

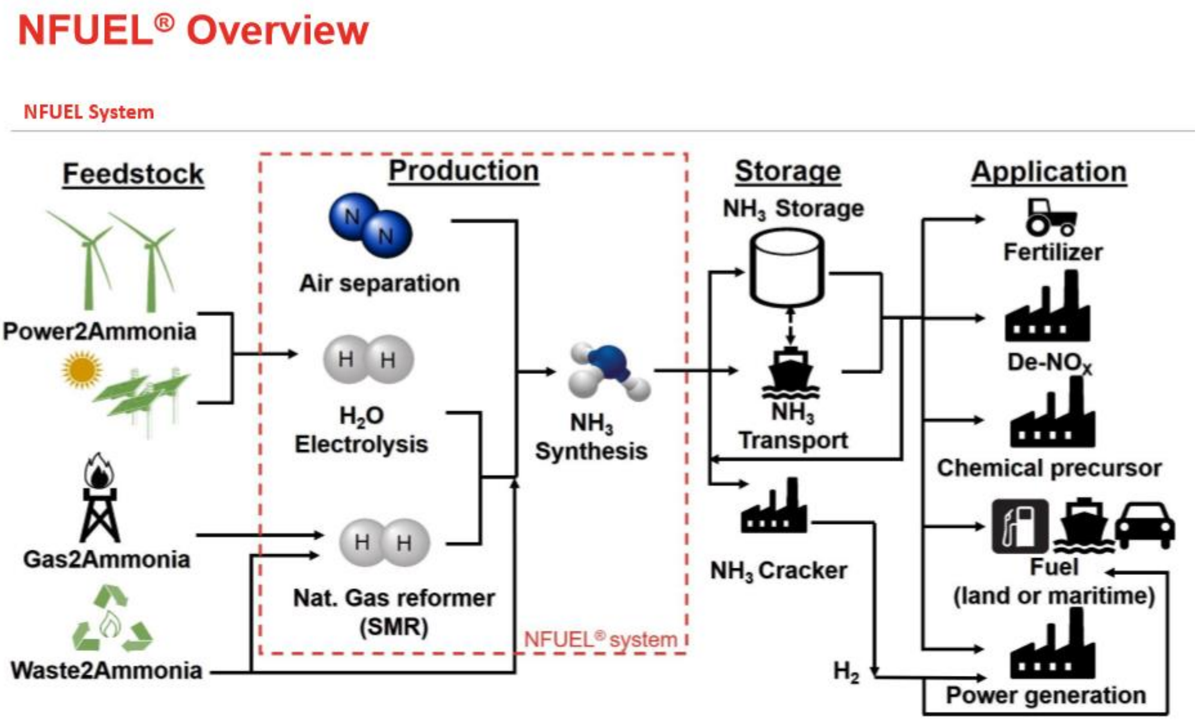


Figure 15: Simplified flow diagram of the ammonia production methods and final ammonia uses that may be available using the Nfuel system. (Proton Ventures, 2018)

Kevin Kardux, an engineer from Proton Ventures, described that for Nfuel units operating via the electrical means of hydrogen production, the cost multiplier is around 100 times, whilst if gas production is used the cost multiplier is approximately 30 times. That is:

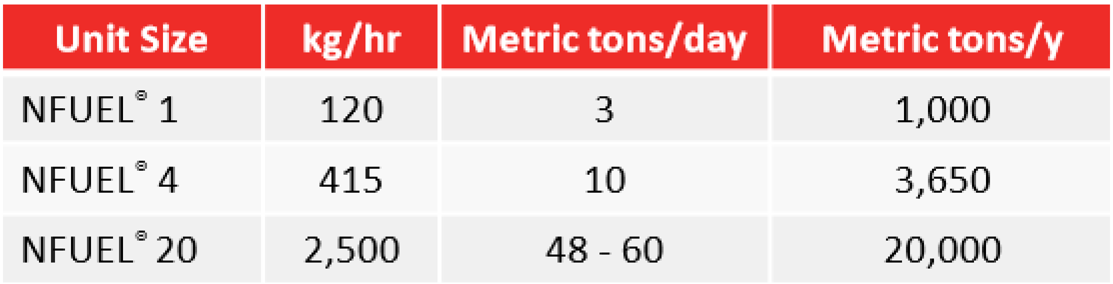
- Electrolysis Production (Electric) – $0.09AUD/KWH electricity price would equate to $900AUD/ton of produced ammonia.

- Steam Methane Reforming (Gas) – $9AUD/million BTU gas price would equate to $270AUD/ton of ammonia; with an additional ~$90AUD/ton for compressors, pumps and storage for an estimated price of $360AUD/ton of produced ammonia.

The Proton Venture team highlighted that whilst the technology has considerably improved there is still a loss in both the process efficiency of smaller facilities, as well as the capital cost per unit of installed production. The cost of production for a plant therefore needs to be carefully weighed against the localised market cost for nitrogen-based fertilisers.

Conversely, having control or ownership of the feedstock or energy source that will be used to supply the plant greatly reduces risk as the produced ammonia price is not tied directly to the natural gas price or electricity market – as is the case with most major producers. One key distinction that must be considered in an APTG context is that the gas supply being considered will be "syngas" produced through the gasification of tomato vine. It will have a lower calorific or energy value per cubic metre of supplied volume, but its component make up of CO, H2, CH4 can also be adjusted to suit by varying the temperature and pressure within the reactor during gasification. (Proton Power, 2018).

Proton Ventures is currently promoting three different sized systems to the small-scale distributed market. Table 3 below details the production capacity of each and highlights that in each case the units are intended to run 24 hours per day with an allowance for around one month of downtime for repairs per year of operation.



Unit Size	kg/hr	Metric tons/day	Metric tons/y
NFUEL® 1	120	3	1,000
NFUEL® 4	415	10	3,650
NFUEL® 20	2,500	48 - 60	20,000

Table 3: Nfuel unit sizes detailing ammonia production capacities (Proton Ventures, 2018)

As the installation is being investigated in an Australian context for an Australian installation, Proton Ventures was not able to provide pricing for a system installation. Indicative costs provided for a European installation suggested a Nfuel1 unit may be in the range $8,000,00AUD or approximately equivalent to 12-years of industry fertiliser costs, with the production capacity to sell almost 50% of the unit's ammonia production each season. This cost may in fact be lower in real terms due to the lower wage, site and material costs likely to be seen in Australia versus the more heavily developed region of the Netherlands.

Chapter 5: APTG Uptake

5.1 How implementation might work

To perform an early, coarse evaluation of the potential that distributed ammonia production may offer the Australian tomato industry, a number of key considerations need to be made.

5.1.1 Annual industry nitrogen consumption

Whilst all growers employ different agronomic practices throughout the season, the production of processing tomatoes is very similar in most instances. All growers supply the vast majority of crop nitrogen demand as "fertigation" through drip irrigation throughout the growing season with this product demand met with the use of either UAN or ammonia (Big N).

Big N and UAN tend to be cost comparable depending on grower location. Big N is employed by a large corporate grower at the northern edge of the tomato growing region near Swan Hill in Victoria. Unfortunately however, this is at the very southern end of the transport supply network as it is produced in Brisbane, hence shortages and slow deliveries can occur when demand is strong in the cotton and other cropping industries further north (Incitec Pivot, 2018). UAN is supplied via transport originally from its import terminal in Geelong in Victoria and carted via tanker to fertiliser distribution agents in the region or pumped directly into individual growers storage tanks at each pumping site ready for injection and use.

Figure 16: Map detailing the extensive freight taking place for nitrogen fertilisers to reach the processing tomato growing region. Approximately 16-hour haul from Brisbane and 3.5 hours from Geelong

In detailing prices, all consideration should be given to possible market fluctuations, business competition and seasonal factors; however, at the point of compiling this report prices paid by growers were for each product as follows:

- Big N: $1250AUD/ ton cash price delivered (Swan Hill Chemicals, 2019)
- UAN: $0.73/litre=> $553AUD/ ton delivered (North West Ag, 2018)

Conversion to applied units of nitrogen, Big N is 82%N, UAN is 46%.

- Big N: ($1250/0.82)/1000 = $1.52AUD/kg N applied
- UAN: ($553/0.425)/1000 = $1.30AUD/kgN applied

It should be noted that whilst in the above example the price of Big N was found to be greater than UAN, in practice they are comparable. The price difference seen above is likely due to the Big N price being an approximate cash quote whilst the UAN figure is cost actually incurred through a current bulk supply arrangement.

In terms of total nitrogen being applied by growers, this figure can vary greatly. This is due to soil type, direct seed versus transplant, as well as whether the paddock being fertilised is fresh ground or has had multiple tomato seasons on it already, reducing natural N levels and driving greater demand to meet yield aims. Based on work conducted by the Australian Processing Tomato Research Council (APTRC) in 2015, measuring nitrous oxide emissions from tomato production four growing sites were compared with the supplied nitrogen summarised in Table 4.

	Nitrogen supply (kg ha^{-1})			
	Soil NO_3-N	Fertiliser-N		
Site		Basal	Fertigation	Total
1	121	126	96	222
2	47	36	134	170
3	26	72	152	224
4	21	49	110	159

Table 4: Total applied nitrogen; varied sites and growing systems. (APTRC, 2015)

Utilising the data collected, an “average” nitrogen use per hectare by the industry was calculated to be 194kgN/hectare. This figure may vary considerably by season and should be viewed as a snapshot in time.

The industries yield per hectare vary considerably by grower and by season, as do the planted hectares. Using a production figure of 250,000tons of tomatoes with a yield of 100ton/hectare, the planted area can be approximated to 2,500 hectares.

Hence for each season of production the industry consumes:

194kg x 2,500ha= 485,000kgN

Therefore, UAN requirement= 485/0.425 =1,141tons/year =864,393litres/year

Or a cost of $631,000AUD/year

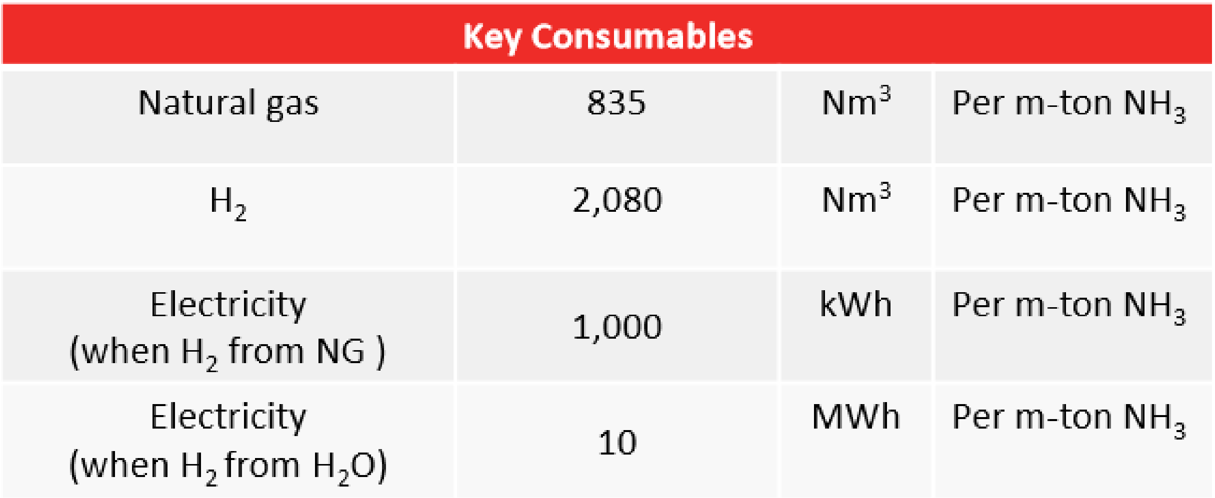
Or alternatively Big N requirement= 485/0.82 =591tons/year or a cost of $738,750AUD/year.

In terms of the environmental cost of this fossil fuel derived nitrogen fertiliser, the Australian Farm Institute 'Energy Paper' uses an energy input figure of 24.3GJ/ton of urea produced (AFI, 2018). This production currently takes place with the use of natural gas as a feedstock. This level of energy consumption translates to equivalent emissions of 1.25kgCO2e/kg urea. Whilst the industry uses UAN and Big N, urea is a product derived from ammonia and as such the magnitude of emissions is likely to be similar, or slightly higher due to the greater processing.

Hence, the Australian processing tomato industry CO2 contribution via fertiliser consumption is approximately 1,425 tons per year; a significant external cost if not a direct economic one at this time.

5.1.2 The cost to produce N demand from tomato vine

The challenge with defining the cost of ammonia production from gasification is that it involves the merging of both gasification and Nfuel technology. Whilst potentially very possible from a technical standpoint this has to date not been done. All estimates derived below should be considered theoretical estimates from available examples. Ammonia production to date has used natural gas as the primary feedstock; its constituent methane and energy composition are well known and proven. The constituent breakdown of consumables required for the Nfuel system are summarised in Table 5.



Key Consumables			
Natural gas	835	Nm^3	Per m-ton NH_3
H_2	2,080	Nm^3	Per m-ton NH_3
Electricity (when H_2 from NG)	1,000	kWh	Per m-ton NH_3
Electricity (when H_2 from H_2O)	10	MWh	Per m-ton NH_3

Table 5: Key consumables and effective conversion using Nfuel production system (Proton Ventures, 2018)

To breakdown the cost of production accurately will require further work with testing at different temperatures to gasify the vine and determine the maximum hydrogen (H2) yield per ton of dry biomass. At this point in the investigation however, an early attempt has been made to derive an approximate figure for comparison using two different methods:

1. **Comparison between the total calorific energy of natural gas versus energy expected in the gasified tomato vine**

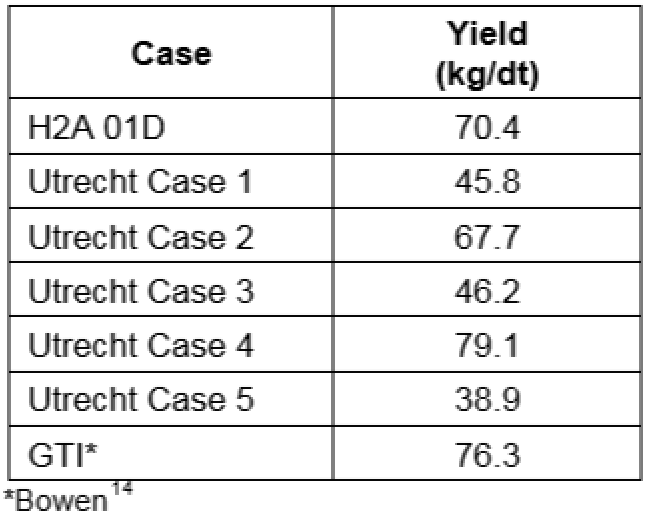
The consumption of 835Nm3 of natural gas refers to a volumetric consumption of natural gas at normal pressure, that is 1atm. 1Nm3 of natural gas at atmospheric pressure contains 0.037GJ of energy; hence a usage of 835Nm3 of gas equates to a gas energy consumption of 30.9GJ per ton of produced ammonia.

The gasification of crop residues can be estimated to yield 2m3 from every 1kg of dry biomass, whilst only retaining 50% of the biomass total calorific energy, the rest remains as non-combusted carbon in the char. (All Power Labs, 2018) A larger gasifier designed specifically to process tomato vines would likely be able to increase this yield further, but the conversion rate above serves as a baseline. Therefore, the gasification of tomato vine with a calorific energy content of 14.8MJ/kg would result in 2m3 of gas, with an energy content of 7.4MJ.

Therefore, to satisfy the energy demand of 30.9GJ per ton of ammonia in gas form would require 8,350Nm3 of produced tomato vine gas. This gas would require approximately 4.2tons of vine to create and cost an estimated $290AUD to collect from the paddock (Kilter 2018).

2. **Current estimates from existing biomass gasification literature**

The literature and data surrounding hydrogen yield from gasification is widely varied; as was the case with sites visited. All gasification is highly dependent on reactor temperature as well as the biomass feedstock being used. A hydrogen from biomass gasification cost estimate was completed by the National Renewable Energy Laboratory in Colorado in 2011, Table 6 at least attempts to combine multiple gasification hydrogen yield results to form a useful average for economic consideration.



Case	Yield (kg/dt)
H2A 01D	70.4
Utrecht Case 1	45.8
Utrecht Case 2	67.7
Utrecht Case 3	46.2
Utrecht Case 4	79.1
Utrecht Case 5	38.9
GTI*	76.3

*Bowen[14]

Table 6: Hydrogen yield per ton of dry biomass feedstock (NREL, 2011)

The average hydrogen yield per ton of dry biomass supplied equates to 60.6kg. Referring back to the H2 demand per ton of ammonia defined by the Nfuel system 2080Nm3 of hydrogen equates to a mass of 186.95kg. This would, according to the data above, require 3.1 tons of tomato vine to produce and cost $217AUD to collect from the paddock.

The other cost associated with ammonia production is the electrical demand defined within the system. This involves running the pressure swing absorption system to produce the nitrogen component of ammonia; however, the biggest demand seen at all ammonia production sites was compressor power to store and move the gases in both the nitrogen and hydrogen flow paths, both before and after reaction. Proton Ventures has defined this electrical demand as 1,000kwh per ton of ammonia produced. Using an electrical price of $0.166AUD/kwh (Momentum Energy, 2018) this equates to a cost of $166AUD per ton of ammonia. This figure could potentially be greatly reduced as the site would likely be located with access to three phase power and the level of consumption would likely achieve a commercial rate lower than the farm rate provided by Momentum Energy.

Compiling the three estimated potential input costs gives a cost of production breakdown per ton of ammonia as:

Hydrogen from tomato gasification: ($290 + $217)/2= $253.5AUD average

Electrical Consumption: $166AUD

Total: $419AUD

Hence, an industry-based plant could be expected to use 3.65tons of tomato vine and cost $419AUD/ton of ammonia. As a comparable rate of applied kgN this translates to a figure of $0.51AUD/kgN, or approximately one third of the current cost. All figures are based purely on raw operating cost, as an estimate, and exclude transport costs, capital repayments and asset depreciation.

5.1.3 Extrapolating the practical application

To meet the feed demands of an Nfuel1 unit, the industry would need to supply the consumables described above at the production rate specified to allow the system to operate with minimum downtime as the energy costs associated with bringing reactor as well as gasifier temperatures and pressures back up after a shutdown may be considerable (Proton Ventures, 2018).

Based on a production rate of ammonia of 3tons/day and 1000tons/year the system would need almost 11tons of vine per day or 3,650tons per annum as well as 1,000MWH of electricity.

As was discussed in the defining the opportunities for industry, with an estimated 10ton/ha of vine present in the paddock after harvest; there is potentially 25,000tons of vine available each season. This volume could be sufficient to produce approximately 6,800tons of ammonia with a market value of over $8,000,000AUD or an approximate 30% increase to the APTG's total revenue.

In the context of the APTG an Nfuel1 (the smallest unit) would effectively fulfil the 590 tons of ammonia required for current levels of tomato production whilst also producing a surplus 410 tons that could be sold into the broader farming marketplace at a profit to the enterprise.

The industry is also very well structured to switch to this form of production. There will be a capital cost in having growers install pressure vessels at pump sites, but the tank storage of nitrogen sources whether as UAN or ammonia is already taking place and not unfamiliar. There also exists further potential cost savings if ammonia is considered as an alternative fuel. The University of Minnesota has completed trials of reactor manifold adaptions that allow diesel to be replaced at up to 50% as the fuel source in diesel engines.

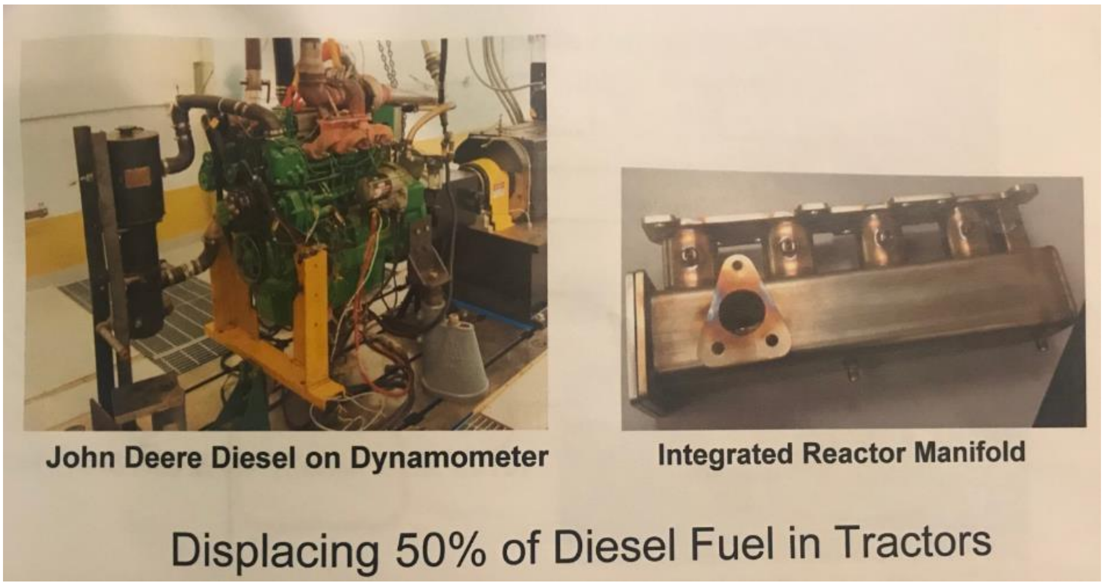


Figure 17: John Deere engine adapted to run on ammonia and diesel fuel blend. (UOM, 2018)

As defined in the industry opportunity section earlier, drip irrigation pumping is very energy intensive due to high pressures of operation and can use approximately 360 litres of diesel per hectare each season. A 50% reduction in diesel use could represent 900,000 litres less diesel being consumed across the industry each year, as well as further reducing the industries CO2e contribution by approximately 2430tons. This use would likely consume all of the excess production from a Nfuel1 unit.

There would need to be careful consideration given to the current diesel price versus the potential value in growers selling excess ammonia into the wider farming marketplace. The cost of the diesel being displaced would need to be higher than the margin that could be achieved by selling excess ammonia as a fertiliser in order for such a use to make financial sense. It does however provide an immediate secondary use for the extra ammonia if potential markets were slow to develop.

Through discussions and a visit with the Solar Thermal team at Australian National University, there may also be possible uses for the chemical by-products of ammonia production, such as CO and CO2, that more useful fuel sources could be also be derived than just ammonia from the primary process. This could further add to plant revenue and operating performance. (ANU, 2018)

Conclusion

The study of potential opportunities to utilise the Australian processing tomato industry's waste vine led to an investigation of a wide variety of technologies around the world. The study was initially conducted with a narrow focus purely on the technical aspects of each system performance, and how it might perform in a practical sense in an Australian setting.

It became very apparent during the investigation that many technologies were entirely unsuitable based on their economics being directly attributable to the country specific marketplace and political environment they were developed and operated in. This almost inadvertently drove the investigation toward ammonia production as a potential solution.

Ammonia production potentially meets the unique needs of an APTG industry that has a geographically distributed, and seasonally dependent, energy demand; with no direct on-farm need for the waste heat expected with any method of direct biomass use. In effect, it offers a potential path to produce a relatively high value product from a low value waste stream.

The potentially biggest positive from such technology is that it creates a revenue stream that is not linked to the primary production or output of the crop itself. In a world of subsidised global supply chains, any minor production gains currently being achieved to further increase the yield gap between Australian growers and the rest of the world are being covered up – or more likely exceeded – by government-funded distortions of the processed products final marketplace. Utilising the vine steps outside this market-based fault.

This investigation has potentially found a way to return income to growers via a very different way of thinking. In place of the growers trying to maintain profitability by producing more fruit per hectare, using the vine as a by-product for ammonia production may offer a way for growers to effectively "sell" their entire crop.

An aspect only briefly touched on within this report is the carbon emissions considerations and potential savings that may be achieved by the industry pursuing a path of nitrogen fertiliser independence. Whilst the total figure of reduction likely to be achieved through fertiliser production, diesel use reduction and the discontinuation of in paddock burning can only be defined as an estimate at this time, it is likely to be very significant.

This presents a great opportunity for the industry not just to be ahead of the market in mitigating rising energy costs, but actually becoming a leader in the reduction of agricultural carbon emissions. Both outcomes are hugely positive environmentally and economically.

Recommendations

- Commence an APTRC project to investigate the gasification of tomato vine to maximise hydrogen production and to accurately quantify the volume of vine produced each season. Seek funding through industry transformation grants and Hort Innovation.
- Form a grower co-op structure, or find interested investors, keen to see the technology commercialised. Set out how the supply of vine versus received ammonia transaction could take place logistically and financially.
- Define the CO2 implications and assess funding possibilities such as Australian Renewable Energy Agency (ARENA), industry transformation, or state government specific programs that may help reduce the capital investment.
- If all the above give positive technical results indicative of performance, build a business case and investment opportunity that may allow a facility to be built.
- Investigate the addition of equipment to convert the ammonia to granular urea. This could increase material storage as well as increasing the potential market of farms equipped to use the produced nitrogen source.
- Clearly define the environmental benefits and aid the Australian processors Kagome and SPC in promoting their environmental credentials by being involved in the project. Help them raise awareness to consumers about the clear environmental benefits of buying Australian. Assess the cost versus benefit of the industry becoming entirely carbon neutral.
- Investigate whether waste heat from the process could be used to dry other waste streams such as tomato pomace from paste production and produce higher value uses from this resource as well.
- Investigate whether other industry waste could form part of the supply chain and an investment vehicle in making a commercial plant a reality.

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Plain English Compendium Summary

Project Title:	**Rethinking Waste Streams. New alternatives for the Australian processing tomato industry**
Nuffield Australia Project No.:	1820
Scholar:	Andre Henry
Organisation:	Glencoe Farms Australia 2333 Loddon River Road Kerang VIC 3579
Phone:	0427 640 844
Email:	glencoefarms@outlook.com
Objectives	The objective of this report was to investigate potential technologies that exist to make use of the waste tomato vine of the Australian processing tomato industry. This could be in the form of a value-added material, or the reduction of an input cost, such as energy or fertiliser, associated with growing the crop.
Background	This project doesn't follow on from any research from previous scholars in this area. It does use data from industry to provide estimates of the cost and volume of nitrogen fertiliser use in the tomato industry currently.
Research	A number of technologies were researched. Cornboard pressed sheets from crop waste, gasification for engines, steam turbines, rankine cycles, stirling engines, uniflow engines and finally distributed ammonia production. The research took place in the UK, the Netherlands, Germany, Austria, Australia and the USA
Outcomes	Distributed ammonia production from gasified tomato vine appears the only technology that may be economically viable in an Australian setting. It represents a new market for industry and potentially a way to increase on farm returns for growers.
Implications	The technology offers serious implications, if proven, for the profitability and future of the Australian Processing Tomato Industry. It also has seriously environmental implications with the potential for the industry to move toward a zero-carbon future quicker than many production sectors.
Publications	The findings have not been published; but a presentation at the APTG forum in May is planned. Presentation at the Nuffield Australia National Conference, Brisbane, September 2019