STATEMENT OF AUTHORSHIP

The thesis contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. I give consent to the final version of my thesis being made available worldwide when deposited in the University's Digital Repository, subject to the provisions of the Copyright Act 1968.
This thesis was made possible with the assistance of many people, in particular my supervisor Professor John Rodger, from the University of Newcastle, who showed constant patience and support during the project.

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Finally, a thank you to Phillip and Aurora Adams who shared this thesis journey.
ABBREVIATIONS

Unless otherwise stated, SI units are used.

ABARES: Australian Bureau of Agricultural & Resource Economics and Sciences (Commonwealth Agency)

CV: Calorific Value

C: Carbon

CBC: Continuous Biomass Converter. The name given to The Crucible Group’s slow pyrolysis technology

CHP: Combined Heat And Power

CMA: Catchment Management Authority

DPI: Department Of Primary Industry

DTE: Dry Tonne Equivalent (dte)

EBITDA: Earnings before Interest, Tax, Depreciation and Amortization

EIA: Environment Impact Assessment

EPA: Environment Protection Authority

FAO: Food and Agriculture Organisation of the United Nations

FC: Fixed Carbon

FTE: Full Time Equivalent

GJ: Giga Joule

GHG: Green House Gas

HTT: Highest Treatment Temperature

HM: Holistic Management

IEA: International Energy Agency

LCA: Life Cycle Analysis

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LGA: Local Government Area
MWh: Megawatt Hour
Mtpa: Million Tonnes Per Annum
MSC: Muswellbrook Shire Council
NSW: New South Wales
N: Nitrogen
PA: Pyroligneous Acid
REC: Renewable Energy Certificate
ROM: Run Of Mine
SOC: Soil Organic Carbon
SMH: Sydney Morning Herald
TNS: The Natural Step
TM: Total Moisture
VM: Volatile Matter
DEFINITIONS

The following definitions have been used throughout this thesis.

AFFORESTATION: Planted on previously non-forested lands

ANTHROPOGENIC: human–caused

BIOSOLIDS: Treated sewage sludge

BIO-FERTILISERS: compost, inoculants, soil stimulants, minerals

CONSERVATION AGRICULTURE: A term used by the industrial agricultural sector

DIOXIN: A toxic molecule that can be formed in some biomass conversion processes, especially in gasifiers that operate at high temperatures.

GROSS BIOMASS ENERGY: The total energy contained in biomass before conversion or after.

GREENHOUSE GASES: Gases that if accumulated in the atmosphere enhance the greenhouse effect, and thereby impact on climate change.

HOMOGENEOUS FEEDSTOCK: Biomass of one type used for bioenergy

INDUSTRIAL FERTILISERS: Fossil–fuel based inputs such as super phosphates

MALLEE: A low growing, multi-stemmed hardwood native timber (can refer to the low rainfall region in Victoria)

REFORESTATION: Planting on previously forested lands

SYNGAS: Made up of CO, H₂, also referred to as synthesis gas and synthetic gas
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ABSTRACT

New technology is important to provide the best solutions to reduce Greenhouse Gas emissions and draw down legacy CO₂ levels. A new slow pyrolysis technology called a continuous biomass converter is investigated for early adoption in the Upper Hunter Valley of Australia. Primarily using The Natural Step sustainability methodology to assess the potential ecological, cultural and economic impacts, this strategic assessment connects business development and regional plans within a changing agricultural sector.

This transdisciplinary approach addresses interconnected questions between the conversion technology, the biomass supply (inputs), the unique products produced (outputs) and their potential applications to create a more sustainable future.

The biomass options in the study area are shown to be diverse and while most are accounted for, a reallocation of some could form the foundation of a secure long-term supply. Green waste is identified as the preferred feedstock for early adoption. Assessment of char (referred to as biochar when used in soil) and pyrolysis liquid (also called wood vinegar) includes a randomised block design field trial to establish dosage levels and confirms biochar and pyrolysis liquid can be advantageous for plant growth.

By engaging with existing industries as well as creating new business pathways, these findings have important implications for future land use and regional climate change mitigation choices.
CHAPTER 1  INTRODUCTION

1.1 Thesis Overview

This research has been undertaken to better understand land use and the value of Hunter Valley biomass in all its different forms with the prospects of its use for a continuous biomass converter (CBC) a new slow pyrolysis technology developed by the project industry partner, The Crucible Group Pty Ltd (TCG).

Using this innovative technology template throughout the thesis provided clear energy efficiency and volume parameters from which the true value of land use change and feedstock could be assessed as well as applications for the products. Prior to this thesis, a technical proof of concept prototype of the continuous biomass converter was designed and tested in Newcastle, Australia, which lead to a series of patents being granted. The design has received Government support and the operation of the first commercial scale demonstration plant was achieved in 2012.

The thesis objective is to test the various requirements for the technology uptake using a sustainability lens to assess the costs, efficiencies and cultural values. As the continuous biomass converter provides three outputs; gas, liquid and solid, the biomass requirements can vary according to the primary output need.

The char output is especially relevant in the Hunter Valley as it offers unique opportunities for carbon bio-sequestration as so much carbon has been removed as coal. Coal mining creates radical land use changes with unknown long-term consequences. At the same time there has been considerable regional discussion at all political levels to develop systems to reduce greenhouse gas (GHG) emissions, sequester carbon and develop less coal dependent industries. (Hunter Region Organisation of Councils, 1995, p. 138).

Research began with a fascination with the char output. This dense carbon rich product has been renamed as biochar in the literature to differentiate its use in land applications (Lehmann, 2007b). Char also has industrial uses as an energy source and as a reductant, but its use as an agronomic amendment
while having extensive historical uses is being rediscovered and applied in modern agricultural systems (Glaser, Lehmann, & Zech, 2002). Could biochar do in the 21st century what archaeologists are claiming it did thousands of years ago? Could it build carbon in soil and create a more fertile landscape? (Sombroek et al., 2002). Recent research suggests the answer is yes.

If this is correct the following questions needed answering.

- Could the continuous biomass converter technology do this?
- Where is the necessary biomass feedstock for production?
- Where is the most cost effective place to apply the biochar?

As the continuous biomass converter technology developed and the liquid output analysed the opportunity of using this output agronomically with or without biochar became important for the full sustainability of the operation. Literature in Asia suggests pyrolysis liquid has important agronomic qualities and can be advantageous in pesticide management. The volumes, rates, crops used for this were so varied in the literature it became important to test the biochar and pyrolysis liquid together in a field trial on soils in the Hunter Valley (Chapter 7). These products may in turn be useful in developing a future biomass supply stream.

In the coal rich Muswellbrook LGA agriculture and non-agricultural biomass options have been devalued and overtaken as the intensification of the coal sector developed. With changing landscapes created by coal mining the future local biomass supply will undoubtedly evolve. Yet a biomass supply needs to be secured before a sustainable continuous biomass converter project can be realised. This will help create the scene for a post coal economy.

**1.2 Thesis Structure**

Chapter 1. Introduction. (This chapter) Explains the overarching concepts, sets the global, national and local context. Introduces the theoretical foundations regarding complexity theory and sustainability and describes the research aims.
Chapter 2. Methodology and Methods. Details the methodologies assessed and chosen and the methods used to develop the arguments. The Muswellbrook Local Government Area (LGA) as the case study is defined.

Chapter 3. Pyrolysis. Reviews slow pyrolysis as a renewable energy system, focusing on the continuous biomass converter (CBC), designed by The Crucible Group (TCG).

Chapter 4. Biomass. Assesses the type, volume and availability of the current biomass in the Muswellbrook LGA. Reviews biomass supply systems from a commercial and ecological perspective. Defines related land use and water use issues. Concludes what biomass could be used for the first production facility.

Chapter 5. Biochar. Discusses the important properties of biochar. Outlines the status of biochar globally from a materials research and production perspective. Assesses potential applications and opportunities in the study area.

Chapter 6. Pyrolysis Liquid. Assesses the properties and expected production rates of the pyrolysis liquid product. Reviews the status of pyrolysis liquids globally from a research and applications perspective. Considers the opportunities that might exist in the Muswellbrook area, in the short and long term.

Chapter 7. Experimental Investigations. Due to the lack of literature using pyrolysis liquid and biochar together, a field trial was carried out during the summer of 2012-2013 to test growth rates of cowpeas on a Hunter Valley soil.

Chapter 8. Discussion. Integrates the key insights from the above chapters and assesses the CBC opportunity as a whole to create a new sustainable land use vision. It addresses the concept of energy crops, the fuel versus food debate, mining rehabilitation obligations, potential emissions, logistics, financial considerations and outlines where the best place to start may be.

Chapter 9. Conclusion.
1.3 Thesis Context

The Global Setting

The beginning of the 21st century will be remembered as a significant point in time when scientific research confirmed planet earth’s present trajectory will lead to climate change. Atmospheric CO$_2$ concentrations have increased by more than 40% compared to pre-industrial levels (Solomon, 2007). This increase is primarily accredited to fossil fuel use but also to net land use change. The attribution of climate change being caused by human influence is viewed by the 2013 IPCC report as being extremely likely.

Coinciding with this is the other global issue of poverty. In the year 2000, 189 nations, including Australia made a commitment to free an estimated 1.6 billion people from extreme poverty and multiple deprivations. Deprived of grid-connected services, 2.4 billion people in developing countries suffer from Energy Poverty. They primarily use only biomass for their domestic consumption (IEA world energy outlook 2010 Paris Energy Agency), and are deprived of many economic and personal opportunities. This United Nations pledge, known as the Eight Millennium Development Goals (MDG’s) was to be achieved by 2015. In September 2010, members recommitted to accelerate progress towards these goals claiming affordable sustainable renewable energy systems are essential to eliminate poverty and achieve the Millennium Development Goals (United Nations, 2011).

By 2012, integrating sustainable development goals (SDG’s) into the MDG’s became necessary since the speed of negative ecological change and the continuation of poverty indicated the goals could not be reached on time and merely extending them for a few more years was unlikely to achieve success (United Nations, 2011). Rapid climate change was creating, or, had already created, a new geological epoch, the ‘Anthropocene’ and was requiring new interpretations of sustainable development (Steffen et al., 2011).

The triple bottom line approach to sustainability, where environmental, social and economic considerations are addressed has been the binding principle since the 1987 Brundtland Commission, but new goal-setting over-arching views ‘safeguarding the earth’s life-support system’ may be needed to articulate
more effectively the urgency in curtailing negative climate change (Griggs et al., 2013).

**Estimated Biomass Volumes**

When the oil era began at the start of the 20th century, plants lost their status as raw materials for fuel in the developed world. Today after almost a century of neglect the bioenergy sector is now identified as a future component of the energy industry. Bioenergy is an industry made up of many different feedstocks and processes and is increasingly varied in terms of its applications. It is the only renewable energy system that can replace fossil fuels in the various solid, liquid, gas and electric forms; heat, electricity, transport fuels etc. Biomass feedstock volumes, types and agricultural requirements are one subset of the industry while technological conversion options and their various products make up another. Within all categories, questions of sustainability and preferred methodologies for analysis exist.

Biomass feedstock production may compete with agriculture, forestry and conservation (ecosystem services) for our natural resources and therefore needs to prove it can be grown sustainably. The International Energy Agency (IEA) suggests bioenergy projects will in most cases lead to direct and indirect land use change. The largest biomass potential is expected to lie in large-scale energy plantations with adequate rainfall to maximise production (Berndes, Hoogwijk, & van den Broek, 2003). There will be some instances where no land-use change will occur (Berndes, Bird, & Cowie, 2011). By-products such as green waste, agricultural and forestry residues can provide accessible biomass without substantial land use change.

Numerous reports and analysis suggest the world has enough volume and variety of biomass feedstocks for diverse industries (Berndes et al., 2003; Bryan, Ward, & Hobbs, 2008; Ericsson & Nilsson, 2006; Field, Campbell, & Lobell, 2008; Klass, 1998). However, there is no consensus on the best conversion technologies or a best method to calculate the ecosystem impact and GHG savings from bioenergy (Klass, 1998; Lowenberg-DeBoer & López-Pereira, 1990; Rosillo-Calle, de Groot, Hemstock, & Woods, 2007).

There is a substantial variation in volumes available from existing agricultural and forestry crops and residues, largely due to regional climatic differences.
Brazil’s sugar, India’s jatropha, and Indonesia and Malaysia’s palm oil crops offer specific energy options not available in the Hunter Valley. Although sugar cane is a well established crop in Australia and the ethanol industry is a growing subset within the bioenergy field it will not be considered in this review, as the Hunter Valley is unlikely to ever be part of the sugar industry due to rainfall and land restraints, nor is it physically close enough to the industry to justify importing the biomass source.

While frameworks for assessing sustainability are many, varied and complex there has been no quantification of sustainable biomass specifically for slow pyrolysis in Australia. A new energy system must overcome technological hurdles to achieve plausibility but thereafter faces political, economic and social hurdles both on a local and national scale to become viable. A new bioenergy pathway needs to have low GHG emissions and existing European bioenergy systems using different technologies indicate there is a GHG reduction potential of 2.5-15.5Gt per year, (which is 5-33% of 2011 GHG emissions) (Sterner & Fritsche, 2011).

While there is agreement of some aspects of what constitutes sustainable biomass production, there remains little consensus on the effects of growing biomass-specific crops on the soil carbon and nitrogen cycles across Australia’s vastly different soil types. The extensive variability of Australia’s biological systems imposes complex statistical procedures. The challenge has been to position The Crucible Group’s continuous biomass converter technology within a logical structure of analysis that also allows for the integration of local characteristics. The potential of the biochar CBC by-product to develop healthier soils and sequester carbon is exciting research territory but to focus on it before it can be sustainably produced seemed futile. Biochar depends on slow pyrolysis and slow pyrolysis depends on sustainable biomass. For a sustainable bioenergy industry to succeed it must become part of a new sustainable agricultural paradigm.

Australia’s land management policies have been undergoing a thorough review in light of climate change data. In New South Wales it is highlighted by the number of land management reports undertaken since 2000 conducted by government, (NSW Government Department of Primary Industries; Rural Industries Research and Development Corporation), joint private and public
assessments (Insight Economics, 2006) as well as private think tanks
(Australian Farm Institute) and Universities. Together these demonstrate a
vast cross section of industries and individuals working to improve Australia’s
land management.

Future projections demonstrate the bioenergy sector is expected to expand
globally by 2050 and at the same time provide welcome greenhouse gas (GHG)
savings and other environmental benefits. This is based on the fact that 2050
world energy demand projections have risen to 1000EJ, suggesting demand
for bioenergy could therefore be as high as 250EJ/yr (IEA, 2009). As the
bioenergy sector grows so too will the trade in biomass (Heinimö & Junginger,
2009).

Improving energy systems is a recognised global necessity and an area where
Australia, and in particular the Hunter Valley, is in a strong position to lead
with energy innovation because after more than a century of investment in
energy delivery, Australia today enjoys electricity access of the highest
standard enabling benefits at the personal, household, community and
industrial level. Slow pyrolysis could be an important option in developing
distributed power production (mini-grid or off-grid) for Australia, across our
vast continent, and for the rest of the world. The changes that will be required
in the future will not only be technological but social, economic and cultural.
This research identifies these political, financial and social constraints needing
to be reconciled before implementation of an industrial scale pyrolysis
industry. It also provides a regional-based framework from which
sustainability can be analysed.

The Australian Political Setting

The politics of Climate Change policy in Australia has been fought with
increasing tenacity since the Rio Summit in 1992. Numerous books have
highlighted the arguments that have raged across most corridors of
commentary, influence, scholarship and power since that time (Flannery,

When this study began, the Australian government had ratified the Kyoto
protocol, the Garnaut Climate Change Review (Garnaut, 2008) had been
published and the government was working on developing an Emissions
Trading Scheme (ETS) called a Carbon Pollution Reduction Plan. When this plan failed to be passed in the Senate (it was blocked by the conservative parties for being unnecessary and the Greens for being inadequate) the then Prime Minister, Kevin Rudd, chose to delay the introduction of any ETS.

Months later Rudd was voted out by his caucus and new Prime Minister Julia Gillard went to the polls a few months later insisting there would be no carbon tax. When forced to form a minority government with the Greens and Independents, Prime Minister Gillard reneged on her undertaking and implemented a carbon tax. On July 1, 2012 a carbon tax was passed in the Senate and for the first time Australia had a national policy to price and reduce the carbon pollution created by the nation’s biggest polluters.

This scheme became a political thorn and by 2013, Gillard was deposed by Rudd, the carbon tax’s death had been decided, an execution date announced. The new Prime Minister promised to convert the carbon tax immediately back to an ETS if re-elected. The Coalition, promised to have neither. In September 2013, Tony Abbott, the coalition parties’ leader, became prime minister having vowed to scrap the carbon tax and in July 2014 the tax was rescinded.

In this volatile political context with its increasingly complex machinations, renewable energy options were constantly being revised. Small schemes emphasising energy efficiency improvements were implemented with state and local regulations leading the way. However, during this time the structural changes needed to curtail our biggest polluting sectors - mining, transport and agriculture - were stalled. A polluting company was only likely to change its ways if law demanded it.

The question became: how long were the polluting sectors going to be allowed to continue in the present political and ecological climate?

The 2012 carbon tax meant the cost of producing coal-fired electricity increased. If the power stations wanted to reduce their carbon tax bill they needed to reduce their emissions. This led to the continuous biomass converter technology being considered as a unique system that could be retrofitted to an existing coal-fired power station. The gas could be fed directly to the boilers and the char stream used as a coal replacement. TCG were offered a location on the Delta Electricity power station premises at Vales Point,
in New South Wales, where their technology could be developed to co-fire char with coal. The carbon tax meant co-firing char with coal and/or biomass was cost effective. It was a clear case of tax forcing a structural change towards a renewable energy alternative. When the carbon tax was rescinded new financial considerations needed adjustment.

News reports have blamed Australia’s fluctuating climate change policy for creating business uncertainty and driving renewable energy investment to the lowest in 13 years. There was a decline from $40m in 2013 to $2.7m in the first six months of 2014 (International Business Times). The political backdrop for this study remains volatile, making financial assessments challenging.

Back in 1992 the Earth Summit (United Nations, 1992) concluded that existing policies were unlikely to create a sustainable world with adequate emission reductions. The world needed to live differently. Doing nothing is not an option (United Nations Environment Program, 2002; Yencken & Wilkinson, 2000).

While bioenergy is currently a small industry in Australia its use is projected to increase. It accounted for only 4% of Australia’s primary energy consumption in 2007–08 representing 78% of Australia’s renewable energy use. The renewable energy target (RET) changed in 2009 and is now expected to produce 20% of Australia’s electricity needs by 2020, requiring an additional 9500GWh (Clean Energy Council). The CBC is one technology that could become part of the new way of doing business.

1.4 Theoretical Foundations

Embedding the research within a sustainability framework was essential to evaluate the full impacts of biomass for a new technology. The challenge has been that sustainability theory itself is fluid and forever broadening. While sustainability theory incorporates economic modelling to evaluate how natural capital as well as financial capital can be sustained (Daly, 1990; Jones, Pimbert, & Jiggins, 2011; Labuschagne, 2005), there are many different models used by different industries. While bioenergy may be perceived to fall within the category of renewable energy and liquid fuels primarily, slow pyrolysis’s unique capacity to provide a solid char output for energy or land use, means it may also be just as important for the natural resource sector.
Consequently, this research inevitably crosses disciplines and business sectors.

Complexity

The overarching philosophical view within the sustainability framework was one of complexity incorporating the relationships between land ownership, innovation, new land use options, biomass capacity and intentions for its use. The environment was not to be separated from its historical evolution to present day ownership nor were financial considerations to be left out. Complexity theory needed to be embedded across the physical, social and ecological sciences.

Holling (2001) points out, when the ecological and social systems come together within this complexity, they form a panarchy where systems invent, experiment and create opportunities. Within the panarchy lay the potential for sustainable development. In visioning the evolution of renewable energy a reminder of the computer sector’s development, provides insights as to how applications of technology drive further change, as the invention of semiconductors led to main frames, which led to integrated circuits, then microprocessors which in turn opened up the personal computer revolution and the cheap computers we can access today (Malerba, 2013). The renewable energy sector also presents a wide variety of evolutionary systems with different capabilities, different uses, different innovators who work across vertical and horizontal boundaries across nations, companies, universities and tiers of government (Nelson & Winter, 1982).

Slow pyrolysis globally is a small renewable energy sector and presently an undeveloped component of Australia’s bioenergy industry. This, combined with the fact that there is no developed market for the multiple outputs of the technology, meant positioning the analysis within a nascent sub section of the greater renewable industry. Slow pyrolysis represents a different way of managing biomass because the outputs are unique.

Critical inquiry alone will not and cannot achieve an end while all relationships are in constant flux. Kincheloe and McLaren (2002) discuss the fundamentals of critical enquiry and outline clearly how our basic assumptions form the foundation of critical thought. These include
assumptions such as the decisions being made through power relationships, how facts are not isolated from values, relationships are not stable, language has a conscious and unconscious awareness and impact, certain people have privileges over others in society, and how historical prejudices are usually embedded in research practices.

The theoretical concept of complexity is valid here as climate change problems and solutions are so interrelated. The over arching fact of the science and the intricate detail of impacts and solutions require unique considerations. Thus the theoretical view behind this research assumes that climate change is an inclusive threat to the entire global community. As solutions to mitigate will drive a positive global outcome there is the potential that a greater primary or direct negative effect could be experienced more in some local areas as economic development moves away from fossil fuel based industries. Could the Hunter Valley be one of those local regions to suffer? Transitioning from coal mining and coal-fired energy is likely to create secondary negative effects, that is, impacts where the scope and timing will be different to primary impacts. These considerations will not be fully realised until the closure of the coal sector is underway and the project monitoring of impacts has slowed or ended. There is the likelihood and expectation of significant impacts, both human and ecological, with particular effect relating to biodiversity loss and water volume and quality. The Energy and Biodiversity Initiative 2001-2007 produced numerous tools during this time and highlighted likely long-term impacts that were generally referred to as negative secondary impacts (The Energy and Biodiversity Initiative). These impacts are discussed in Chapter 8.

In conclusion this research led to exploring linkages between the physical reality of the biomass availability, the infrastructure development options available in the LGA and the government directives to incorporate energy efficiency and GHG mitigation.

**Sustainability: Transdisciplinarity Approach**

The terms inter-disciplinary and trans-disciplinary have come to mean hybrid knowledge where multiple academic and non-academic thought-styles are engaged to both refine the theoretical fundamentals of research and reach a useful socially relevant real-world outcome (Pohl, 2011). Recognising the
importance of multiple participants is important in transdisciplinary research. For instance, in this thesis the research of the Dairy Cooperative Research Centre (CRC), while not immediately obvious for bioenergy research, revealed the scope and present status of dairy farmer’s management techniques used to increase their fodder output. While the data gained was primarily for industry knowledge and farmer education, it revealed for this research the present status of farm mechanisation and the level of productivity gains. This provided a potential biomass capacity framework and helped in understanding how fodder is presently produced in the area.

To properly reimagine our biomass resources, whether naturally or specially grown or generated by what we have come to call a waste stream, needs this uniting of knowledge from different disciplines. Underlying this research has been the principles of sustainability, and how these are incorporated into the various inter-disciplinary methodologies used in biological processes and agricultural modelling. Initially the study considered sustainability requirements for the three different components necessary for a pyrolysis industry.

- The biomass needed for the technology.
- The conversion technology itself.
- Char and pyrolysis liquid as unique products produced during the process.

The thesis accepts that reality exists on many levels (Nicolescu, 2002), and that any new technology should not automatically be viewed as an improvement. An inter-disciplinary approach has been chosen to examine the socio, ecological and financial impacts of biomass for a continuous biomass converter.

Transdisciplinarity has its beginnings with Erich Jantsch, who advocated the value of coordinating science, innovation with education for specific benefits for society (Jantsch, 1972; Pohl, 2008). The application of this approach has been frequently applied to the collaboration of medical, natural, and social sciences, plus engineering and humanities (Pohl, 2011). A useful example of transdisciplinary research by ( Aeberhard & Rist, 2009) demonstrated how organic agricultural practice in Switzerland evolved. When organic farming began as a formal defined idea in the 1920’s, farmers, scientists and extension
agencies collaborated with a common philosophical goal. Ideas were generated by both pioneering scientific knowledge and local farmer experience. As the innovations within organic agriculture grew and institutions were established to develop and promote it, a gradual segregation of thoughts emerged yet cooperation remained a strong core value.

**Sustainability: An Evolving Concept**

Any new energy technology needs to be examined in light of meeting the latest and accepted sustainability criteria. While there have been many global and local summits on climate change, there have also been ongoing additions to what are considered ‘essential’ aspects of sustainability (Bell & Morse, 2008; Dovers, 2005; Kates et al., 2001; Lal, Stewart, Uphoff, & Hansen, 2005; Stigson, 2011). New protocols are constantly being advanced for consideration.

The broad concept of sustainability or sustainable development has not stopped evolving since the Brundtland Commission Report (World Commission on Environment and Development, 1987). It has become a concept defined in many different ways according to industry and need, but a few fundamental principle assumptions have gained consensus. Namely that there are limits to the world’s natural resources and that inequitable access to them is due to historical and social discrimination (World Commission on Environment and Development, 1987).

The Commission defined sustainable development as meeting the needs and aspirations of present and future generations without compromising the ability of future generations to meet their needs. (Brundtland, 1989)

Recognising and accepting the finite nature of Earth’s bounty needs to be the new starting point from which all measurements and assessments should derive. Different industries have drawn up new indicators to reveal actions leading towards or away from sustainability. In chapter 8 of Agenda 21, *Making Decisions for Sustainable Development* (United Nations, 1992), criteria for economic, social and environmental dimensions were outlined and reaffirmed in 2002. By 1997 the United Nations had established their Global Reporting Initiatives. Different scientific understandings and different knowledge bases for similar problems could often lead to multidisciplinary approaches being difficult to integrate. While all approaches may seek to ask
the same ultimate question; what is the capacity of this ecosystem to sustain itself? The threads to the answer are long and diverse.

People, an important part of any resource base, have been repositioned with gender finding a new focus in future partnerships. Gone are the old constructs of women being used for breeding or cheap labour (Waring, 1988). Proper accounting of paid and unpaid human services in the natural world are now firmly on the table. The evolving principles are showing the emergence of language specifics as the ambitions of sustainability become better understood and taken up. In the process numerous frameworks have evolved. As the literature on sustainability grows, covering wider areas of study, there has become a canon of sorts, with a strong differentiation between sustainability in ecology and sustainability in economic policy and ethics.

The task for this thesis has been to overcome the isolation of sustainability within different disciplines (Daly, 1990) and to develop new operational principles, while at the same time be inclusive. The development of so many unique sustainability frameworks has meant increasing complexity.

Hawken, Daly, Holmberg, and Robert (1997) outline four principles - System Conditions, or first order principles of sustainability and argues for a ‘compass’ for ecological sustainable development.

• Does this measure decrease our dependence on lithospheric metals, fuels and other minerals primarily when waste from such materials are already accumulating in the ecosphere?
• Does this measure decrease our dependence on persistent unnatural substances, primarily when such substances are already accumulating in the ecosphere?
• Does this measure decrease our dependence on activities which encroach on productive parts of Nature, e.g. long distance transport or other deleterious exploitation of green surfaces, over-fishing etc?
• Does this measure decrease our dependence on using an unnecessary large amount of resources in relation to added human value? (Hawken et al., 1997)

These principles are all necessary, do not overlap, and are applicable for different activities and different scales. Therefore a sustainable renewable
resource is one where the harvest rate needs to, at least, equal the regeneration rate. Otherwise the yields cannot be sustained (Daly, 1990). Hargroves and Smith (2005), suggest the equation of assessment is simple. A sustainable development must have the ‘ability to sustain’ itself. Since this research project focuses on the Muswellbrook LGA where the coal industry is the dominant economic driver, coal will be an important consideration when assessing the bioenergy alternatives. As coal is mined, not grown it presents a challenge to interpretations of sustainability. Its extraction is not sustainable because once removed it cannot be replaced (in the geological short term). But are the peripheral industries servicing the mining sector such as engineering, mechanical, environmental management companies sustainable enough in their own right to be profitable in a post coal economy? And does it matter?

In general, business has been slow to integrate sustainability principles into core business practises (Stigson, 2011). According to the World Business Council for Sustainable Development at the Business Council of Australia conference in 2011, there was no agreement within business associations on how to solve the issue of the four main natural systems of Energy, Water, Food and Land Use. Stigson (2011) argues for the pressing need to improve understanding between environmental and economic dimensions, the pricing of energy to be clarified and the funding for infrastructure to be secured so progress can be achieved.

Biological processes are complex and forever changing, therefore it is to be expected that complexity theory when applied to sustainability will broaden. This in turn has the potential to thwart or delay decision-making and this has been one of the biggest criticisms of the ever-broadening sustainability space (Robert et al., 2002) which may account for why the business sector is slow to reach agreement.

### 1.5 Research Aims

The goal of this research is to add to the knowledge necessary to develop economically sustainable renewable energy hubs and provide an understanding of the decisions and ecological underpinnings that guide this new continuous biomass converter renewable energy innovation. Specifically it will:
• Investigate the existing available biomass in the Muswellbrook LGA for a slow pyrolysis industry. This stage of the project examines the data collected as outlined in the methodology.
• Assess where and how future biomass can be grown, harvested and delivered for a slow pyrolysis industry.
• Test the CBC products use in the study area.
• Identify and analyse the constraints a CBC may face.

This research:

• Investigates the biomass options in a selected region.
• Analyses the full capacity of the biomass conversion.
• Collates a more extensive database of land use practises.
• Explores agro ecology options.
• Defines a future sustainable agricultural system.
• Identifies options for biomass use.
• Uncovers new values for biomass
• Suggests where and how the CBC outputs could be used

1.6 Summary

Slow pyrolysis technology is not easy to explain or promote to the non-scientist. The word pyrolysis, unlike wind or solar, is not in common use in the vocabulary. And while the technology of wind and solar may not be deeply understood, the core knowledge, that wind drives a turbine to produce energy which becomes electricity, is generally understood. The same principle of the sun capturing energy for our use is understood. Pyrolysis does not enjoy the same knowledge base underlying the innovation.

It is hoped that this research will contribute to a better understanding of the technology as a renewable energy option. Slow pyrolysis will only become a successful climate change mitigation technology solution if it can initially secure sustainable biomass.

While good ideas abound in the theoretical renewable economy, application of a developing technology is at the heart of this study. This is why the research defined a precise geographical location and non-theoretical data was assessed. Sustainability criteria and the concept of land use change have been
problematic when considering bioenergy. ‘No land-use change’ is often highlighted as a bioenergy sustainability criteria and yet, the present land-use is unsustainable. There is a conflict of intentions where we need to improve existing land use management and uptake sustainability principles - yet there is resistance to most bioenergy production for fear of changing our unsustainable land-use. The only generally accepted land-use change is where previous croplands or agricultural lands have been abandoned. This is an important consideration for the Muswellbrook LGA with so much abandoned agricultural and mine-used land.

This catch-22 scenario needs to be overcome for bioenergy to succeed. Evaluating the true impacts and costs of a CBC in the Muswellbrook LGA via a sustainability lens will hopefully contribute to clarification.

The thesis does not seek to add to climate science but to explore specific, possible responses. It adopts the prevailing scientific view that global society is impacting on the climate in a way that threatens major ecological, societal and economic harm, primarily through the use of fossil fuels and poor agricultural practices. Appropriate responses must therefore include both a shift to renewable energy and regenerative land practices, and moreover address the legacy issues of accumulated GHG in the atmosphere and the accumulated impact of unsustainable use of land.
CHAPTER 2  METHODOLOGY AND METHODS

2.1 Background to Methodology and Method Review

Chapter 1 outlined the ‘philosophical stance informing the methodology’ as described by Crotty in *The Foundations of Social Research* (Crotty, 1998) and drew on the notion of complexity and the use of transdisciplinarity. Defining the philosophical stance was a priority to provide the context for the methods used to ground the logic and criteria of the research. This thesis accepts that current ideology influences social research and agrees with Crotty that ultimately the goals of critical enquiry are to focus on justice, freedom and equity. Therefore it was important to embed this research within a cross section of methodologies where the ‘culture’ of present day agriculture and its biomass could be analysed in different ways so that all its diversity and needs be acknowledged and included. It is as Crotty points out, ‘knowledge in the context of action’ (Crotty, 1998). The research is problem driven and theoretical analysis is linked to practical solutions of climate change mitigation and global sustainability.

The thesis sought to understand the true volume and value of the present biomass as it currently stands. Then, with understanding the natural resources and inputs used to grow the biomass, perhaps some of the bioenergy systems operating overseas could be useful for comparison and lead to an understanding of developing bioenergy specific crops.

The starting hypothesis began with the assumption that there was likely to be an ample supply of biomass. What was unclear was the value of it, the present use of it and its location.

At the start it was necessary to review sustainability systems used to see which method of analysis was most applicable. Without agreed global accreditation standards, assessment criteria were drawing on numerous frameworks and tools used in urban and rural areas developed within such social sciences as economics as well as environmental and technical analysis. Thus combining relevant sections is needed to understand what a sustainable use of biomass for pyrolysis could be in a designated geographical area.
Different terminology is also used in different frameworks when measuring the same thing. For example ecosystem services is sometimes referred to as an externality; a life cycle assessment is also a sustainability assessment tool. Sustainability Frameworks developed since the 1992 Earth Summit, now cross-reference each other and are regularly updated and expanded to include new considerations. Sustainability is often addressed within the supply chain management of a business. Monitoring risk, transparency and disclosure requirements have become more important in the sustainability assessment process (International Finance Corporation, 2012) but there is a significant difference between an operating company or institution reviewing their existing processes and a new company or institution creating, for the first time, their sustainability framework.

From a local government perspective, Local Government NSW has outlined preferred methods to assess climate change mitigation options for their own operations (Local Government New South Wales, 2014). This is a local government lead-by-example initiative where the work varies greatly across different LGA’s. An internet based multi criteria analysis (MCA) tool is used to classify emission reduction actions into high, medium or low priority is recommended. Muswellbrook Shire uses this and has undertaken climate change assessments that are incorporated into their State of the Environment reports.

The 2009 RIRDC document, Sustainable Production of Bioenergy (O’Connell et al., 2009) was especially useful in viewing assessment systems, and exposing problems. There are outstanding issues to be resolved around the burden of proof of sustainability being placed on bioenergy especially in situations where land and water resources are shared between many production systems; the drivers for land use change are many-fold and the causal linkages to indirect effects are not clear. As there is no bioenergy industry presently operating, assumptions have been made to justify cross-referencing for comparisons.

Does the delivery of biomass as a feedstock for a single pyrolysis unit offer a greater return for the landowner than, for instance, the sale of hay, conversion to milk, beef, wool or horticulture? Understanding where the potential profit of biomass production is will always be site specific, as it must be compared with real alternative land uses. Will the biomass be created and supplied by many
land owners, thus democratising the business of bioenergy delivery or will the feedstock be intensified and controlled by a few, even the pyrolysis operator?

With this in mind it was decided to focus on action research with document and comparative analysis.

Vitousek, Mooney, Lubchenco, and Melillo (1997) points out, ‘it is clear that we live on a human-dominated planet’ and that the concept of ‘human dominated ecosystems’ applies everywhere. No ecosystem can claim to be free from human influence therefore a systems thinking approach is useful. With this in mind, many tools and terminology have been considered and at least implicitly informed the research. These include:

The Natural Step
Backcasting
State of the Environment
Holistic Management
Environment Impact Assessment
Industrial Ecology
Input-Output Analysis
Life Cycle Analysis
Material Flow Analysis
Substance Flow Analysis
Ecological Capitalism
Ecosystem Health Framework
Ecosystem Services and Natural Capital Approach
Multifunctionality
Policy Decision Support System
Sustainable Impact Assessment Tool
Millennium Ecosystem Assessment

Following is a brief description of these different sustainability systems.
The Natural Step

This framework instigated by Kark-Henrik Robert (Robèrt, 2002) has at its core four System Conditions for a sustainable future, which reflect the separate mechanisms by which systemic ecological and social harm can be done. They are designed to identify unsustainable practices; they operate within the constraints of conservation principles, thermodynamics and the laws of nature; they reflect the role of natural cycles and bio-geochemical evolutionary processes in making life possible; they build on an understanding of fundamental human needs and the material foundations of the quality of our personal and social lives. From this it follows that the strategic objective of organisations is to learn how to fulfil their purpose and prosper without contributing to:

- the systematic build up in nature of substances extracted from the Earth’s crust
- the systematic accumulation in the bio-sphere of industrial substances foreign to nature
- the long term degradation of natural systems through physical impacts on land, water and bio-diversity
- social, economic and political conditions that undermine the capacity for people to meet their needs (Herbertson & Tipler, 2006)

Application of the Natural Step system has a simple four-step process.

Step A - Awareness. What is the desired end point?

Step B - Baseline. What is the present situation, the current reality?

Step C - Visioning. What are the options for a sustainable future?

Step D - Action. Setting and managing priorities for sustainable outcomes?

Each step is tested against the following questions.

- Does this measure proceed in the right direction with respect to all System Conditions?
- Does this measure provide a stepping stone for future improvements?
- Is this measure likely to produce a sufficient return on further investment?
The systematic approach and the stepwise process are part of a Five Level model for planning in complex systems.

- Level One: The System
- Level Two: Conditions for Success in the System
- Level Three: Strategic Guidelines
- Level Four: Actions
- Level Five: Tools

This framework has already been utilised by numerous businesses, that have restructured their core principles to incorporate sustainability (Nattrass & Altomare, 2001; Tipler, 2010) and has been promoted by governments around the world as being a basic, easy step-by-step process to follow. Its proven successful application and the importance of focusing on a ‘vision’ first was appealing. Visioning a new system drives the concept of backcasting.

**Backcasting**

This is a planning methodology developed by Holmberg and Robert, as part of the systems thinking used in the The Natural Step (Holmberg & Robert, 2000; Robert et al., 2002) as steps A, B, C, D outlined above. Backcasting analysis starts with a vision of the future a desired outcome, holds a mirror to the past and is performed from a set of non-overlapping principles to assist in foreseeing ecological changes. Or, as Cook (2004) describes, place ourselves in the future imagining we have achieved success. Then we look back and ask ‘How did we achieve this? These questions can be asked specifically regarding the Muswellbrook LGA study site and The Crucible Group’s continuous biomass converter technology; one cannot rely on the past to analyse the future because:

- The problem to be studied is complex
- There is a need for major change
- Dominant trends are part of the problem
- The problem to a great extent is a matter of externalities
- The scope is wide enough and the time horizon long enough to leave considerable room for deliberate choice (Holmberg & Robert, 2000).
State of the Environment Reports

These annual documents prepared by New South Wales State and Local Governments, were legally enforced in 1993. Born out of the Agenda 21 directives, they were originally created to help local areas better understand their sustainability benchmarks. The possibility of using this format for the thesis was considered as it was a government designed and applied process. However, the templates used are not consistent across Local Government Areas (LGA) and this inhibits cross council analysis. One year a thorough analysis may be done while another year almost nothing is reported. Therefore the effectiveness of cross-country and over-time comparisons are often rendered ineffective (Muswellbrook Shire Council, 2011c). Then during 2013 the NSW government restructured land use management regulations and SOE reports were axed as annual reference documents and are now going to be conducted each decade. Despite the scrapping of these valuable documents all of Muswellbrook Shire’s SOE reports were reviewed and provided an important source of local information for this research. These documents provided many measurements relevant for understanding the scope, assessment and comparison.

Holistic Management

Designed by Zimbabwean biologist, ranger and politician Allan Savory, and described in his pivotal book Holistic Management (HM) (Savory, 1999) the system is generally referred to as ‘a decision making process’. Savory outlines essential testing questions to assess sustainability improvements. The focus here is on grassland management, an area that makes up more than 50% of the earth’s terrestrial landscapes and 54% of Australia. Improvements to water and soil are the end game with obvious carbon sequestration benefits. The unique characteristic of his methodology is the use of animals as tools to improve soil development and grass cover. This is especially relevant in the Muswellbrook LGA where so much land is dedicated to dryland grazing.

Proven case studies demonstrating biomass increase due to stock movement changes alone, now cover most continents but is not part of reviewed literature. According to Holistic Management Australian office records, numerous farmers in the area have studied this land management process. As
most of the agricultural land in the Muswellbrook LGA is designated Class 4, and used for grazing, the HM prism could offer insights into the full biomass capacity on this type of land. While the theories and practise of this system are relevant and Holistic Management principles are used in government training schemes (NSW Department of Primary Industries) they are frequently not referred to as Holistic Management. Therefore, while these principles are regarded as valid, the system, unlike TNS, has not reached the level of uptake in the sustainability space.

Environment Impact Assessments

These are reports presented to the government by developers and provide a rich source of micro analysis. These have developed out of legislative requirements but respond to principles of sustainability. There are many of these documents relating to land use in the Muswellbrook LGA and they have been an important resource of document analysis.

Industrial Ecology

The conceptual framework of Industrial Ecology is considered a merger of economics and ecology aligning industrial activities with sustainability principles. Addressing the challenge of allowing short-term profit to be achieved without compromising ecological goals (Holmberg & Robert, 2000) is a key factor in this system. Allenby outlines issues relating to engineering requirements to drive improved sustainability outcomes and addresses the problems of relevancy of biological ecology to technology (Allenby, 1999). Like TNS, IE’s approach is to integrate all systems in the analysis, accepting that the human alteration of earth is extensive. This is useful for two core reasons, firstly because pyrolysis is considered to be a technology that can address multiple biological needs, and secondly, because the Muswellbrook LGA is an industrially intense region sharing resources with agriculture.

Input Output Analysis

This common method used in national accounting is useful for sustainability assessments and is important in this study where basic inputs costs can be collected and reviewed and has been useful in the financial analysis in
Chapter 8. Monetising the inputs and outputs is commonly called a Physical Input Monetary Output (PIMO) model.

Input Output Analysis extends to include Life Cycle Analysis (LCA). Recent guidelines for LCA (International Reference Life Cycle Data System [ILCD] guidelines) are used. Another variation of Input Output Analysis is the material flow analysis. This is a major tool in Industrial Ecological (IE) assessments. Unlike linear input and output assessments, MFA is systems based and has been used by councils in the United Kingdom to fully understand material flows for new industries. Again, this was a useful tool to analyse the system of slow pyrolysis. Substance Flow Analysis, as another variation of the methodology used when a unique or specific product such as biochar is to be analysed.

**Ecological Capitalism**

Papers theorizing negative impacts from environmental regulations often draw the conclusion that capitalism will prove a difficult system when creating a sustainable future (Vlachou, 2004). Resource depletion and pollution are often understood in terms of price increases and social conflict. The restructuring of capitalism can be seen in terms of ecological directives, such as the carbon tax to drive the changes of resource management to become more sustainable. Ecological capitalism seeks to shift the mantra of economic growth to one where the economy is viewed as a stable-state. In the process the commitment to economic growth may fade to allow a new system of cooperation to break though. As land use is certain to change when the coal industry shuts down, focusing on the creation of a different agricultural paradigm will be necessary, concepts of ecological capitalism have been incorporated in the discussion about an Australian agricultural paradigm in Chapter 8.

**Ecosystem Health Framework**

There is now a suite of indicators employed to assess ecosystem health. While the concept of sustainability grows to include social as well as ecological, ‘ecosystem health framework’ is deserving of a mention here because there is considerable literature using this title (Cairns, McCormick, & Niederlehner, 1993; Rapport et al., 1999; Rapport, Costanza, & McMichael, 1998). As suggested earlier, Muswellbrook Shire’s development of specific policies to
address ecological impacts (Muswellbrook Shire Council, 2011a) can be viewed as the development of a collaborative management system overseeing radical ecological change and management. Ecosystem health assessments demand a system all to itself, but function within a much broader field of assessment.

**Ecosystem Services, Natural Capital, Multifunctionality**

Predicting sustainable carrying capacity is difficult, as government reports often state (Australian Government. Department of the Environment Water Heritage and the Arts, 2009). Ecosystem Services refers to the benefits provided to humans through the transformations of resources and includes all environmental assets such as land, water, vegetation and atmosphere, into a flow of essential goods and services e.g. clean air, water, and food (Costanza & Daley, 1992). Ecosystem services are natural capital. The vulnerability of ecosystems and resilience have been considerations throughout this thesis analysis.

While multifunctionality is a term with many meanings, it is frequently used within the sustainability debate to ensure that all considerations be included when assessing plant and animal interactions in agriculture, and especially when considering fungi and bacteria, the unseen important functions of plant life. Hector and Bagchi (2007) *Nature* essay outlines how maintaining a high number of species is important in securing the multi functional needs of ecosystems. This has been important is assessing biodiversity gains or losses in this research project. Multifunctionality is also used as a means of visualising interrelationships, especially in literature relating to land use (Knickel & Renting, 2000), and is often used to help re-define and quantify micro and macro data.

This is not an exhaustive assessment of frameworks but an example of the systems presently used to argue more accurately sustainable development. Other frameworks such as, Policy Decision Support Systems, Sustainable Impact Assessment Tools (SAIT), Millennium Ecosystem Assessments (MA) all have merit and indicate that methodologies are unlikely to be standardised.

In conclusion, there are a number of specific methodologies arguing bioenergy’s potential sustainability (Buratti & Fantozzi, 2010; Rosillo-Calle et al., 2007). The security of supply, logistics, efficiencies, economics, scale, plus
the social license to grow fuel rather than mine it, are the main issues the industry is presently grappling with (FAO (Food and Agriculture Organisation of the United Nations), 2012; Hanegraaf, Biewinga, & van der Bijl, 1998; International Energy Agency (IEA), 2007).

Legislative changes in Europe after the 1970s oil crisis saw the creation of renewable energy targets drive bioenergy innovations, even though most of the biomass was imported. This meant research focused on conversion technology rather than growing the biomass. With the exception of US research on ethanol, and a focus on a sterile hybrid, Giant Miscanthus (*Miscanthus x giganteus*) as a viable perennial feedstock, it has been European research that has exposed numerous technical constraints regarding the conversion efficiencies.

As no standardised system to measure biomass prevails, nor an agreed formula to access accounting procedures, the Food and Agriculture Organisation (FAO) has compiled various tools and methods (FAO (Food and Agriculture Organisation of the United Nations), 2012; FAO (Food and Agriculture Organisation of the United Nations), 2008). There is emerging agreement that the most useful analysis of bioenergy is site-specific (IEA, 2009; Rosillo-Calle et al., 2007). Area-specific analysis does have one fundamental drawback when focusing on land-use change issues, as residues and waste may be abundantly accessible only temporarily (Sterner & Fritsche, 2011).

The Australian government has funded biomass research via CSIRO and the Rural Industries Research and Development Corporation (RIRDC), to assess different feedstocks using Australian native plants (Chivers & Henry, 2011; Stucley et al., 2004) and some Australian native species have been categorised (Hobbs, Bennell, & Bartle, 2009) using their own specific criteria. CSIRO has conducted a number of trials in an effort to examine bioenergy’s impact on water yield, salinity changes, stream flow impacts (Gallant, Arancibia, B, an Dijik, & Freebairn, 2006). All these studies have been useful reference points.
2.2 Methodology Design

As stated above, a sustainable pyrolysis industry is dependent on the sustainable supply of biomass and the application of its outputs.

The Natural Step, Backcasting and Holistic Management are all sustainability assessment processes requiring a Vision to be established before any analysis can be conducted. The Vision Question of this thesis is: What is required to establish a sustainable slow pyrolysis industry?

As pyrolysis is a process, assessment of the biomass feedstock, the pyrolysis itself and the character and volume of all outputs from the process need consideration. Therefore this research examines these core components:

- Pyrolysis
- Biomass
- Biochar
- Pyrolysis liquid

Data and Information is drawn from published literature, historical documents, local industry, government departments, legislation, and the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), and a field and pot trial.

The sustainability prism has derived first from a question. The next question is:

What will it take to have a sustainable supply of biomass for a pyrolysis industry?

This key question has to be addressed separately for each of the four biomass criteria chosen for analysis:

- Agriculture
- Mine used Lands
- Municipal
- Forestry

These four biomass sources have unique components impacting their current physical reality and any drivers changing their supply will provide data to
enable the key issues to be extrapolated. Three themes within each focus area were selected.

- Current Physical Reality
- Drivers for Change
- Key Issues and Conclusions

The current physical reality is a stock take of the biomass presently growing and disregards final use in the Muswellbrook LGA study area. In general non-irrigated biomass availability widely fluctuates. ‘Opportunity harvests’ the unexpected harvesting of biomass has played a key role in all biomass supplies across all agricultural industries. Weather is the main determinant and has at times been responsible for doubling biomass supply in any one season. Historically ‘opportunity harvests’ can be viewed as experiments. Before lucerne hay-making became the highly technical business that it is today, farmers were harvesting excess summer grass to feed animals in winter. Eventually crops specifically dedicated to hay making were planted. Different commercial varieties of plants are constantly evolving to maximise volume, protein and energy. Volume, Price, Geography, Historical Trends, Variability and Type of biomass will be assessed through the prism of the current reality.

Australia’s agriculture is the third biggest carbon emitting industry (Garnaut, 2008, 2011) and this is the foundation for most drivers for change. Each biomass type irrespective of whether it is destined for the food, fibre or fuel sectors will be impacted. The Carbon Farming Initiative (CFI) policy and the Coalition Government’s Direct Action Plan (DAP) are the two main political drivers for change but there are many other lesser known state and local legislative directives. For instance Muswellbrook Shire Council has a recommendation that biochar be used in mine rehabilitation (Muswellbrook Shire Council, 2011a).

The Key Issues and Conclusions are drawn from all of the above.

2.3 Study Site

The research began within the broader region of the Upper Hunter Valley it soon became clear a more narrow geographic focus would be advantageous. With this in mind, Muswellbrook Local Government Area, (LGA) was selected
as the site for this study because it provides a microcosm within the broader Upper Hunter Valley. Although the area has evolved along historic and often incomprehensible frontier lines, it provides a legally recognised boundary. While businesses and most residents would access resources outside the shire boundary the land itself, mining not withstanding, cannot be moved.

Figure 2:1 Map of New South Wales showing Muswellbrook LGA

Definition

Muswellbrook (LGA) had been part of the Hunter-Central Rivers Catchment Authority (HCRCMA) jurisdiction and the largest coastal catchment in New South Wales. The Central Management Authorities under the *Catchment Management Authorities Act 2003* were disbanded by state government in 2013 and together with the *Rural Lands Protection Act 1998, the Rural Lands Protection Amendment Act 2008* were repealed. In January 2014 the *Local Land Services Act 2013* began operating. This new system brings together natural resource management with agricultural advisory services into a different zone that extends beyond Muswellbrook local government boundaries.
Muswellbrook LGA is based on the Hunter River system with the catchment area covering 22,000 square kilometres. The Hunter River begins at the Barrington Tops and meets the Pacific Ocean at Newcastle, flowing through the Muswellbrook LGA. It is fully contained within this catchment and contains no headwaters. A large number of un-regulated creeks flow into the Hunter River.

Many soils types can be found in the Muswellbrook LGA. There is no dominant soil type overlaying coal deposits. The soils have been consistently described in reports as being low quality, even, ‘virtually useless’. The alluvium, on the other hand is heralded as exceptional (Story, Galloway, Van de Graff, & Tweedie, 1963).

**History**

A verbal and spatial separation in the Hunter Valley into 'Lower' and 'Upper' has occurred over time. While this description is not a geographical definition, for planning purposes the demarcation line is considered to be between Branxton and Singleton. This has largely come about as the old coal mining towns of the Lower Hunter, such as Weston, Kurri Kurri, and Cessnock made way for the modern technological system of open cut mining around Singleton and Muswellbrook in the Upper Hunter. This is also the area where the influence of coastal rain ends.

Muswellbrook LGA is part of the 'Upper' Hunter Valley. The designated shire of Muswellbrook has evolved many times since it was first surveyed by Henry Dangar in 1822 (Wood, 1972) and later defined in 1870 as its own municipal area (Muswellbrook Shire, 2011). Many boundary adjustments have since taken place but Muswellbrook and Denman are still the two main townships within the LGA.

Before white settlement the Indigenous people, the Wonnarua, ranged over the whole area. Although areas of traditional Aboriginal occupation are continuously being revised, many designated Aboriginal landmarks are now formally registered or noted in all environmental assessments lodged with NSW Department of Planning during mine approval assessments (NSW Department of Planning, 2005).
Early explorers in 1824 made frequent reference to the high levels of flooding of the Hunter River and tributaries (up to 60 feet in some areas) along the Goulburn River; the open forested country; the remarkably rich alluvial soils that at the time were considered the best in the colony (Wood, 1972). A most extraordinary aspect of the white settlement of the Upper Hunter Valley was the speed with which land was claimed and domesticated animals introduced. Within eight weeks of European discovery all the land in the Upper Hunter Valley to Segenhoe had been apportioned (Wood, 1972). This included the whole of what we now call the Muswellbrook LGA.

**Land Use Evolution to Coal Mining**

Historical records describe Europeans occupying a lush, biologically diverse Upper Hunter Valley, dotted with trees. Rivers were fringed with a rainforest and wetland vegetation complex imparting stability to the ecosystem (Archer, 2007). These records give us some hint of the natural biomass capacity of the region. The original grasslands of the Hunter Valley underwent irrevocable changes after white settlement introduced European land use systems. The rapid demise of native grasses occurred quickly, within six years (Archer, 2007). There was realisation by the 1850’s that botanical losses and reduced plant biodiversity were a fact not a theory (Rolls, 1981).

**Table 2:1 Land use within the Muswellbrook Shire**

<table>
<thead>
<tr>
<th>Land use in Muswellbrook Shire</th>
<th>Area (000' hectares)</th>
<th>Per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>National Parks</td>
<td>145,550</td>
<td>43.0</td>
</tr>
<tr>
<td>Nature Reserves</td>
<td>3,500</td>
<td>1.0</td>
</tr>
<tr>
<td>Power Stations</td>
<td>13,000</td>
<td>3.7</td>
</tr>
<tr>
<td>Coal Mine leases</td>
<td>16,517</td>
<td>4.8</td>
</tr>
<tr>
<td>Prime Agricultural Land</td>
<td>20,690</td>
<td>6.1</td>
</tr>
<tr>
<td>Vacant and Grazing</td>
<td>140,333</td>
<td>41.1</td>
</tr>
<tr>
<td>Urban Areas (approx )</td>
<td>950</td>
<td>.3</td>
</tr>
<tr>
<td><strong>TOTAL SHIRE</strong></td>
<td>340,540</td>
<td>100.0</td>
</tr>
</tbody>
</table>


Table 2:1 shows clearly the diverse land use and in particular the considerable area (140,333 hectares), dedicated to dryland grazing and National Parks in the Muswellbrook LGA. The expansion of coal mining in the area was a big factor in defining the methodology. The exportation of natural resources from the Hunter Valley began in the earliest days of white settlement with the export of coal from Newcastle dating from 1799. Two years later the first cedar
trees were shipped out. Yet it would be almost another 100 years, in 1890, before coal in Muswellbrook was mined. Those marine based coal seams are still being mined today at Drayton Mine and Muswellbrook Coal. The other three operating mines in the area, Mangoola Mine, Bengalla Mine and Mt Arthur Mine have a different non-marine based geomorphology.

Geologists mapped the Hunter coal seams around 1886 and since then miners have been testing the full capacity of the reserves. We now know that these reserves remain extensive in the valley and that the coal seams extend beyond the Hunter Valley northwards into the Liverpool Ranges and Gunnedah Basin. The seams also continue throughout and south of the Sydney Basin. Mine plans lodged with NSW Department of Planning prove coal expansion in Muswellbrook LGA could be considerable during the next decade.

The evolution of economic activity in the Hunter Valley since white settlement has not focused on food production and by 1963 only 6% of the population in the whole valley was employed in the agricultural sector (Story et al., 1963). Agricultural land in the area was subdivided into smaller than average blocks after the 1939-45 World War. Class 4 agricultural land dominates the Muswellbrook LGA. This land is classified as being of low productive value in terms of food production and not suitable for cultivation due to a shallow soil profile. Grazing has therefore been the main Agricultural activity on native pastures (NSW Agriculture, 2002). Today 43 per cent of the area is designated as National Park.

Producing meat on small acreage no longer exists as prime income businesses and is deemed to be economically unsustainable. Muswellbrook Shire Council did once own and operate a sale-yard, when infrastructure for the sale of meat was deemed essential for development (NSW Government, 1886). Now local small beef and sheep operators feed into an extensive, well established, nationally coordinated supply chain.

The dominance of the singular extractive coal industry drives Muswellbrook towards diminishing its ‘natural capital’. Natural Capital can be renewed because it is utilises the sun’s energy for growth. Coal on the other hand is not renewable in the human time scale. The Muswellbrook LGA thus cannot lay claim to being a region based on sustainable development. While the economic
benefits of developing a coal industry have driven increasing land values, income, and access to services, the ecological and social impacts are not yet fully calculated (Farr, 2006).

The Hunter Valley is a global coal exporter and the biggest national user of natural gas and producer of aluminium (ACIL Tasman, 2012; ACLUMP, 2009). Muswellbrook LGA is also home to the state’s biggest coal mine, BHP Billiton’s Mt Arthur Mining Complex and presently generates 40% of NSW’s electricity needs at two-fired power stations operated by AGL (formerly Macquarie Generation).

![Muswellbrook Shire Mining Footprint](image)

**Figure 2:2 Muswellbrook LGA Mining Footprint 1995-2015**

The Hunter Valley and in particular Muswellbrook LGA, has been and remains undeniably a leading energy hub. Figure 2:2 demonstrates clearly the increase in land use by coal mining up to 2015.

Mining continues to grow with 15% more land exposed by mining than the previous year. There has also been 10 times more land cleared than rehabilitated in the Muswellbrook LGA due to mining in the past year (Muswellbrook Shire Council, 2011c).
The coal industry has created significant land use change and designed its re-landscaping with the direction and management of government. Stability of landscape is prioritized during the rehabilitation process as well as re-establishing the previous land use which in most cases was grazing. The landscape’s ecological capacity is assessed to facilitate biodiversity re-establishment with little or no consideration for the land’s future economic capacity, (Hannan, 1995; Muswellbrook Shire Council, 2011a; Rio Tinto Coal Australia, 2010). A rehabilitation re-landscaping directive takes on a largely back-to-the-past approach as outlined in government documents. However, the process is a flexible one, where design and application are being constantly assessed for effectiveness and changes to plans are continuous (Hannan, 1995; NSW Department of Mineral Resources, 1999).

While the actual area of land re-landscaped may be small within the boundaries of the LGA, the surrounding areas have also witnessed road closures, home ownership loss or removal, school and church service closure and cultural isolation (Muswellbrook Shire Council, 1997-1998).

Never before has Muswellbrook LGA undergone such massive land changes and it is unclear how stable the future land will be. In the process, it is creating a new ecosystem in the short term and will, in the long term, create new ecological ownership issues. Will the property rights of rehabilitated overburden be equal to land that has never been mined? Who will bear the long-term responsibility for the development and protection of the re-landscaped land? And who will pay for any unintended consequences? There is already and will be in the future thousands of hectares of newly designated land, of a type that has never before existed; a new land with an unknown and untested biological capacity. If this land cannot support the economic activity of the past can it support something new?

The act of re-designing the land - within a sustainability framework - should first define an intention for future economic activity and not only focus on ecology. There needs to be an agreed strategic vision, as described in background to methodology.

The creating of degraded land by mining is considered an accepted trade-off because economic benefits outweigh ecological impacts. It is a professed belief
of the mining sector, endorsed by the government that science can create a new successfully functioning regional ecology post mining – even though this has never been achieved anywhere in the world. In 2014 in response to local concerns about rehabilitated land’s use for stock grazing a joint mining and government group set up a short term experiment (NSW Mining). Short-term responses have been known to achieve some results but then adding fertiliser always does show some growth; the issue is ecological resilience in the long term. The final characteristics of the rehabilitated land cannot be fully known until mine closure is complete. Complicating understanding the projected final area of rehabilitated land is the fact that often rehabilitation areas are dug up for a second or third time, as mine design and developments change all within the approval process of the government (Muswellbrook Coal Company, 2011). Ecological planning on site usually gives way to coal price pressures. These modifications are recorded on government and mining company websites (NSW Trade and Investment Resources and Energy, 2014).

A qualitative assessment of the capital and resources for this new land is important to confidently assess its future sustainability. Could anything economically substitute the coal that has been removed? Could any product ever be that valuable? If industries like slow pyrolysis are to develop they will begin business in a market with existing infrastructure (Larsson, 2009) and inevitably function for some time alongside the coal industry. One industry rarely ends before a new one emerges. In the process the new industry may piggyback on the old until new infrastructure and support services are built.

Strangely it is the unsustainable coal industry that conducts numerous reports to justify its business. These reports are recorded on government and company websites. Agriculture on the other hand functions with laws and recommendations for land use but no formal reporting except the annual Local Land Services Annual Return of Land and Stock is required.

What does a mine have to report to government that a farmer does not?

• Manage with a permanent reference site.
• Respond to a pollution reduction scheme.
• Monitor biodiversity
• Measure water connectivity
• Measure dust
• Measure water quality
• Measure water extraction volumes
• Measure water collection volumes ie dams.

While Landscape Function Analysis is now an accepted methodology for mines in the region to assess ecological impact, this is not a method carried out by other sectors.

A comparison could probably be made with present day mining companies moving in to an area and irrevocably changing the ecology as white settlers did more than 200 years ago. The consequences in both cases were, and remain, swift. There is almost no sharing of resources with existing land owners. Just as white settlement wiped out the Indigenous way of life, coal mining displaces agriculture. Indigenous people were forced to live on the margins of white culture, just as farmers today struggle on in close proximity to mines, confronted with dust, impacts on water, diminishing agricultural infrastructure and community.

In conclusion, Muswellbrook LGA provides a unique opportunity to assess the development of sustainable industries within an economy heavily engaged with the fossil fuel intensive sector. The coal industry has been the focus of much of the climate change debate and anti coal campaigns are now embedded in all coal communities, including Muswellbrook. However, this has not stopped the rapid expansion of the coal industry.

2.4 Methodology Summary

As described above methodologies used by business to access their sustainable goals have been evolving with the aid of numerous tools. World Resources Institute for instance designs tools to develop assessments. These protocols include GHG Corporate standards, Life Cycle standards. They are action research methodologies seeking to expose precise and quick solutions to an urgent problem.

Sustainability Methodology in this thesis is aligned to the principles designed by Karl-Henri Robert for The Natural Step (TNS), which is frequently used by the corporate sector as well as in government documentations.
2.5 Research Methods

According to Crotty research methods are the ‘techniques or procedures used to gather and analyse data related to some research question or hypothesis.’

This thesis adopts an action research approach accepting that mitigating climate change could arguably be the ultimate problem to demand the attention of complexity theory. Negative climate change is destined to impact on all life forms in one way or another and inquiring into the precise way it will impact demanded a review of methods. The techniques and procedures undertaken to qualify data used in this research is primarily document analysis. This required collection of data from publically available sources and private communications.

Document analysis from various sources include:

- Intergovernmental Panel on Climate Change’s reports (IPCC)
- Australian Commonwealth Government
- NSW Government
- Muswellbrook LGA
- Hunter and Northern Rivers CMA
- Mining companies reports and AGM documents
- Published reviewed literature and government reports
- Maps
- Local Historical documents
- Farm records
- Forest inventory data
- Business Management Plans
- Procurement assessments

Whilst many planning decisions function under state legislation, local governments provide input and direction regarding land and water use. For
practicalities of this research data collection has been from all tiers of government as well as private and corporate sources.

As the research unfolded so too did the development of The Crucible Group’s pyrolysis technology. The outputs created became more clearly defined and once the volume of water produced during the process became more certain a randomized plot trial was devised to provide an indication of agronomic effects. As this pyrolysis liquid was a new product there was no available literature assessing its environmental use and impacts, nor its financial worth in the Australian context, especially the Upper Hunter. Therefore sampling and statistical analysis were used to evaluate impacts of pyrolysis liquid.

This field experiment then led to another case study being designed at Muswellbrook Coal rehabilitation site.

As bioenergy technology develops so too will the measurement methodologies. For this research the measuring method will be weight not volume. Biomass is irregularly shaped, as each twig in nature is different, making volumetric recording difficult. The biomass availability needs to be understood within the existing commercial supply and demand framework. Is the biomass supply being taken from one sector or is the supply created from a new source? For example; energy crops grown on marginal land.

As the Muswellbrook LGA is an area under radical land use change due to coal mining, it was not applicable to rely solely on the Geographic Information System (GIS), although mapping was important to outline spatial parameters and specially useful in locating roads and residues within a certain radius of a bioenergy site. Maps were created with the assistance of the local catchment authority, (now Local Land Services) using their government datasets for soil and vegetation types.

While historical documents have been helpful, crop volume measurements in many documents were varied. This is discussed in detail in Chapter 8. Comparing like for like was a challenge as bioenergy is not standardized and scale means different things in different sectors and in different countries.
2.6 Research Methods Summary

This thesis tackles at its heart a complex systems problem. Given the nature of the challenge the work takes a transdisciplinary approach, combining academic and other forms of investigation with an orientation to values-driven outcomes. There is an assumption that the proposition under investigation would benefit society if it could be realised in a viable and sustainable fashion. This is not an examination of something that already exists, so the approach adopted is one of “backcasting from success” and assesses the possibilities for a slow pyrolysis industry to emerge in the Muswellbrook LGA.

As this thesis takes advantage of transdisciplinarity, there is a risk that conclusions cannot be properly attained, as each discipline of research demands more and more input for consideration (Robért, 2000; Robért et al., 2002). This is a fundamental difficulty in sustainability analysis everywhere but has been resolved by not branching out into qualitative interview based research.

At a conceptual level the biochar proposition is impressive because it can drive restorative land practices and draw down atmospheric carbon, but in terms of a solution it is undeveloped. Turning the vision into a reality is an innovative challenge that must be practical, viable and sustainable at a local level. The study therefore chose to explore the possibilities for a CBC to be introduced in a particular area, Muswellbrook LGA in the Upper Hunter Valley. Innovation such as this is not simply about technology development. It depends on current realities, including the geography of an area, the business and political environment, local natural resources, community perspectives and so forth.

The study was conducted within the Tom Farrell Institute, Newcastle University, and is well aligned with its mission to develop ‘Regional Solutions for A Sustainable Future’.
CHAPTER 3  PYROLYSIS

Definition

Pyrolysis is the thermal decomposition of organic material, for example, biomass in the absence of oxygen producing gas, liquid and char products. It is often referred to as ancient charcoal making technology because of the long use of the char products by indigenous people along the Amazon (Glaser,
2007), in Japan, China and Korea (King, 2004), and Europe (Lehmann) and in Australia (Downie, Crosky, & Munroe, 2009). In these basic systems the released gas and pyrolysis liquid are rarely used.

Misunderstanding often derives from failing to differentiate between pyrolysis and incineration. Pyrolysing is a form of carbonization and therefore needs to be associated with the concept of carbonizing, not combustion under oxidizing conditions. To take a piece of wood and pyrolyse it is to capture its carbon, whereas wood that is burned cannot be turned into charcoal. Its carbon is not captured but lost as CO₂.

There are essentially two types of industrial scale pyrolysis: a fast, high temperature type (Bridgewater & Peacock, 2002) that focuses generally on making liquid fuels, and a slow pyrolysis system using lower temperatures to create the gas, various liquids and charcoal (Caputo, Palumbo, Pelagagge, & Scacchia, 2005). Fast pyrolysis and a similar system called flash pyrolysis, designed for making primarily liquid fuels, have not been included in this research, as they produce little or no char.

While historically the sole purpose of pyrolysis was to produce charcoal primarily for kitchen fuel, modern slow pyrolysis can be a multi-task continuous process, generating two renewable energy products, char and gas. Electricity generation is frequently considered the most lucrative option for biomass conversion (Bridgewater, Toft, & Brammer, 2002) but slow pyrolysis with its multiple outputs offers more alternatives.

As a general principal, when there is an increase in temperature during slow pyrolysis there will be an increase in the volume of gas produced, and consequently a decrease in the volume of char (Koufopanos, Maschio, & Lucchesi, 1989). The gas produced is sometimes called ‘syngas’ or ‘synthesis gas’ and refers to the mixture of molecules suitable for a variety of different products. Syngas or synthesis gas, contains CO and H₂. Syngas and synthesis gas can also be made out of coal. However, syngas differs from natural gas, which is mainly methane, and it cannot be put into a natural gas pipeline. Syngas can be used to replace some or all of the natural gas for industrial heat and power. It also has the building blocks to create products presently made by the petrochemical sector, such as synthetic liquid fuels.
Technology Development

Despite the historical uses of char, no commercial global industrial-scale slow pyrolysis industry has yet emerged. This raises the question: Why has it not flourished? The answer is primarily due to three factors.

- The abundance of coal and its relatively cheap price
- The capital intensity for pyrolysis has typically been too high
- The energy conversion efficiency has traditionally been low, around 60% (Brown, 2009).

In other words, there has not been the technology to do it. While the basic principles of pyrolysis have been understood for centuries many have not been taken up with manufacturing (Brown, 2009). Technical difficulties have been largely due to improving effective heat transfer between the heat carrier and the biomass particles. Conversion efficiencies have been recorded as low as 8% with traditional systems (Brown, 2009; FAO (Food and Agriculture Organisation of the United Nations), 1983). Various prototypes have evolved over the years and been tested in the market but have then failed to achieve the energy conversion efficiencies required to be profitable. Brown (2009) researched the technology development and concluded that fundamental manufacturing issues have previously been unresolved. These include:

- Continuous feed pyrolysers to improve energy efficiency and reduce pollution emission associated with batch kilns
- Exothermic operation without air infiltration to improve energy efficiency and char yields
- Recovery of co-products to reduce emissions and improve process economics
- Control of operating conditions to improve char properties and allow changes in co-product yields and
- Feedstock flexibility to allow both woody and herbaceous biomass to be converted together.

The technological challenges for developing pyrolysis specifically for carbon offsetting outlined in the 2010 report for the Climate Action Review, Evaluation of the Opportunities for Generating Carbon Offsets from Soil sequestration of
biochar (De Gryze, Cullen, & Durchinger, 2010), concluded that pyrolysis technology is undeveloped. The volatile nature of business in this nascent industry was partly to blame but the main culprit was that there simply has not been the technology to drive a breakthrough into the market. Many of the technology companies reviewed in this study, including some based in Australia, have either changed their core business focus, merged, changed ownership or no longer exist.

**Different Pyrolysis technologies**

The availability of smaller pyrolysis equipment of various types and sizes from drum and screw pyrolysers, rotary kilns and gas stoves is also limited (Jirka & Tomlinson, 2013). These small-scale options have primarily been designed for undeveloped countries in the form of low-cost domestic ovens to help eliminate energy poverty, with the bonus of biochar for soil improvement. In the developed world, different pyrolysis machines for the small farmer or gardener have been designed as backyard charcoal makers primarily for soil improvement. Mobile continuous process systems and batch systems are also presently available in Australia. These are often called biochar makers (Macdonald & Kookana, 2013), and are useful if charcoal is the only output desired. Many of these are linked to regional sustainability groups, alternative farmers, permaculture practitioners and the recently formed transition towns (Brigg, Campbell, & Hirth, 2013).

These small batch systems require external energy to initially heat the biomass, often using LPG cylinders. The energy efficiency of batch systems will always be less than a continuous process (Bridges, Paterson, & Jones, 2013). Small, modular systems can provide a better fit to available biomass, accessing underutilized species or temporary biomass stands such as damaged forest or areas where fire risks demand short term intensive management. However, none of these small pyrolysis machines capture gas, deliver heat or make electricity.

Biomass energy developments in China provide useful comparisons as different biomass energy conversion technologies have been applied in rural areas since the 1980s (Yuan, Wu, Huang, & Lin, 2002) and biomass already supplies 20 per cent of China’s energy needs (Chang, Leung, Wu, & Yuan,
Biomass gasification and power generation in China has reached efficiencies at some large scales (Wu, Huang, Zheng, & Yin, 2002). Pyrolysis systems designed primarily for the production of char are developing with 1 tonne per hour continuous process plants reportedly operating near Shanghai (Joseph, 2013), although there is no published literature confirming their production methods or efficiencies. Gasification for power is used in China but gas engine efficiency often remains as low as 20% in most Chinese systems (Wu et al., 2002).

Literature focusing on continuous industrial pyrolysis, between 1-3t per hour biomass capacity with heat production, grid connection and electricity generation as well as char production is limited because the technology is neither fully developed nor commercially integrated. Pyrolysis literature often only focuses on one output stream, either the char component as an important energy by-product, or the gas. The full economic value is not being realised unless all outputs are included.

The highest treatment temperature (HTT) is the maximum reached during the process and determines the physical properties of the gas and char formation (Downie et al., 2009). Increasing the HTT can also increase the pH, ash concentration, carbon, phosphorus, potassium, total base cation concentrations and pore volume of the char (Cantrell, Hunt, Uchimiya, Noval, & Ro, 2012; Downie et al., 2009). Gaining conversion efficiencies is often discussed within the context of changing the feedstock, especially pre drying it rather than changing the technology (Bridgewater, 2007; Bridgewater et al., 2002). However, this does not address the fundamental inefficiencies of the actual conversion process.

In 2012 the US Biochar Initiative undertook a voluntary membership survey to ascertain the volumes of char presently being made across all the different pyrolysis systems. The survey answers confirmed a surprisingly low annual volume of 430 tons (390 tonnes) of char was being manufactured for sale (Brunjes, 2012). Although the survey did not include recent developments in China and is not assumed to be a complete record, it confirms that there has not been a viable technology to make the volumes of char needed to become a significant climate change mitigation solution.
3.2 The Crucible Group

The Crucible Group’s (TCG) continuous biomass converter (CBC) technology was designed to rectify this technology–profitability gap. This slow pyrolysis system provides products that can be used for heat, electricity generation, or land applications. This new thermo-chemical technology has simplified the process engineering. Except for starting purposes, no external energy is needed to operate. Its uniqueness is that it combines the functions of dewatering, char-making, tar-cracking (the breaking down of the larger complex hydrocarbon molecules) and gas-scrubbing (the cleaning of the gas to remove impurities) all within a single stage reactor (The Crucible Group Pty Ltd, 2008)

![The Crucible Group’s Continuous Biomass Converter (CBC) Vales Point, NSW](image)

**Figure 3:1 The Continuous Biomass Converter**

The scale of the CBC is shown in Figure 3:1. This unit is scaled for production up to 10 000 tonnes per annum, although units from 4000 tonnes per annum will be available. Figure 3:2 shows the simple input and output structure. Gas cleaning processes are needed in some conversion technologies to manage the
organic and inorganic impurities such as tar, sulphur, chloride and oxygen and need further catalytic conversion (Hu, Yu, & Lu, 2012), but within the CBC this is streamlined and the extra process of cleaning the gas is not required. This innovation is protected by a number of patents; four patent families covering the process fundamentals, equipment innovation, integrated power generation and resource recovery are being progressed around the world and the first US Patent No 8,888,962 has been granted (The Crucible Group Pty Ltd, 2013, 2014a).

![Diagram of Continuous Biomass Converter inputs and outputs](image)

**Figure 3:2 Continuous Biomass Converter inputs and outputs**

The scale of the operation and the yields of char and gas depend on feedstock and operating parameters. For planning purposes the standard module plant is designed to process approximately 10 000 dry tonnes per annum delivered in a continuous, automatically controlled way, averaging 1.25 tonnes of biomass per hour of operation. Each dry tonne of woody biomass holds the potential of 20 GJ as shown in Table 3:1. Typically approximately 11 GJ convert to char, 8 GJ to gas with a 1 GJ loss, resulting in a 96 per cent conversion efficiency of the process. The relative mass and energy breakdown
between the char, gas and water depends on feedstock and process conditions. The heating value has not been found to vary significantly between different biomass sources on a dry weight basis. The pyrolysis liquid output also depends on feedstock but is typically around 400 litres per tonne of biomass.

**Table 3:1 Continuous Biomass Converter Indicative Products**

<table>
<thead>
<tr>
<th>Pyrolysis Products</th>
<th>Product per tonne biomass = 20GJ</th>
<th>Use of Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas</td>
<td>8 GJ</td>
<td>Heating, Power generation, Synthetic fuels, Chemicals</td>
</tr>
<tr>
<td>Biochar</td>
<td>11 GJ (~350 kg Biochar)</td>
<td>Soil amendment, Filtration, Steel making reductant, Energy source, Bio-coal</td>
</tr>
<tr>
<td>Process Losses</td>
<td>1 GJ</td>
<td></td>
</tr>
<tr>
<td>Liquid</td>
<td>400 litres</td>
<td>Herbicide, pesticide, Water treatment management, Horticultural use, pH adjustments</td>
</tr>
</tbody>
</table>

The performance characteristics of the CBC also achieve greater efficiency compared to traditional downdraft gasifiers, which also use biomass as a fuel. Using data from Jorapur and Rajvanshi (1997), Table 3:2 shows the production difference with 1t/DW of biomass and the high process energy losses with the downdraft gasifier compared to the CBC. The variation in efficiency is significant with the downdraft gasifier at 57 per cent, while the CBC achieves 96 per cent.

**Table 3:2 CBC and Gasifier differences**

<table>
<thead>
<tr>
<th>Technology</th>
<th>Downdraft Gasifier</th>
<th>CBC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Quantity</td>
<td>Energy Content</td>
</tr>
<tr>
<td>Biomass Feed Rate</td>
<td>1 tonne</td>
<td>20 GJ</td>
</tr>
<tr>
<td>Air Injection Rate</td>
<td>1500Nm³</td>
<td>260Nm³</td>
</tr>
<tr>
<td>Gas Production Rate</td>
<td>1800Nm³</td>
<td>6.5 GJ</td>
</tr>
<tr>
<td>Char Production Rate</td>
<td>240kg</td>
<td>4.8 GJ</td>
</tr>
<tr>
<td>Process Energy Losses</td>
<td>8.7</td>
<td>.9</td>
</tr>
<tr>
<td>Process Energy Efficiency</td>
<td>57%</td>
<td>96%</td>
</tr>
</tbody>
</table>

Note. Adapted from The Crucible Group. Downdraft gasifier efficiency based on Jorapur and Rajvanshi (1997)

In another comparative example when compared to a different gasifier, (Fengyu) and a different type of pyrolyser, (Pacific Pyrolysis Pty Ltd) as shown in Table 3:3, not only is there a differential regarding conversion efficiency but
also a large variation in the volume of char and gas outputs as well. (Pacific Pyrolysis process does not create a separate pyrolysis liquid stream so no comparison can be made, and the gasifier only produces gas). The CBC’s produced gas yield is even greater than the gas made via the Fengyu gasifier. Research on energy efficiency by Mulligan et al analysing the net energy transfer pyrolysing wheat straw and mallee, found TCG’s CBC could achieve 96.4% efficiency using mallee residues and 95.5% with wheat straw (Mulligan, Strezov, & Strezov, 2010).

Table 3:3 Technology conversion comparisons

<table>
<thead>
<tr>
<th>Energy Efficiency of Technology Comparison (per t dry/weight)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology</td>
</tr>
<tr>
<td>Biomass Feed Energy GJ</td>
</tr>
<tr>
<td>Natural Gas Consumption GJ</td>
</tr>
<tr>
<td>Energy to offset Electricity Use GJ</td>
</tr>
<tr>
<td>Gas Output GJ</td>
</tr>
<tr>
<td>Char Output GJ</td>
</tr>
<tr>
<td>Net Energy Output GJ</td>
</tr>
<tr>
<td>Net Energy Efficiency GJ</td>
</tr>
</tbody>
</table>

Note. Adapted from The Crucible Group Pty Ltd (2013a)

An indicative breakdown of the chemical components of the CBC gas is provided in Table 3:4. Although the specific chemical composition will depend on the biomass feedstock and the operating procedures, this demonstrates the quality of the gas, which is comparable in quality to gas made specifically in a gasification plant (The Crucible Group Pty Ltd, 2013). The CBC can be operated whereby the energy in the gas can be delivered at higher volumes and lower energy density.

Table 3:4 Typical Syngas Composition

<table>
<thead>
<tr>
<th>Substance</th>
<th>Composition (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂</td>
<td>20-40</td>
</tr>
<tr>
<td>CO</td>
<td>35-40</td>
</tr>
<tr>
<td>CO₂</td>
<td>25-35</td>
</tr>
<tr>
<td>CH₄</td>
<td>0-15</td>
</tr>
<tr>
<td>N₂</td>
<td>0-20</td>
</tr>
</tbody>
</table>

Note. Adapted from the Crucible Group Pty Ltd (2013b)
3.3 Continuous Biomass Converter Key Issues

The above points highlight the value of the innovative CBC system. The key issues facing the establishment of a CBC in the Muswellbrook area are diverse and include:

- Confirming technical readiness
- Defining the process capacity to meet different project sizes
- Resource recovery
- Securing a sustainable biomass supply
- Defining the GHG emission abatement
- Integration of a CBC within the present energy system
- The potential use for the gas
- Management of particulate matter emissions

Confirming technical readiness

While all new technologies undergo processes of review, technical readiness levels (TRL) is a systematic process of development and is graded from levels 1-10. The Crucible Group has now operated a demonstration plant at a commercial scale and confirms a number of benchmarks:

- 24 hour automatic operation has been achieved
- Keeps details logs of all operations; this includes continuous monitoring all process and equipment conditions and in line gas composition.
- Analysed char, gas and liquid properties
- Provided tonnage samples of char for industrial trials
- Provided tonnage samples of pyrolysis liquids for field trials
- Researched outputs for biochar in field and pot trials (The Crucible Group Pty Ltd, 2013)

This indicates the Continuous Biomass Converter is operating at Technology Readiness Level (TRL) 7, defined as:

System prototyping demonstration in an operating environment; at or near full scale; most functions available for demonstration and testing; well integrated with ancillary systems (Australian Government, 2014b)
At this stage financial cost analysis can be undertaken with more accuracy. According to Geoscience Australia, Australia’s biomass supply is undeveloped because it is constrained by the ‘current immaturity of technologies’ to convert it (Geoscience Australia and ABARES, 2010). No other slow pyrolysis technology is known to have reached level TRL 7.

**Defining the process capacity to meet different project sizes**

The CBC modular shape is advantageous for a variety of project sizes. It is suitable for an area where 10 000 tonnes of biomass per annum is available, but it can be supplied at a smaller level, 4000 tonnes per annum, or scaled up by linking multiple modules together. Therefore the capacity to process upwards of 10 000 tonnes per annum of biomass is feasible, with the maximum being ultimately limited by biomass supply in the region. This modularity of the technology is important in a nascent industry where minimising capital outlay is beneficial.

**Resource Recovery**

Linak et al reviewed a selection of biomass materials including municipal solid waste where unacceptable high levels of cadmium and lead emissions were recorded and suggested separating potential contaminants can be difficult (Linak & Wendt, 1993). Wiinikka, Grönberg, and Boman (2013) tested emissions of particulate-associated heavy metals (Lead, Cadmium, Arsenic, Chromium, Thallium, Zinc, Nickel, Vanadium) during combustion of various northern hemisphere softwoods, peat and coal. Testing the levels against the EU waste Incineration Directive, some elements were within the particle range while others greatly exceeded. Zn for instance was several times higher from birch bark. Lead and Zinc both had the highest volatile fraction. The correlation between the metal concentrations and the original fuel must be considered when selecting a biomass feedstock.

Some biomass sources like municipal solid waste may be a potential future use for a CBC plant. When these substances are pyrolysed the toxic components could be redirected and captured and at the same time improve landfill management. Table 3:5 outlines various polluting treated timbers that often end up as landfill and includes propositions on how the CBC processing might effect such materials. The Crucible Group has undertaken a program of
work to test these propositions with various waste woods. Preliminary results with engineered timbers, pallets, crates, termite treated timbers and residual plastics have been positive (The Crucible Group Pty Ltd, 2013).

**Table 3:5 Mixed Waste Recovery**

<table>
<thead>
<tr>
<th>Material Groupings</th>
<th>Issues</th>
<th>TCG Value Propositions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 CCA Treated Timbers</td>
<td>Cr6+</td>
<td>• Reduction to Cr3+ at 650 under reducing conditions</td>
</tr>
<tr>
<td></td>
<td>As</td>
<td>• Removed in the pyrolysis water, then precipitates out</td>
</tr>
<tr>
<td>2 Timber &amp; Wood waste</td>
<td>Paints</td>
<td>• Thermal decomposition and detoxification, reporting as energy in gas.</td>
</tr>
<tr>
<td></td>
<td>Lacquers</td>
<td>• Reduction to Cr3+ at 650 under reducing conditions</td>
</tr>
<tr>
<td></td>
<td>CCA Contamination</td>
<td>• Removed in the pyrolysis water; then precipitates out</td>
</tr>
<tr>
<td>3 Green Waste (Contaminated)</td>
<td>Heavy metals</td>
<td>• Removed in the pyrolysis water; then precipitates out</td>
</tr>
<tr>
<td></td>
<td>Garden Chemicals</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Plastics, including PVC</td>
<td></td>
</tr>
<tr>
<td>4 Biosolids</td>
<td>Heavy metals (Hg, Pd, Cd)</td>
<td>• Removed in the pyrolysis water, then precipitates out</td>
</tr>
<tr>
<td></td>
<td>Pathogens</td>
<td>• Destruction of pathogens</td>
</tr>
<tr>
<td></td>
<td>Sulphur</td>
<td>• No dioxin formation (below pre-cursor formation temperatures)</td>
</tr>
<tr>
<td></td>
<td>Ammonia</td>
<td></td>
</tr>
<tr>
<td>5 Engineered Timbers</td>
<td>Formaldehyde</td>
<td>• Thermal decomposition and detoxification, reporting as energy in gas</td>
</tr>
<tr>
<td></td>
<td>Melamines</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Resins, glues</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Plastics</td>
<td></td>
</tr>
<tr>
<td>6 MURF Residues</td>
<td>Flock</td>
<td>• All of the above</td>
</tr>
<tr>
<td></td>
<td>Organics</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Heavy metals</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PVC</td>
<td></td>
</tr>
</tbody>
</table>

*Note. Adapted from The Crucible Group Pty Ltd (2013b)*

**Securing a sustainable biomass supply**

The first thing a pyrolysis project needs is to secure a reliable, clean biomass feedstock supply for the life of the project. The information gathered to confirm this, needs to be unambiguous in the short term and with a detailed analysis of availability, accessibility, convertibility, present uses and potential future trends (Rosillo-Calle et al., 2007). This topic is the subject of the following chapter.

**Defining the GHG emission abatement**

The most significant issue driving recent interest in pyrolysis is the reduction of GHG emissions. Although pyrolysis is officially considered a Climate Change
mitigation technology (Garnaut, 2008, 2011), there is uncertainty in calculating the precise value of the GHG avoidance due to the variation in conversion technologies (Intergovernmental Panel on Climate Change, 2013; Raymer, 2006). Once a CBC is established and commercial, the GHG abatement will be defined more precisely. For example, biomass diverted from landfill will create significant GHG savings as will particular applications if the gas and char are substituted for coal or natural gas.

**Integration of a CBC within the present energy system**

In the United States, the Department of Energy (DOE) and the Electric Power Research Institute (EPRI) began testing and analysing the technical and economic issues of co-firing coal and biomass after the Rio Summit in 1992. A significant database has now been created identifying biomass properties, boiler performances and combustion mechanisms (Hughes, 2000; Hughes & Tillman, 1998). Most core technical issues that had hindered the uptake of co-firing have fundamentally been resolved (Hughes, 2000).

Co-firing biomass at coal power stations has been successful with up to a 20 per cent biomass mix. These biomass-coal blends have shown they can even improve boiler efficiency, reduce fuel costs and emissions. Since woody biomass has low elemental sulphur so SO$_2$ emissions can also be greatly reduced (Demirbas, 2003). Sterner and Fritsche (2011) also showed that higher GHG emission reductions can be gained when raw biomass fully replaced coal-fired power stations. Previously only co-firing was thought to provide the best GHG mitigation option (Sterner & Fritsche, 2011).

Biomass co-firing has also been conducted in the Hunter Valley. In 1999 Macquarie Generation (now AGL) started co-firing biomass at Liddell Power Station as part of its GHG reduction initiatives. License conditions allowed up to 5 per cent biomass to be blended with coal. The biomass was primarily woodchip waste from sawmills delivered by road from outside the Muswellbrook LGA. Although it was successful in reducing GHG emissions it ceased in June 2006 due to financial and mill constraints caused by increased transport costs and the falling price of renewable energy certificates (RECs). The return on energy produced from woodchips, combined with the REC price at the time, did not cover the cost of transport and on-site handling. Grinding
the woodchips to the consistency required at Liddell was problematic and caused interruptions to operations as increased demand for electricity post 2005 required Liddell to operate close to capacity. This jeopardised the reliability of the power station and reduced its capacity to supply electricity at critical times. Macquarie Generation continued its biomass program for some time using other sources of bio-waste (e.g. glycerol) to overcome the operational problems associated with grinding and burning wood chips in equipment designed to process coal. Presently no biomass or waste is co-fired at Liddell or Bayswater Power stations (R. Cooper, personal communication, 15 August 2014).

Biomass density and grindability are not always compatible with coal as some mills are designed to pulverize hard coal. Different blends of raw biomass such as radiata pine sawdust and Hunter Valley Drayton Coal have also been laboratory tested to try and define co-firing performance improvements (Moghtaderi, Meesri, & Wall, 2004), but the conversion of the biomass first to a char could hold the answer to improved performance, not the adjustment of biomass blends or mills adaptation. This is because pyrolysis breaks down the hemicellulose matrix of the biomass and depolymerizes the cellulose, converting the char to a much more suitable renewable product for co-firing. Vales Point’s license, (like AGL’s Bayswater and Liddell) allows 5 per cent biomass to be co-fired, which is equivalent to 100 000 tonnes per annum.

If the CBC was positioned adjacent to a coal fired power station, the gas and the char could both be used for electricity generation. Burning coal for electricity produces increasingly unacceptably high levels of pollution and co-firing different types of wood biomass in a coal fired power station has become an established practice around the world to reduce GHG emissions. Carbon dioxide (CO₂) carbon monoxide (CO) volatile organic hydrocarbons VOC’s, nitrogen oxides (NO and NO₂), acid gasses from sulphur and chlorine are all pollutants from coal fired power stations (Murphy, 2004). To help overcome some of the pollution issues, filters have become mandated on Australian power stations and 24hr air quality networks monitor particulate emissions. Furthermore CH₄ emissions are reduced as a direct result of using biomass feedstock with coal thus avoiding the wood biomass entering landfill. Specific technical challenges faced by each power plant such as biomass access,
handling and storage generally rarely hinder this low-risk, low-cost, renewable energy option with low volume blends and can provide immediate affordable emissions reduction (Baxter, 2005). The percentage of biomass for co-firing suitable for each boiler design will vary. Reviews of a variety of fuel blends and conditions suggest co-firing provides an immediate way to reduce emissions from existing power plants (Sami, Annamalai, & Wooldridge, 2001).

On October 25, 2013, char supplied by TCG was mixed with coal to produce electricity for the first time in Australia. This occurred at the Delta Electricity Vales Point coal-fired power station, situated on the edge of Lake Macquarie. Subsequent trials with increasing char rates demonstrated that biomass co-firing could be increased substantially if the biomass was processed in a CBC (The Crucible Group Pty Ltd, 2014b).

The biomass used in all the Vales Point co-firing char trials, was a blend of native hard woods from timber mills at New South Wales. It was tested for undesirable trace elements as listed in Table 3:7 and found to have low concentrations. The volatility of trace elements is an important consideration in understanding the pathway of any potential pollutant. The potential of contaminated feedstock to be used remains an important challenge sourcing suitable biomass (Sami et al., 2001). After the char was sent along the conveyer belt to the power station, mill performance was tested. Table 3:6 shows in this case the calorific value of char at 28.10 is higher than coal at 27.91, but with much lower ash and sulphur levels, demonstrating how char is like a coal but much cleaner. This is why char can be referred to as “bio-coal” or clean-coal.

<table>
<thead>
<tr>
<th></th>
<th>Hunter Valley Coal</th>
<th>Biomass Woodchip</th>
<th>CBC Char</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ash</td>
<td>15.6</td>
<td>0.8</td>
<td>1.1</td>
</tr>
<tr>
<td>Volatile Matter</td>
<td>28.4</td>
<td>81.0</td>
<td>30.8</td>
</tr>
<tr>
<td>Fixed Carbon</td>
<td>53.6</td>
<td>13.9</td>
<td>63.8</td>
</tr>
<tr>
<td>Carbon</td>
<td>83.8</td>
<td>49.4</td>
<td>80.4</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>4.91</td>
<td>5.86</td>
<td>2.88</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>1.98</td>
<td>0.08</td>
<td>0.36</td>
</tr>
<tr>
<td>Sulphur</td>
<td>0.76</td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>Oxygen</td>
<td>8.80</td>
<td>44.59</td>
<td>16.36</td>
</tr>
<tr>
<td>Gross Calorific Value</td>
<td>27.91</td>
<td>18.46</td>
<td>28.10</td>
</tr>
</tbody>
</table>

Note. Adapted from Delta Electricity and The Crucible Group Pty Ltd 2013
The potential use for the gas

The location of a plant will ultimately define the best use for the outputs. The chemical make up of the gas is different to natural gas and this means the two cannot be piped or mixed together. In other words, it cannot piggyback on the natural gas infrastructure and will not be used as a retail gas. The gas needs to be used locally as gas for heating or drying or further converted to produce electricity. As Muswellbrook Shire presently does not have significant commercial need for industrial heat, generating electricity would be the preferred option. To achieve this a CBC plant will need to be connected to an electricity generator to enable the energy to be used on site or delivered into the grid system. The Crucible Group has demonstrated the ability to generate electricity directly in line with the CBC, without an intermediate gas cleaning plant (The Crucible Group Pty Ltd, 2012).

Pollutants

Coal contains multiple toxic substances and all coal-fired power stations are granted a license to emit certain pollutants. These are referred to as Type 1 or Type 2 volatile trace elements, (as defined by the Clean Air Regulations). Annual returns recording pollution levels are required by each power station. These are submitted to the EPA and recorded in the National Pollutant Inventory (NPI), and on each power station’s web site. (Delta Electricity. Vales Point Power Station).

Pyrolysis systems will also be required to define and prove safety during production and with all outputs. As listed in Table 3:7, in so far as these may be in the biomass they are most likely to present as emissions. To meet the admissible levels granted to Delta Electricity, the concentration of these trace metals must be <350mg/kg. Type 1 or Type 2 volatile trace elements in a CBC char have been tested at Vales Point and found to be well below approval standards (The Crucible Group Pty Ltd, 2013).
Table 3:7 Type 1 & Type 2 Substances

<table>
<thead>
<tr>
<th>Type 1 substances</th>
<th>Type 2 substances</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antimony</td>
<td>Beryllium</td>
</tr>
<tr>
<td>Arsenic</td>
<td>Chromium</td>
</tr>
<tr>
<td>Cadmium</td>
<td>Cobalt</td>
</tr>
<tr>
<td>Lead</td>
<td>Manganese</td>
</tr>
<tr>
<td>Mercury</td>
<td>Nickel</td>
</tr>
<tr>
<td></td>
<td>Selenium</td>
</tr>
<tr>
<td></td>
<td>Tin</td>
</tr>
<tr>
<td></td>
<td>Vanadium</td>
</tr>
<tr>
<td></td>
<td>Or any compound containing one or more of the above</td>
</tr>
</tbody>
</table>

Note. Adapted from Protection Of The Environment Operations (Clean Air) Regulation 2010 - Reg 31

As a dispatchable clean renewable-energy system, pyrolysed biomass (in the form of gas and char) can meet two clear climate change mitigation outcomes and toxic pollution issues when co-fired with coal

- reduce GHG emissions
- reduce SO$_2$ emissions
- reduce mercury emissions

One reoccurring question in the environmental and energy literature is, Does co-firing lead to bigger or better biomass energy use beyond co-firing?’ (Hughes, 2000). This has been a particularly important issue in Australia where co-firing biomass with coal is often seen as prolonging the life of coal fired power stations and a divergence from other renewable industries like wind and solar. On the other hand, it is an opportunity to utilise existing societal assets and develop a pathway for a new technology that produces renewable baseload power (unlike wind and solar).

Coal consumption for energy has grown with China presently accounting for 75% of global coal consumption. Therefore biomass and/or char co-firing is one way to reduce GHG, SO$_2$ and other emissions in the short term (Zhang, Xu, Zhao, & Liu, 2007).

**Particulate Matter Emissions**

Concern over increasing GHG emissions has also coincided with strict air pollution guidelines that need to be met (Murphy, 2004). Standards for control of particulate matter (PM) sizes 1-10 have also become progressively stringent.
While dust from mines and power stations are usually monitored by PM10 stations, the finer, more dangerous particulates <10 can elude monitoring devices and spread more easily (Zhang & Ninomiya, 2006).

The development of biomass feedstock will need to meet regulations governing all types of emissions, from heavy metals to different particulate levels. As there is more variation between biomass types than coal types, this is certain to be a growing area of research. Wiinikka et al. (2013) have shown the emission variation from a variety of biomass feedstock compared to coal.

Particulate matter (PM) has been an important public issue relating to coal fired power use in the Hunter Valley with significant increases in PM 2.5 and PM 10 emissions coinciding with the development of the coal industry. The Upper Hunter Valley has a separate air quality-monitoring network managed in conjunction with the other networks by the EPA (Upper Hunter Air Quality Monitoring Network).

Consequently the fact that emissions under PM 10 from biomass combustion can be high has raised concern (Baxter, 2005; Hughes & Tillman, 1998). In 2013 a new report by CSIRO and the Australian Nuclear Science and Technology Organisation (ANSTO) evaluated PM 2.5 particles recorded in the monitoring stations at Muswellbrook and found that domestic wood smoke, from different types of open fires, was the main contributor to fine particle pollution (Hibberd et al., 2013; NSW Government Environment and Heritage, 2014). Despite being surrounded by five coalmines, the significance of biomass, in particular wood, as a potential source of pollution is an issue in Muswellbrook.

Zhang et al demonstrated how in one circumstance biomass co-firing led to a direct increase in <10PM. When comparing calorific values of cedar chip biomass and coal, the quantity of PM1 increased proportionally with the increase in woodchip used (Zhang & Ninomiya, 2006). Pyrolysing the biomass first, and mixing char with coal could overcome this.

Research into understanding the development and control of particulate emissions via combustion and incineration is ongoing. Pyrolysis emissions are discussed further in Chapter 8.
Particulate measurements when combusting CBC gas have been measured by The Crucible Group at Vales Point and are well below the high air quality industrial standards set by the EPA for Group 6 Plants (NSW Environment Protection Authority) (The Crucible Group Pty Ltd, 2014b).

3.4 Summary

Pyrolysis for char production has a long history of use. However, modern pyrolysis is more than a char making process as it produces gas and pyrolysis liquids. Incorrect negative assumptions regarding the efficiency potential for a modern application of this thousand year old thermal decomposition technology have hindered its development. The below quote from Geoscience Australia, Pg 326, is a paradigm example of this analysis as it appears in government documents.

Pyrolysis encounters technical difficulties, which have prevented its implementation on a commercial-scale. These include effective heat transfer between the heat carrier and biomass particles or the quenching of vapours to stop further reactions that result in bio-oil quality variations (Geoscience Australia and ABARES, 2010).

The assumptions made in the analysis do not apply to the CBC. Rather, the invention of the CBC dealt with the core issue thwarting the industry’s development: the lack of efficient technology.

The technical breakthrough with The Crucible Group’s CBC is the energy efficiency of the process, the clean gas produced and the cost effectiveness of the whole operation (Mulligan et al., 2010; The Crucible Group Pty Ltd, 2013). Table 3:8 summaries the ten clear advantages of this technology, referring to the above key issues and highlighting the scope of integrating pyrolysis from an input and output point of view into a local economy where a more sustainable biomass resource can be utilized and land use improved.
### Table 3:8 Continuous Biomass Converter distinguishing characteristics

<table>
<thead>
<tr>
<th></th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>96% Efficient as cleaning is not needed</td>
</tr>
<tr>
<td>2</td>
<td>Continuous process</td>
</tr>
<tr>
<td>3</td>
<td>Biomass can be processed directly without pre drying</td>
</tr>
<tr>
<td>4</td>
<td>A small fraction of the energy within the biomass is needed to meet the process requirement</td>
</tr>
<tr>
<td>5</td>
<td>The gas made is clean enough for direct use and does not need to undergo further treatment</td>
</tr>
<tr>
<td>6</td>
<td>The reaction chamber has a plurality of zones along its length</td>
</tr>
<tr>
<td>7</td>
<td>Will accept flexible biomass sizes</td>
</tr>
<tr>
<td>8</td>
<td>The gas, liquid and char leaves the chamber via separate points</td>
</tr>
<tr>
<td>9</td>
<td>Scalable modular system</td>
</tr>
<tr>
<td>10</td>
<td>Affordable</td>
</tr>
</tbody>
</table>

For a CBC to be viable in the near future, a starting point must be found in which it is possible to:

- identify a suitable location
- secure a sustainable biomass supply
- secure product applications

The CBC has the capacity to drive climate change solutions, in particular carbon sequestration and renewable energy. To start with, the CBC has tested performance parameters at a coal-fired power station. The char and water outputs have been tested in field and pot trials and are discussed in Chapters 5 and 6.
CHAPTER 4  BIOMASS

'I feel like the time to do something was yesterday'
Mark Pagani, Yale geochemist, 2013

4.1 Introduction

Chapter 3 described the fundamentals of slow pyrolysis and the new CBC developed by The Crucible Group that has reached early commercialisation stage. The principle biomass feedstock used in trials has been timber mill residues and wood waste. In contrast to competing pyrolysis technologies, The Crucible Group’s system from a process and equipment perspective, has high conversion efficiency.

When considering the vision of this thesis; to understand the requirements needed to establish a pyrolysis industry in Muswellbrook, the range of biomass options to secure a supply for the life of a plant is needed. A sustainable biomass supply not only requires an adequate volume but must also be at the right price and in the right area.

This chapter describes fundamental biomass characteristics as a general energy source. The existing biomass availability within the Muswellbrook LGA is examined within four sectors, Agriculture, Mine-used Lands, Municipal and Forestry. Yield levels are provided and options and constraints discussed. As there is no existing biomass industry it is likely future supplies will utilize resources differently, but to start with, in the here and now, there would need to be a shift in resource allocation to start a slow pyrolysis industry.

Definition

The United Nations Framework Convention on Climate Change defines biomass as:

A non-fossilized and biodegradable organic material originating from plants, animals and micro-organisms. This shall also include products, by-products, residues and waste from agriculture, forestry and related industries as well as the non-fossilized and biodegradable organic fractions of industrial and municipal wastes (Intergovernmental Panel on Climate Change, 2007).
Biomass is organic matter that comes in many non-fossil forms, including the leaves, stems, roots, twigs and trunks of plants and all animals dead or alive. It is complex, heterogeneous, stored solar energy, distributed the world over and capable of supplying electricity, heat, steam, liquid fuels, gaseous organic fuels and a variety of useful chemicals. It is often considered the only ‘indigenous renewable energy resource’ or ‘renewable carbon resource’ (Klass, 1998; Reijnders, 2006). Burning fossil fuels is burning yesterday’s biology. Biomass is today’s biology and technically a fossil fuel substitute. In the many millions of years of geological time the carbon in fossil fuels could eventually be renewed but humans cannot grow fossil fuels quickly enough in time for use within centuries.

**Carbon Neutrality**

Biomass is classified as carbon neutral because it removes carbon from the atmosphere as plants grow and release O$_2$ (Intergovernmental Panel on Climate Change, 2007). This closed carbon cycle can maintain atmospheric CO$_2$ levels, provided there is no net clearing (Searchinger et al., 2009).

**Global Supply Estimates**

Globally, biomass for bioenergy is the most widely used renewable energy source, making up 10% of the global world supply (Berndes et al., 2011). Yet 80% of that 10% comes from traditional uses, within traditional cultures, such as cow manure and wood used in Indian village kitchens (FAO (Food and Agriculture Organisation of the United Nations), 2008).

Klass (1998) suggests most of the data used to support the theoretical claim that the world does have enough biomass for a diverse bioenergy sector is based on potential supply. It assumes that while many places can grow adequate biomass, topography often dictates whether the biomass can be cost-effectively collected. Even so, the standing biomass of the world could, if harvested supply 10 times the world’s energy consumption (Klass, 1998). The World Energy Council 2005, estimates the global biomass capacity to be 40GW per year (Schiermeier, Tollefson, Scully, Alexandra Witze, & Morton, 2008). When considering the supply together with is geographic limitations, legislative restrictions and local customs, the potential of biomass supply is usually adjusted downwards.
Biomass Classification

Biomass grown specifically for energy production use is often referred to as ‘virgin biomass’ or ‘primary biomass’. It is differentiated from the biomass designated as ‘waste-biomass’ or ‘residue biomass’ made from agricultural, commercial or industrial by products. Table 4:1 shows the Two Major Groups of Biomass and their Sub-classifications

Table 4:1 Two major groups of biomass and their sub classification

<table>
<thead>
<tr>
<th>Virgin Terrestrial biomass</th>
<th>Aquatic biomass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest biomass</td>
<td>Algae</td>
</tr>
<tr>
<td>Grasses</td>
<td>Water plants</td>
</tr>
<tr>
<td>Energy crops</td>
<td></td>
</tr>
<tr>
<td>Cultivated crops</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Waste Municipal waste</th>
<th>Agricultural solid waste</th>
<th>Forestry residues</th>
<th>Industrial wastes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Municipal solid waste</td>
<td>Livestock and manures</td>
<td>Bark, leaves, floor residues</td>
<td>Demolition wood, sawdust</td>
</tr>
<tr>
<td>Biosolids</td>
<td>Agricultural crop residue</td>
<td></td>
<td>Waste oil</td>
</tr>
<tr>
<td>Green waste</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Landfill gas</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. Adapted from Biomass classifications pg 29, Basu, 2010

Further categorising is shown in Table 4:2. Here the selection for biomass is usually divided into three groups, grasses, forest materials and cultivated plants and classified as either first, second or third generation etc. First generation biomass is the food crops, most notably corn, sugar, soy and wheat, which are actually grasses. There are over 400 genera and over 6000 grass species throughout the world. Second generation biomass includes grasses that are not food crops, or the inedible part of food crops. The non-edible fibrous or woody portion of plants is the ligno-cellulosic material. These are used in the research, development and demonstration stage of various bioenergy processes. Also included in this second generation group are forest materials including everything growing in plantation forests. Acacia, Casuarina and Eucalyptus are three Australian natives widely used globally in commercial plantations (Klass, 1998). Third generation biomass includes algae. They are regarded as an important potential biofuel (Brennan & Owende,
2010) because they can produce biomass quickly and use less land than the ligno-cellulosic biomass production of grasses and trees. The core difference between second and third generation biofuels is the source of biomass.

### Table 4:2 Bioenergy Classification

<table>
<thead>
<tr>
<th>Classification</th>
<th>Feedstock</th>
<th>Business stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>First generation Biofuel</td>
<td>Sugar and starch crops for ethanol.</td>
<td>Proven and commercial</td>
</tr>
<tr>
<td></td>
<td>Vegetable oils and animal fats for biodiesel</td>
<td></td>
</tr>
<tr>
<td>Second generation Biofuel</td>
<td>Lignocellulosic material and some algae to biochemical fuels</td>
<td>Research, development and demonstration stage</td>
</tr>
<tr>
<td>Third generation Biofuel</td>
<td>Algae</td>
<td>Research and development stage</td>
</tr>
</tbody>
</table>

Note. Classifications based on Geoscience Australia 2012

### 4.2 Biomass Characteristics

#### 4.2.1 Elemental Composition

The elemental composition defines the energy content, which in turn indicates potential efficiency value of the biomass in conversion. Sources vary in their complex physical structure; the hemi-cellulose, cellulose and lignin components. Table 4:3 shows some elemental differences between a biomass sources such as legume straw and coal.

### Table 4:3 Comparison of proximate and ultimate analyses of straw and coal

<table>
<thead>
<tr>
<th>Sample</th>
<th>Legume straw</th>
<th>Dayan lignite (coal)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Proximate analysis (wt.%)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moisture</td>
<td>9.8</td>
<td>27.96</td>
</tr>
<tr>
<td>Ash</td>
<td>1.62</td>
<td>7.9</td>
</tr>
<tr>
<td>Volatile matter</td>
<td>73.74</td>
<td>35.09</td>
</tr>
<tr>
<td>Fixed carbon</td>
<td>14.84</td>
<td>29.05</td>
</tr>
<tr>
<td><strong>Ultimate analysis (wt.%)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon</td>
<td>43.3</td>
<td>76.35</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>5.62</td>
<td>5.33</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>0.61</td>
<td>2.08</td>
</tr>
<tr>
<td>Sulphur</td>
<td>0.12</td>
<td>0.15</td>
</tr>
<tr>
<td>Oxygen (difference)</td>
<td>50.35</td>
<td>16.09</td>
</tr>
</tbody>
</table>


Compared to fossil fuels biomass is an oxygenated fuel with less carbon and therefore a lower heating value. The heating values do not vary significantly between different biomass sources (Parikha, Channiwala, & Ghosal, 2007). Carbon, oxygen and hydrogen are the main elemental components of plant biomass, while nitrogen, chlorine and sulphur are also present in smaller
volumes. Tao, Lestander, Geladi, and Xiong (2012) showed the C, O and H were less variable with biomass types than the N, S and ash content. Up to 45 per cent of biomass dry weight can be oxygen, while the nitrogen, sulphur, and chlorine are usually well below 1 per cent each. Tao et al assessed 260 peer-reviewed papers to evaluate potential fuel characteristics of various plant groups and collated data on 144 species. There was a large variation in herbaceous materials while woody plants were more homogeneous. Fuel capacity was highest with wood plants. The C4 perennials (plants that have adapted to wet conditions) were the next highest group, whereas the C3 perennials, (the cool climate group that tolerate frost) had the least fuel capacity. Both C3 and C4 plants are important to the study area and often group together in the landscape providing diverse groundcover range for both native animals and grazing operations. Tao et al. (2012) analysis showed that the ash content was the largest factor differentiating biomass fuel capacities between species.

4.2.2 Bulk Density

The bulk density of a material is its weight per unit volume. Biomass has a lower density than coal and this fact is frequently cited by the fossil fuel sector as a prime reason for being a lower quality energy source. In some instances biomass bulk density can be as low as 20 per cent of coal. Yet in a future sustainable paradigm, local biomass supplies that are renewable will be more important. Table 4:3 highlights some the core differences between straw and NSW coal. The low density of biomass has driven the development of the pellet sector. Straw is pelletised in some countries although wood is the main feedstock for the European pellet industry. Improving logistic efficiencies by improving the bulk density is discussed in Chapter 8.

4.2.3 Calorific Value

The calorific value or heating value is the energy potential embedded in the biomass and is determined experimentally and calculated from ultimate and/or proximate analysis (Erol, Haykiri-Acma, & Küçükbayrak, 2010; Sheng & Azevedo, 2005).
A proximate analysis provides a simple and easy estimation and is acceptable for engineering estimations (Erol et al., 2010). This type of analysis of calorific value has been conducted on a number of potential biomass sources.

Table 4:4 shows different proximate analysis results on a variety of typical fibrous agricultural by-products. All are potential biomass sources and reveal large variations in moisture, fixed carbon, ash and heating value. Heating values are typically between 15 and 20 MJ/kg on a dry basis; note that wood typically is at the high end of this range.

Table 4:4 Proximate Analysis of some biomass samples

<table>
<thead>
<tr>
<th>Biomass sample</th>
<th>Moisture (%)</th>
<th>Fixed carbon % (db)</th>
<th>Ash % (db)</th>
<th>Volatile matter % (db)</th>
<th>Organic matter % (db)</th>
<th>Heating value MJ/kg (db)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broad Bean Husk</td>
<td>10.75</td>
<td>8.68</td>
<td>5.88</td>
<td>85.44</td>
<td>94.12</td>
<td>16.07</td>
</tr>
<tr>
<td>Sunflower Shell</td>
<td>10.25</td>
<td>11.70</td>
<td>3.62</td>
<td>84.68</td>
<td>96.38</td>
<td>17.86</td>
</tr>
<tr>
<td>French Bean Stalk</td>
<td>9.00</td>
<td>4.67</td>
<td>6.32</td>
<td>89.01</td>
<td>93.68</td>
<td>15.41</td>
</tr>
<tr>
<td>Sunflower Stalk and Stover</td>
<td>8.12</td>
<td>5.17</td>
<td>8.98</td>
<td>85.85</td>
<td>91.02</td>
<td>15.87</td>
</tr>
<tr>
<td>Sourcheery Stalk</td>
<td>6.00</td>
<td>14.10</td>
<td>5.05</td>
<td>80.85</td>
<td>94.95</td>
<td>17.59</td>
</tr>
<tr>
<td>Walnut Shell</td>
<td>10.00</td>
<td>16.94</td>
<td>3.89</td>
<td>79.17</td>
<td>96.11</td>
<td>18.91</td>
</tr>
<tr>
<td>Almond Shell</td>
<td>1.25</td>
<td>18.73</td>
<td>4.05</td>
<td>77.22</td>
<td>95.95</td>
<td>17.96</td>
</tr>
<tr>
<td>Peanut Shell</td>
<td>8.12</td>
<td>13.60</td>
<td>5.99</td>
<td>80.41</td>
<td>94.01</td>
<td>18.46</td>
</tr>
<tr>
<td>Cornelian Cheery Stone</td>
<td>5.50</td>
<td>23.80</td>
<td>2.96</td>
<td>73.54</td>
<td>97.04</td>
<td>19.02</td>
</tr>
<tr>
<td>Apricot Stone</td>
<td>4.00</td>
<td>17.83</td>
<td>1.04</td>
<td>81.13</td>
<td>98.96</td>
<td>18.80</td>
</tr>
<tr>
<td>Peach Stone</td>
<td>5.00</td>
<td>20.79</td>
<td>1.05</td>
<td>78.16</td>
<td>98.95</td>
<td>19.52</td>
</tr>
<tr>
<td>Apricot Bagasse</td>
<td>3.50</td>
<td>15.80</td>
<td>3.89</td>
<td>80.31</td>
<td>96.11</td>
<td>18.56</td>
</tr>
<tr>
<td>Peach Bagasse</td>
<td>6.50</td>
<td>6.15</td>
<td>1.87</td>
<td>91.98</td>
<td>98.13</td>
<td>16.24</td>
</tr>
<tr>
<td>Hybrid Poplar</td>
<td>9.00</td>
<td>6.87</td>
<td>3.44</td>
<td>89.69</td>
<td>96.56</td>
<td>17.14</td>
</tr>
<tr>
<td>Ash Tree</td>
<td>8.75</td>
<td>14.12</td>
<td>5.75</td>
<td>80.13</td>
<td>94.25</td>
<td>18.06</td>
</tr>
<tr>
<td>Pine Cone</td>
<td>9.25</td>
<td>15.15</td>
<td>6.89</td>
<td>77.96</td>
<td>93.11</td>
<td>18.55</td>
</tr>
<tr>
<td>Soybean Cake</td>
<td>12.50</td>
<td>16.00</td>
<td>7.14</td>
<td>76.86</td>
<td>92.86</td>
<td>18.30</td>
</tr>
<tr>
<td>Cotton Cake</td>
<td>8.25</td>
<td>11.58</td>
<td>4.77</td>
<td>83.65</td>
<td>95.23</td>
<td>17.50</td>
</tr>
<tr>
<td>Rapseseed</td>
<td>10.75</td>
<td>5.60</td>
<td>8.13</td>
<td>86.27</td>
<td>91.87</td>
<td>16.81</td>
</tr>
<tr>
<td>Potato Peel</td>
<td>8.50</td>
<td>9.56</td>
<td>6.29</td>
<td>84.15</td>
<td>93.71</td>
<td>17.18</td>
</tr>
</tbody>
</table>

Note. Adapted from Erol M et al (2010). *(db) = dry basis

4.3 Muswellbrook LGA Biomass Supply

From a business perspective the biomass supply, regardless of type, must be available over the life of a project. Rosillo-Calle et al (page 29) highlights the difficulties in accurately assessing biomass types in their Ten Commandments of Biomass Assessment.

This ten point declaration, a philosophical background note, has been useful while considering biomass’s complex role in the Muswellbrook LGA.
• Never confuse consumption with need.
• Do not separate consumption from supply.
• Make your assumptions explicit.
• Your data requirements must be driven by your problem.
• Be aware of the dangers of devoting too many resources to data collection and too few on analysis.
• Do not ignore it because you cannot measure it.
• Do not be beguiled by averages.
• There is no single, simple solution so distrust the simple, single answer.
• The users are the best judges of what is good for them.
• Be flexible and modify any of the above if it seems sensible to do so (Rosillo-Calle et al., 2007).

When taking Rosillo-Calle’s points into consideration one realizes evaluating biomass is as much a cultural task as it is agricultural and ecological. No matter how many satellite views, maps or GPS points there are, when it comes to the crunch securing biomass demands a multitude of considerations. As the IPCC regularly points out, sustainable biomass is very site specific, uncertainties are large and a variety of assessment tools will be needed to evaluate its full potential (IPCC, 2011). As no bioenergy industry is operating in the Muswellbrook LGA there has previously been no need to understand biomass within a framework of multiple choices that includes energy production.

To establish a clear indicator of the proximate biomass in the Muswellbrook LGA across its 340,200 hectares and because biomass is site specific (Rosillo-Calle et al., 2007) it was decided to categorize the different types into subgroups:

• Agriculture
• Mine-used lands
• Municipal
• Forestry.
some Crown Land has been shifted to the Aboriginal Land Council. The transfer of land to the Land Council is ongoing, and presently makes up a considerable portion of the area.

### 4.3.1 Aboriginal Land

There is one other category of land separate from those mentioned: local Aboriginal Land. Since the Aboriginal Land Rights Act of 1983, management of some Crown Land has shifted to the Aboriginal Land Council. The transfer of land to the Land Council is ongoing, and presently makes up a considerable portion of the area.
area as the number of land parcels as Table 4:5 shows. Although ownership is transferred, the area must still comply with existing rules and designations. Most of the land is not suitable for economic activities due to its geographic position, mainly on top of ridges. Traditional owners living in the Muswellbrook LGA are the Wanaruh and Kambilari peoples. The 2011 Census showed 5.4 per cent of the local population was indigenous, double the NSW average of 2.5 per cent (Muswellbrook Shire Council, 2012a).

One parcel, though, Muswellbrook Common, situated on the edge of town next to the waste depot is different. It has low undulation, is mostly cleared, and possible for biomass development if land use changes were accepted. Due to the close proximity to town this is not an area likely for immediate development.

<table>
<thead>
<tr>
<th>Name</th>
<th>Hectares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Denman Common</td>
<td>89</td>
</tr>
<tr>
<td></td>
<td>73</td>
</tr>
<tr>
<td>Sandy Creek</td>
<td>570</td>
</tr>
<tr>
<td>Sandy Hollow</td>
<td>500</td>
</tr>
<tr>
<td></td>
<td>710</td>
</tr>
<tr>
<td>Giants Creek</td>
<td>2920</td>
</tr>
<tr>
<td>Muswellbrook</td>
<td>730</td>
</tr>
<tr>
<td>Muswellbrook Common</td>
<td>3460</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>9052</strong></td>
</tr>
</tbody>
</table>

*Note: Collated from data provided by Wanaruah Land Council 2014*

### 4.4 Agricultural Sector

#### 4.4.1 Introduction

There is no reason to suggest agricultural practices in the Muswellbrook LGA are particularly unique. Agricultural costs and income are estimated to be equal to the national average (Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES)). Growing bio-energy crops requires the same technical expertise as growing food or fibre. Agriculture is the main user of land in the world, in Australia, and the main enterprise on most of the privately owned land in Muswellbrook LGA. There remains a dedicated, diverse agricultural sector in Muswellbrook largely based on growing fodder for livestock; a diminishing dairy industry; thoroughbred sector; a contracting
grape growing sector; wine making; and at time of writing, one surviving semi commercial vegetable grower. The Hunter Valley is not devoid of a professional farming culture, despite being a net importer of food (Hunter Valley Research Foundation, 2009).

**Area**

Muswellbrook LGA in 2011 had 161,023 hectares of prime and grazing agricultural land. This ‘Prime Agricultural’ land, designated as Class 1 (NSW Agriculture, 2002), is adjacent to the Hunter River and its tributaries. The townships of Muswellbrook, Denman, Wybong and Sandy Hollow are also established on or adjacent to these agricultural lands.

![Figure 4:2 Land Capability Muswellbrook LGA](image)

Figure 4:2 gives a clear representation of land use. Historically all major grains, wheat, rye, oats, barley and corn have been grown on class 1 and 2 lands and used for human consumption and animal feedstock (Wood, 1972). Grazing has been undertaken on Class 3, 4 and 5.
Land Ownership

Most pastoral businesses in the area reveal dynamic changes in land ownership throughout the 20th century where holdings originally evolved as mixed farming operations, endured enforced subdivision after World War 2, and have been repeatedly aggregated and subdivided.

Agricultural land in Muswellbrook LGA features different land ownership structures.

1. Freehold land owned by rural companies who undertake some form of agricultural activity.
2. Land owned by individuals for profit making and pleasure.
3. Land owned by mining companies, usually adjacent to a mine pit or near by and used as offsets and referred to as mine-owned lands. Muswellbrook LGA is unique with mine-owned lands occupying substantial areas of prime agricultural land. This land is often leased to a third party and while there is agriculture undertaken it is limited by conditions of use. The land is not managed with the same financial and cultural considerations as private and publically owned land but is used for agricultural purposes.
4. Crown Land leased to individuals and companies.
5. Land managed by the Aboriginal Land Council, (formerly Crown Land)

4.4.2 Agricultural Industries

The different agricultural industries are discussed separately below. Each sector has endured expansion and contraction due to economic, social and land competitive issues. Their historical evolution helps define a future biomass capacity.

Dairy

Historically the area was a leading dairy region. The milk factory in town has since converted for wine processing. There has been a reduction in the number of dairy farms due to a combination of industry restructure, closures due to mining, competition for land with horse studs and amalgamation.
The NSW DPI Upper Hunter Region Dairy Profile Fact Sheet No 3, published in June 2013 states there are 42 dairies in the shire. In fact there are 14 dairies in the LGA operating in 2014 (NSW DPI, 2013).

All biomass produced on dairies is fed to the herd. Moreover each dairy buys in more than 50% of their feedstock from outside the area (NSW DPI, 2013). As the numbers of dairies have decreased so too have dairy services. This is most evident with only one vet servicing dairy cows in the area, while sixteen other vets in the LGA specialize in small pets and horses.

Despite the restructuring and increased uncertainty regarding milk pricing there remains a professional dairy sector in Muswellbrook LGA. NSW DPI coordinated an industry research project FutureDairy in the Hunter Valley in 2009-11 (Lisle A & Kempton, 2011), to test the capacity to sustainably intensify growing feed on dairies using a Complementary Forage System (CFS), where three crops a year are grown on 35% of the diary while 65% is managed with pasture. Three farms that took part in this research were in the Muswellbrook LGA. All increased their home grown feed as a result. Dairies are intensive agricultural businesses that usually maximise productivity with high stocking rates, irrigation and fertilisers and where financial risk and defining the feed production limit is challenging. FutureDairy reported minor management changes led to increased productivity. It has been interesting to view the productive capacity of dairy land as most of this land is class 1 and 2 and represents the highest value. Production increase usually means costs increase and this can only be justified if the value of the product remains high.

As Table 4:6 suggests there is both manure and pasture biomass on dairies but the value of it is high and could not be substituted for biomass. The land is the most productive and unless different energy crops were grown or crops with a high residue these areas cannot supply immediate biomass.

**Table 4:6 Biomass supply from dairies in Muswellbrook LGA**

<table>
<thead>
<tr>
<th>Biomass</th>
<th>Proximate volume (tonnes)</th>
<th>Available</th>
<th>Issue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pasture</td>
<td>2000+</td>
<td>No</td>
<td>All consumed</td>
</tr>
</tbody>
</table>

*Note. Collated from Muswellbrook LGA Dairy farms*
Grazing Land

The meat industry in the Hunter Valley includes beef, sheep and pigs and is a fully integrated system. Multiple farms, graziers, - both breeders and finishers, abattoirs, tanneries, designated transport, stock and station agents, high school, TAFE, University courses and banking, all service domestic and export markets with 200 years experience. Cattle grazing is primarily conducted on Class 3, 4 and 5 land where opportunity harvests of grass (hay making) are undertaken.

The native vegetation of the shire represented 60 per cent of the total area, with 43 per cent designated in forests where no grazing takes place (Muswellbrook Shire Council, 2009). The remaining 17 per cent of land offers a productive capacity of opportunity biomass harvesting but only if a high price could be met.

The volume of potential opportunity harvests is shown in Table 4:7 and is calculated on hay made on 100 hectares, conservatively producing 10 tonne per hectare.

Table 4:7 Proximate biomass across grazing land

<table>
<thead>
<tr>
<th>Biomass</th>
<th>Proximate volume (tonnes)</th>
<th>Available</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grass supply in Opportunity harvests</td>
<td>1000</td>
<td>No</td>
</tr>
</tbody>
</table>

The meat sector provides no biomass supply, either as manure, or animal waste in Muswellbrook LGA.

Grapes

Grape growing dates back to 1860s in the Upper Hunter. The industry has restructured and slowed with the expansion of the coal sector. Not all the grapes grown are processed locally. Muswellbrook has approximately 1275 ha vines across 23 vineyards (Upper Hunter Region Viticulture Profile Fact Sheet No. 5, 2011). Three have winemaking facilities and one separate wine processor is based in Muswellbrook township. The local viticulture industry and the Council have also identified an important economic wine cluster area surrounding Denman (Muswellbrook Shire Council, 2012b).
Vine plantings vary from 1700 to 1900 per ha. Volumes of wine fluctuate from 5 t/ha in dryland vineyards to 16 t/ha with irrigation. Grape management and canopies vary and grape varieties define pruning style and volume, however 5 t/ha is an industry benchmark for prunings. Presently these prunings are mulched along rows and left to decay on site. Measuring volumes with such variability is problematic. One tonne of grapes creates approximately 300kg of grape marc (skin, seeds, stem waste). This is collected from processing sites and removed at no cost or fee by a local composting business, sent back to the vineyard from where it came for mulch, or fed to livestock. Grape waste has been reviewed extensively in Europe as a major agricultural residue source but it has not been integrated into a bioenergy system yet. In Australia the focus has been to use grape marc in animal feedstock (The Australian Wine Research Industry, 2014).

Processing volumes have varied at one local plant from 700 t in 2014 to 1700 tonnes in 2014, with the marc component being 210 t and 510 t respectively. With so much variability in vineyard management the proximate volumes of biomass from the grape sector are difficult to calculate. The lower figures are used in Table 4:8 because prunings are not currently collected for re-use and wine marc already is.

<table>
<thead>
<tr>
<th>Grape Biomass</th>
<th>Volume (tonnes)</th>
<th>Available</th>
<th>Issue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grape prunings</td>
<td>&gt;300</td>
<td>Possible</td>
<td>Not collected</td>
</tr>
<tr>
<td>Wine production waste (Marc)</td>
<td>&gt;1000</td>
<td>Possible</td>
<td>Already used</td>
</tr>
</tbody>
</table>

The potential for chemical residues found in grape waste to transfer to emissions was considered by Picchi, Silvestri, and Cristoforetti (2013) who compared emissions from combustion of vineyard prunings and wood chips. No difference in terms of heavy metal emissions was found.

**Hay Production**

The Hunter Valley is a summer rain dominant area and as a consequence most farmers prefer to make silage (wrapping of hay bales to ferment the grasses) as opposed to hay. This is because silage can be harvested in two days and tolerates greater variation in moisture levels, whereas traditional haymaking requires a strategic effort to secure leaf conservation and can not
tolerate wet weather. Straw making, the baling of crop stubble also requires a longer time to cure.

Hay is a difficult product to evaluate. ABS data estimates wholesale values but these do not always capture the full contribution of hay to the agricultural sector (Australian Bureau of Statistics, 2011-12). Local hay producers sell most of their hay to buyers outside the area. The highest prices are gained through sales to the thoroughbred industry. Opportunity hay and silage production is high. Traditional crops for making hay and silage include lucerne, oats, barley, sorghum and maize. Native un-fertilised pasture is frequently converted for silage during wet seasons. The system of hay making is standardised in Australia and around the world (Australian Farm Institute, 2011) with equipment variations reflecting personal preferences for size and shape of bales. It has become a technical and professional business with a vast variation of crops supplying hay. The NSW DPI’s ‘Feed Cost Calculator’ provided a useful tool (NSW Department of Primary Industry, 2014), to evaluate different hay products to compare values and price. The higher the crude protein the more expensive and valuable hay is for feedstock. Even oat stubble with a crude protein of only 3MJ/Kg dry matter is valuable as feedstock as part of a feed mix.

The Table 4:9 shows the volume capacity indicative in the area based on real commercial production driven by demand and profit. Based on 2011 sales figures from local hay producer D.W Burkill (personal communication, March 2011) on 60.5ha next to the Hunter River, production values were extrapolated.

### Table 4:9 Hay production Muswellbrook LGA

<table>
<thead>
<tr>
<th>Biomass Type</th>
<th>Volume (tonne per annum)</th>
<th>Price (AUD per tonne)</th>
<th>Issue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lucerne</td>
<td>500</td>
<td>400</td>
<td>Price high</td>
</tr>
<tr>
<td>Oaten hay</td>
<td>85</td>
<td>330</td>
<td>Price high</td>
</tr>
<tr>
<td>Total</td>
<td>585</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note. Compiled from data provided by D. W. Burkhill, 2011*

Rain forecasts have a strong influence on hay markets driving a very fluid price signal. In 2014 NSW lucerne traded between $350-$400 per tonne while straw was as low as $110 per tonne (Australian Fodder Industry Association). The market prices for different hays remain above the likely acceptable price for biomass. Therefore while improved agricultural systems are utilizing
residues as feedstock and prices remain high it is unlikely that these will be available for biomass in the near future.

If the same land was required to grow biomass of a lesser quality and during different seasons, it is estimated a 20 per cent production increase could be achieved by growing energy crops equivalent to winter dominant lucerne or cereal crops such as high yielding oats and forage sorghum. Having a professional hay making culture with technical skills and machinery in the area means making hay from energy crops would be an easy transition. Yet as shown in Table 4:10, the production costs of hay making need to be contained if this sector is to shift into baling for bioenergy purposes. Production costs vary across districts but these are indicative for Muswellbrook; this represents production costs for hay of $100 to $140 per tonne for a productivity range of 7-10 t/ha.

Table 4:10 Hay production costs Muswellbrook LGA

<table>
<thead>
<tr>
<th>Production cost per hectare</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>cultivation</td>
<td>$37.00</td>
</tr>
<tr>
<td>seed and fertiliser application</td>
<td>$65.00</td>
</tr>
<tr>
<td>fertiliser general 150kg/ha $60 per 40kg bag</td>
<td>$225.00</td>
</tr>
<tr>
<td>Seeding @120kg/ha $50 per 40kg bag</td>
<td>$150.00</td>
</tr>
<tr>
<td>cut and bale 260 bales @ $2.00 bale</td>
<td>$520.00</td>
</tr>
<tr>
<td><strong>Total costs</strong></td>
<td><strong>$997.00</strong></td>
</tr>
</tbody>
</table>

Note. Adapted from ABARES (2014)

The ABS no longer collects separate data on hay production (Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES)). Statistics for hay production are based on average NSW wholesale price for generic pasture. The price for lucerne hay is higher. Table 4:11 records the 105 farms contribute $4Million to the wholesale hay market and if the horse industry continues to grow in the district, hay production is further secured inhibiting production for bioenergy purposes from these farms.

Table 4:11 Number of hay farms in Muswellbrook LGA

<table>
<thead>
<tr>
<th>No of Farms</th>
<th>Estimated wholesale value of hay (Mill AUD)</th>
<th>Av Annual Yield per ha (tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muswellbrook</td>
<td>105</td>
<td>$4.0</td>
</tr>
</tbody>
</table>

Note. Adapted from Hay-Hemp profile Upper Hunter Region (2011)
Hemp

Industrial Hemp has been grown in the Muswellbrook LGA during the past eight years in conjunction with Ecofibre Pty Ltd who is trialling a number of cultivars, harvesting techniques and processing systems. Hemp is a fast growing annual crop capable of producing 6 - 12 t/ha without herbicides or pesticides (Ecofibre Industries Operations Pty Ltd, 2013; European Industrial Hemp Association, 2011) and has extremely strong, durable fibres (Jarabo et al., 2012).

The hemp plant *Cannabis sativa* L., native to Central Asia, (Robinson, 1995) and part of the family *Cannabaceae*, consists of two main genera, with a large number of sub species. This variety and versatility has dictated many uses. The outer fibre (bast) and the inner pith (hurd) produce the raw materials for paper, textiles and more recently for composite materials, while the seeds are used for food and oil. Hemp is frequently compared to cotton, but while the end products have similarities the growing needs are different. Cotton prefers a sub tropical climate and large volumes of water and is traditionally a heavy user of chemicals. Hemp on the other hand endures a wide range of moderate climates and environmental conditions and uses less water and chemicals to deliver high yields. Just as wool is not just wool, so too hemp is not just hemp. Historically it has been used for coarse textiles and ropes but attention is now given to fibre length, fineness, strength, flexibility, brittleness and elasticity (Bengtsson, 2009; Robinson, 1995). It is the success of these different uses that will drive increased production and lead to the likely volumes of lesser quality hurd with its high cellulose component, which could be used as a bioenergy feedstock.

The soil requirements for hemp are the same as those for lucerne, but the nutrient needs are much less. Hemp can also use the nitrogen generated from the lucerne crop. Hemp compares favourably to a stand of lucerne, which, in a season produces similar volumes per hectare but with four or five harvests. Hemp is an annual and lucerne a perennial grown in 4-5 year rotations. Crops grown immediately after hemp are very strong with wheat achieving up to 20 per cent higher yields (Bócsa & Karus, 1998). In Muswellbrook LGA hemp has met all crop performance criteria (Ecofibre Industries Operations Pty Ltd, 2011; Nelson, 2010). Hemp is better compared to annual summer crops such
as sorghum and corn, with which it would most likely compete. Hemp provides a suitable rotational crop with deep roots improving soil structure and a capacity to break fungi and nematode loads (Nelson, 2010). As Hemp requires specialist harvesting equipment crop location will be defined by distance. Presently there is a restriction to crops being grown within a 50 km radius from the hemp processing facility. Table 4:12 shows the present development of hemp in the Muswellbrook LGA where the volumes are too low to support a secure biomass supply.

**Table 4:12 Hemp volumes in Muswellbrook LGA**

<table>
<thead>
<tr>
<th>Hemp</th>
<th>No of farms</th>
<th>Area (ha)</th>
<th>Av yield (tonnes/ha)</th>
<th>Estimated Yield (tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muswellbrook</td>
<td>4</td>
<td>27</td>
<td>10</td>
<td>270</td>
</tr>
</tbody>
</table>

Note. Adapted from Hay Hemp profile Upper Hunter Region (2011)

Table 4:13 shows that if hemp is double cropped the gross margin is substantially improved and may offer the best incentive to grow hemp as a complementary crop to lucerne. However, although hemp grows quickly, produces more fibre per hectare than tree plantations, can replace cotton and wood based paper it will remain a minor plant of interest while a permit and police check are needed to grow it.
Table 4:13 Gross Margin Crop Budgets for Hunter Valley

<table>
<thead>
<tr>
<th></th>
<th>Ecofibre</th>
<th>Double crop</th>
<th>Lucerne Hay</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hemp</td>
<td>90 + 90 days</td>
<td>Small Square</td>
</tr>
<tr>
<td><strong>Gross income</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Price($/t)*</td>
<td>$200</td>
<td>$200</td>
<td>$308</td>
</tr>
<tr>
<td>Yield (t/ha)**</td>
<td>12</td>
<td>18</td>
<td>15</td>
</tr>
<tr>
<td>Gross Income ($/ha)</td>
<td>$2,400</td>
<td>$3,600</td>
<td>$4,620</td>
</tr>
<tr>
<td><strong>Variable costs</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Establishment (Average over 4 yrs)</td>
<td>$220</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-sowing Spray</td>
<td>$45</td>
<td>$45</td>
<td></td>
</tr>
<tr>
<td>Agrow plow</td>
<td>$85</td>
<td>$85</td>
<td></td>
</tr>
<tr>
<td>Disc / chisel plough</td>
<td>$65</td>
<td>$65</td>
<td></td>
</tr>
<tr>
<td>Power harrow</td>
<td>$90</td>
<td>$90</td>
<td></td>
</tr>
<tr>
<td>Sowing</td>
<td>$70</td>
<td>$90</td>
<td></td>
</tr>
<tr>
<td>Seed</td>
<td>$250</td>
<td>$500</td>
<td></td>
</tr>
<tr>
<td>Fertiliser</td>
<td>$150</td>
<td>$150</td>
<td>$220</td>
</tr>
<tr>
<td>Herbicide</td>
<td>$0</td>
<td>$0</td>
<td>$70</td>
</tr>
<tr>
<td>Insecticide</td>
<td>$0</td>
<td>$0</td>
<td>$40</td>
</tr>
<tr>
<td>Irrigation at $70/ML</td>
<td>$210</td>
<td>$225</td>
<td>$420</td>
</tr>
<tr>
<td>Regulatory fee</td>
<td>$50</td>
<td>$50</td>
<td>$0</td>
</tr>
<tr>
<td>Total Variable Growing Costs</td>
<td>$1,015</td>
<td>$1,300</td>
<td>$970</td>
</tr>
<tr>
<td><strong>Gross Rtn - Growing Costs</strong></td>
<td>$1,385</td>
<td>$2,300</td>
<td>$3,650</td>
</tr>
<tr>
<td>Harvesting Costs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-harvest sprays</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Harvesting</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mowing, Raking, Baling</td>
<td>No</td>
<td>No</td>
<td>$1,800</td>
</tr>
<tr>
<td>Field Processing</td>
<td>Cost</td>
<td>Cost</td>
<td></td>
</tr>
<tr>
<td>Module making/drying-cleaning</td>
<td></td>
<td></td>
<td>$0</td>
</tr>
<tr>
<td>Transport &amp;/or Storage</td>
<td></td>
<td></td>
<td>$300</td>
</tr>
<tr>
<td>Harvest &amp; transport (Ecofibre)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total harvesting &amp; transport</td>
<td>$0</td>
<td>$0</td>
<td>$2,100</td>
</tr>
<tr>
<td>Gross Margin ($/ha)</td>
<td>$1,385</td>
<td>$2,300</td>
<td>$1,550</td>
</tr>
<tr>
<td><strong>Other considerations</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Production risk</td>
<td>Low</td>
<td>Low</td>
<td>Med-High</td>
</tr>
<tr>
<td>Price fluctuations</td>
<td>Contract</td>
<td>Contract</td>
<td>High</td>
</tr>
<tr>
<td>Cash cost of growing</td>
<td>Low</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>Capital investment</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Harvest timeliness</td>
<td>Flexible</td>
<td>Flexible</td>
<td>Critical</td>
</tr>
<tr>
<td>Management skills</td>
<td>Medium</td>
<td>Medium</td>
<td>High</td>
</tr>
</tbody>
</table>

*Note. Adapted from Ecofibre (2012)*

**Olives**

The Muswellbrook LGA has eight commercial olive groves. Olive trees are irregularly productive, but a 2013 tree count estimated 40 000 mature trees across 160 ha are in production. Olives are traditionally pruned annually but as mechanical pruning has become a standard management practice biennial heavy pruning has become more common. Estimates based on Pukara Estate data (S. Goodchild, personal communication, March 2013) suggest olive
pruning yield averages of 1.5 t/ha per year. These are collated in Table 4:14 where the 240 tonnes of estimated prunings are cut in situ and used as mulch in the grove. While these could be collected there is no system available in the area to collect and transport such prunings.

Olives have not been used for any bioenergy project in Australia. During the 1990s in Italy though, agricultural residues were assessed as bioenergy feedstock with fruit tree prunings, particularly olives, regarded as high value. It was estimated that 14.5mt/yr could be accessed in Italy alone (Di Blasi, Tanzi, & Lanzetta, 1997). Historically olive groves were planted on steep hills with large spacing, while new groves are now mostly hedged, therefore the potential pruning volume in different systems can be significant. A study by (Velazquez-Marti, Fernandez-Gonzales, Lopez-Cortez, & Salazar-Hernandez, 2011) collated key data more accurately to measure biomass capacity. Including, rootstock, age of the plantation, fruit yield, irrigation or no irrigation, year of the last pruning and aim of the pruning, trunk diameter, diameter of crown, distance from soil to crown, and height of the tree. Research found that residual biomass from olive prunings could yield up to 10.5kg of dry biomass per tree per year. In less productive groves the yield was reduced to 3.5kg per tree. Collectively olive prunings are a potential valuable source of biomass and if pruning takes place biennially the pruning volume is substantially greater which further advantages logistically planning.

Inconsistent harvesting volumes, irregular pruning schedules and the high costs to carry out both hinders collecting olive prunings from small groves in the Muswellbrook area. While olive tree prunings in Europe and North Africa account for an abundant biomass resource, (Di Blasi et al., 1997), prunings are primarily a high cost and a disposable problem not an income opportunity in the Hunter Valley. Olive prunings remain an unexploited source of biomass both in Europe and Australia. There is a small local supply available as Table 4:14 shows.

<table>
<thead>
<tr>
<th>Olive</th>
<th>Annual Volume (tonnes)</th>
<th>Available</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prunings</td>
<td>240</td>
<td>possible</td>
</tr>
<tr>
<td>Olive Processing waste</td>
<td>30</td>
<td>unlikely</td>
</tr>
</tbody>
</table>

Note. Compiled from Muswellbrook LGA olive groves (2012)
**Pecans**

Pecan plantations were once considered a viable crop option in the region. However, today only three pecan plantations operate in Muswellbrook LGA. Previously fresh nuts were sold locally after processing and packing on-farm. Recent industry development has seen the pecan industry consolidate with processing now almost 100 per cent centralized at Toowoomba in Queensland. Trees are alternate bearing and volumes fluctuate. Harvested pecans are trucked to Toowoomba for shelling. Table 4:15 shows maximum volumes are only 150-200 tonnes per year. Muswellbrook’s pecans are part of the approximately 2 500 tonnes of Australian pecans of which 1600 tonnes are exported. The shells are stockpiled at Toowoomba and sold for mulch and stock feed filler for $50-$100 per tonne. Prunings at the Muswellbrook plantations are annually heaped and burned and therefore are not presently an available biomass source.

**Table 4:15 Biomass from pecans in Muswellbrook LGA**

<table>
<thead>
<tr>
<th>Pecans</th>
<th>Volume (tonnes)</th>
<th>Available</th>
</tr>
</thead>
<tbody>
<tr>
<td>nuts</td>
<td>150-200</td>
<td>No</td>
</tr>
<tr>
<td>prunings</td>
<td>10</td>
<td>No</td>
</tr>
<tr>
<td>Shell residue</td>
<td>-</td>
<td>No</td>
</tr>
</tbody>
</table>

*Note. Compiled from Muswellbrook LGA Pecan farms*

**Agricultural Summary**

From the above data it can be concluded that there is no immediate reliable agricultural supply of biomass for bioenergy purposes from local industries. This is because all sectors have limited scale to drive new residue and waste stream management for bioenergy. Agricultural systems are also thwarted by competing factors with coal mining due to:

- No wage parity
- Reduction in local agricultural suppliers and infrastructure
- Reduction in private agricultural players
- Reduction in on-farm investments
- Increase in corporate ownership
- Distant management
- Lack of innovation
Agricultural practices will dictate the uptake of new systems for biomass growing and harvesting. As ABS points out in their 2012 analysis.

The main crop residue management practices undertaken by agricultural businesses in Australia were: leaving stubble intact (no cultivation) (64% of total area of crop residue managed); ploughing crop residue into the soil (12%); and removal of crop residue by baling or heavy grazing (8%).

Leaving stubble intact was the most popular crop residue management practice in all states and territories except Tasmania where ploughing stubble into the soil (45% of total area of crop residue managed) and in the Northern Territory where, removing stubble by baling or heavy grazing (55%) were the most popular practices.

Nationally, the area of crop residue management has decreased by 1% to just under 24 million hectares since 2009-10, mainly influenced by a 4% decline in New South Wales (Australian Bureau of Statistics, 2011-12).

Therefore baling crop residue is a common but decreasing practice in Australia whereas overseas bioenergy policies advocate this practise to facilitate and secure biomass supplies (Baral & Malins, 2014; Di Blasi et al., 1997). The EU has focused on agricultural residues to be used primarily for biofuels in an effort to reduce their oil dependency, it is estimated that if 33 per cent of agricultural residues were left for soil ecology purposes, there would still be 122 million tons potentially available for bioenergy (Searle & Malins, 2014).

There is no agreement on how much residue should be left in a paddock to fill soil ecology needs. This will never be a simple equation because each type of farming enterprise requires different soil properties and will achieve optimum yields with differing techniques. Some estimates suggest residue removal will further drive down soil carbon levels and carbon sequestration potential at a time when we need to be maximizing it. Retaining excessive crop residue can also be disadvantageous and negatively affect elemental nutrient balance, where high C can impede the N availability in the following crop. Agricultural residues are also considered fire risks with the NSW Fire Brigade designing many strategies for fire hazard reductions (NSW Rural Fire Service, 2014).

Yet Lal suggests removing above ground biomass could inevitably exacerbate soil degradation and facilitate food insecurity (Lal, 2008), suggesting that only by increasing the SOC pool through crop residue retention will the world’s soil support increased food production. This suggests that the only place bioenergy
feedstock can be sustainably grown is on agricultural marginal or degraded lands in established bioenergy plantations. Lal estimates ‘Increasing the soil organic carbon (SOC) pool by 1 Mg C ha\(^{-1}\) yr\(^{-1}\) through residue retention on soil can increase world food grain production by 24–40 million Mg yr\(^{-1}\), and root/tuber production by 6–11 million Mg yr\(^{-1}\)’ (Lal, 2008). The above point is relevant for harvesting olive branches where under the existing management practice in Muswellbrook 100% of prunings is returned to the soil. Crops cut for silage use almost 100% of the above ground biomass and management of the residue is primarily to facilitate the preparation for the following seedbed. Baling crop stubble is not a common local practice.

If Lal’s view was accepted the volume of marginal land in Muswellbrook LGA could certainly provide a large area of degraded soils for biomass crops but the problem is, these same areas have restrictions placed on them under mining license conditions.

Developing systems to cost effectively mobilise agricultural residues, access degraded lands, free up the use of hemp could all help to liberate a biomass supply but a rethinking of the present laws will be required. After all biomass for energy will always compete with other needs for agricultural residues, such as mulch, compost, animal feed and bedding.

Agricultural activities in the Muswellbrook LGA are diverse and interactive. Resources are shared with the energy sector but there is not economic interaction. If agriculture were to engage with the bio-energy sector, to grow bio-energy crops, it will use land, water, capital equipment and energy like any other crop, but should not require higher levels of fertiliser, chemicals or create soil erosion, nutrient and pesticide run off or further biodiversity losses. Bio-energy crops need not displace agricultural land designated for food in the Hunter Valley.

4.5 Mine-used Land

Each mining company in Muswellbrook LGA owns land managed or leased for agriculture. This has occurred because the mining lease covers a wider area than just the mining zone. These buffer zones, usually adjacent to the mining
area are used but not owned by agricultural companies and have been incorporated into Section 4.4.

For the purpose of this section, mine-used land refers to land owned by mining companies and used for any operation relevant to mining and includes all disturbed land. It was initially thought some biomass could be supplied from such lands but this is prohibited by the conditions to mine granted by the NSW Government. Each mine has specific conditions with which to operate and all are available on the NSW government website (New South Wales Government Mining Approvals). Mine-used land is growing and unique to the area.

4.5.1 Introduction

Muswellbrook town sits at a road and rail junction between the port of Newcastle and the Gunnedah, the Western and Hunter Coal fields and is almost entirely surrounded by coal mining activity. The rail line dissected the township as does the main road, the New England Highway, making the township one of the most important industrial hubs servicing the coal network.

The 2011-2012 Hunter Valley Corridor Capacity Strategy prepared by the Australian Rail Track Corporation (ARTC) predicted coal exports in the region will increase to 216 million tonnes in 2015 (Australian Rail Track Corporation, 2012) and be transported through the shire on two rail tracks that intersect at the southern end of town (Muswellbrook Shire Council, 2014).

Muswellbrook’s coal reserve is essential to meet this export goal and represents more than half the supply of the Upper Hunter. Coal mine modifications and approvals to extract more coal from existing mines has meant 2014 projections for the Muswellbrook LGA are 80 million tonnes per annum, covering 17 400 hectares. In 2012, mining occupied 15% more land than the previous year. (Muswellbrook Shire Council, 2012a). While mining growth and maintenance will continue to 2025, decline is assumed thereafter. Managing expansion and contraction of the coal industry is one of the region’s biggest challenges.
Disturbed Land

When coal mining expands, virgin land becomes overburden land. Its very existence creates marginal land. With so much coal mining being undertaken tracking the ratio of cleared land for mining with the rehabilitated land is fluid. Table 4:16 records the hectares cleared, mined and rehabilitated over three consecutive years of normal mining practices and demonstrates the scale of land disturbance.

Table 4:16 Area of Mining in Muswellbrook LGA

<table>
<thead>
<tr>
<th>Coal Mining Areas in Muswellbrook LGA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td><strong>2009-10</strong> (Hectares)</td>
</tr>
<tr>
<td><strong>2010-11</strong> (Hectares)</td>
</tr>
<tr>
<td><strong>2011-12</strong> (Hectares)</td>
</tr>
<tr>
<td>--------------------------------------</td>
</tr>
<tr>
<td>Cleared</td>
</tr>
<tr>
<td>688</td>
</tr>
<tr>
<td>853</td>
</tr>
<tr>
<td>452</td>
</tr>
<tr>
<td>Active Mining</td>
</tr>
<tr>
<td>1492</td>
</tr>
<tr>
<td>1795</td>
</tr>
<tr>
<td>1936</td>
</tr>
<tr>
<td>Rehabilitated</td>
</tr>
<tr>
<td>116</td>
</tr>
<tr>
<td>96</td>
</tr>
<tr>
<td>216</td>
</tr>
</tbody>
</table>

*Note. Adapted from Muswellbrook Shire Council, State of the Environment Report 2012*

The Synoptic Plan created by the NSW Department of Mineral Resources in 1999 has guided the design of each rehabilitation site (NSW Department of Mineral Resources, 1999) up until 2013 when the Upper Hunter Mining Dialogue was formed. There is still no Master Landscape Management Plan for the Upper Hunter Mine rehabilitation areas (Muswellbrook Shire Council, 1997-1998).

Table 4:17 shows the five active mines and their existing Run of Mine (ROM) projections. When considering Table 4:17 with Table 4:16 the scale of disturbed land is significant. Recognising the risk that rehabilitated mine lands might become idle land with abandoned biomass Muswellbrook Council has been active in driving positive rehabilitation outcomes.

Table 4:17 Mine Approvals and Run of Mine (ROM) in Muswellbrook LGA

<table>
<thead>
<tr>
<th>Mine Approval and Run of Mine (ROM) dates Muswellbrook LGA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal Mine</td>
</tr>
<tr>
<td>-----------</td>
</tr>
<tr>
<td>Bengalla</td>
</tr>
<tr>
<td>Drayton</td>
</tr>
<tr>
<td>Mt Arthur</td>
</tr>
<tr>
<td>Mangoola</td>
</tr>
<tr>
<td>Muwellbrook Coal</td>
</tr>
</tbody>
</table>

*Note. Compiled from AEMR (2012) reports from each mine*
Most plans attempt to reinstate agricultural productivity but the reduced local ecology inhibits success (Muswellbrook Coal Company, 2011). The council defined their preference for mine rehabilitation in their 2012 land use strategy plan.

The rehabilitation plan for each coal mining proposal must include a soil rehabilitation and enhancement plan (or make further commitment for the development of such a plan) that considers, amongst other things, the use of biochar as a soil ameliorant and as a form of carbon sequestration, as well as any other appropriate ameliorant including the use of sterile or temporary cover plantings. (Muswellbrook Shire Council, 2014)

The council’s advocacy of biochar in rehabilitation is important and is discussed further in Chapter 8. Mine closure is a term being phased out in preference for Mine Life Plans. If a mine operates for more than 20 years, it must by law update its Mine Life Plan every 7 years. These plans are recorded only in mining company documents not Government State of Environment Reports. If the mine is expected to operate for 20 years or less it must be reviewed every 5 years (Rio Tinto Coal Australia, 2010). This inbuilt review process could incorporate new sustainable land use principles (Pretty, 1999) and reevaluate rehabilitation to incorporate soil development and carbon sequestration as desired by local government.

It is not a mining company’s core business to create a new one after its demise, but few businesses devalue local ecologies on the scale of the mining sector thus inhibiting future land use options. Maintaining land use for energy rather than food should not prove a cultural obstacle in this mining zone.

**Water**

All industry needs water to operate. The mining and power generation sectors in the Muswellbrook LGA hold approximately 70 per cent of water licences (by capacity). This locking up of water compromises the sustainability of other competing industries and has dire implications for the development of new land use developments. Table 4:18 shows the volume of water the five operating mines in the shire have access to via their Water Access Licenses and other water entitlements. These change when modifications to their operations change. During wet seasons, the annual water consumed by the mines has been less than their entitlement. On site water storage also varies due to mine seepage and rainfall.
Table 4:18 Coal Mine water access in Muswellbrook LGA

<table>
<thead>
<tr>
<th>Mine</th>
<th>Total permissible Hunter River Extraction Rights (ML/per yr)</th>
<th>Ground water Extraction entitlement (ML/pe yr)</th>
<th>Total Water Access (ML/per yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bengalla</td>
<td>1,000</td>
<td>125</td>
<td>1,125</td>
</tr>
<tr>
<td>Drayton</td>
<td></td>
<td>958</td>
<td>958</td>
</tr>
<tr>
<td>Mangoola</td>
<td>4,996</td>
<td></td>
<td>4,996</td>
</tr>
<tr>
<td>Mt Arthur</td>
<td>7,938</td>
<td></td>
<td>7,938</td>
</tr>
<tr>
<td>Muswellbrook Coal</td>
<td></td>
<td>8,000</td>
<td>8,000</td>
</tr>
</tbody>
</table>

Note: Compiled from each mine’s AEMR’s.

Water use and access is a key limiting factor for new industries in the Hunter Valley. Hunter River water has traded above $2000/ML making it some of the most expensive water in the state (National Water Commission).

This is further discussed in Chapter 8.

Mine-Used Lands Summary

As coal mining technology changes the mining application and modification process also changes. Mines not only adjust their mine plan designs during the life of mine but often increase the volume of coal extracted and the life of mine operation.

No policy or person knows in advance precisely when a mine will end or how the rehabilitated land will be shaped. Company merger and take-overs, management changes and the price of coal will also impact on rehabilitation plans.

Mine closures overseas expose the issues all mine life plans will face. While unique geological settings may vary, carboniferous strata, no matter where they are, share common features. As the black coal mines of Europe near their end, their closure plans expose many on-going management issues, which someone is going to have to pay for.

Issues such as:

- The mobilisation of soluble iron salts during flooding.
- Rising water tables connecting mine water with aquifers
- Voids filling with water reaching higher than normal temperatures
- Rock collapse in underground mines due to water impacts
• Open voids filled with mine gas which poses risks during flooding when the
gasses are pushed to the surface (Klinger, Charmoille, Bueno, Gzyl, &

Mining plans presently require rehabilitation and mine closure agreements to
reflect the previous land use (NSW Department of Mineral Resources, 1999).
This objective is not consistent within each mine’s lists of ‘conditions for
approval’. It is also not expected to meet the previous agricultural productivity
volumes. The mining industry is under no obligation to use their water
allocation to facilitate the development of new industries post coal. Nor is there
a priority to maximise the opportunity to build soil immediately after the
disturbance is created.

4.6 Municipal

4.6.1 Introduction

Muswellbrook township is the dominant urban area within the LGA and
Denman is a growing regional town while Sandy Hollow village is diminishing
in size. Only Muswellbrook and Denman have town services such as library,
health, education facilities, green waste collection and wastewater treatment
plants.

Muswellbrook Shire reports annually on the volume and categories of the
waste it collects. This information is publically documented with the NSW
Environmental Protection Authority. The regulatory changes affecting landfill
have changed the management of Muswellbrook’s void and extended its life
span to 2027. In the last reporting period, (2012) 28,688 tonnes of material
went to landfill, while 2,617 tonnes was recovered and sent on to a materials
recovery facility.

Green Waste

Data gathered from Muswellbrook LGA show fluctuations of green waste
volumes collected during the past decade. Seasonal changes in weather play a
significant factor in volumes, as does the one-off clearing for developments. In
the last decade the highest annual volume of green waste collected was 6000
tonnes (Muswellbrook Shire Council, 2009).
Council approvals for clearing include burning to promote regeneration, branch lopping, exotic weed clearing and selective mine site preparation. For example in 2004 it covered 241 hectares (Muswellbrook Shire Council, 2004). These areas approved for clearing are also a source of biomass that could be consolidated with the green waste supply.

The council regularly collects green waste and then mulches it at the waste depot. Plans to sell green waste mulch as a commercial product have not been successful with some mulch being given to coal mines for rehabilitation or returned to landfill. Storing large volumes of mulch at the waste depot is not feasible due to space constraints and the risk of spontaneous combustion (Muswellbrook Shire Council, 2012a).

The Shire is presently negotiating with adjacent shires to regionally consolidate green waste and create a local central delivery point. Development in this area is rapidly changing as the present voids used for municipal waste in adjoining shires reach full capacity. This could see three to four times the present volume of green waste becoming available as a potential biomass source.

**Waste water and Biosolids**

Two sewerage treatment plants in Muswellbrook and Denman coordinate with three local businesses, one coal mine and two golf courses, to take the effluent as biosolids, allowing the sewage treatment works to operate as a nil discharge plant. A new wastewater treatment plant for Muswellbrook will be defined in 2015.

**Municipal Summary**

Biosolids from the two plants are a potential source of biomass feedstock as are the increasing volumes of green waste as shown in Table 4:19.

**Table 4:19 Waste Muswellbrook Shire**

<table>
<thead>
<tr>
<th>Municipal biomass waste</th>
<th>Annual Volume (tonnes)</th>
<th>Increasing or Decreasing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green municipal collection</td>
<td>3055 – 6000</td>
<td>increasing</td>
</tr>
<tr>
<td>biosolids</td>
<td>900</td>
<td>increasing</td>
</tr>
</tbody>
</table>

*Note: Compiled from Muswellbrook Shire data, (2011-2012)*
New regulations for energy efficiency and wastewater are driving the development for new council managed energy systems (Muswellbrook Shire Council, 2011b). As a general term, renewables are frequently identified in government reports as a possible future industry for the region (Buchan Consulting, 2011). No renewable energy projects have yet become commercial although a solar thermal demonstration site was built at Liddell power station and in 2013 a research project for algae was also initiated at Lake Liddell.

As regulatory restrictions on the disposal of biosolids increase research developing alternative processes using it for energy has been tested with various technologies such as updraft gasifiers mixed with wood pellets (Seggiani, Vitolo, Puccini, & Bellini, 2012). Biosolids have also been used as a composting aid on different mine rehabilitation sites. However, high moisture levels have constrained use and the cost of pre-drying has been prohibitive. Mixing biosolids with raw biomass has been a preferred and successful option to manage the high moisture content for bioenergy in gasification trials (Seggiani et al., 2012). For a CBC plant though both biomass sources offer potential use with the benefit of a char output. Therefore, the increasing supply of green waste and biosolids provides an immediate reliable biomass feedstock stream for a CBC plant.

The Crucible Group, in a trial for Melbourne Water, has demonstrated that biosolids can be processed in the continuous biomass converter, when blended with woody material (The Crucible Group Pty Ltd, 2014b). Biosolids have relatively high ash, low energy biomass compared to wood for instance. This fits NSW EPA policy that char from biosolids be used for land applications, not for energy.

4.7 Forestry

Collectively the Wollemi National Park, Goulburn River Nature Reserve, Manobolai Nature Reserve and Coricudgy State Forest cover 145,500 hectares, 43 per cent of Muswellbrook LGA, yet commercial forestry is of minor economic significance.
4.7.1 Introduction

As a possible post coal industry, the idea of forestry has driven research projects, engaged council and been allocated significant funding during the past 20 years (Mercuri, Duggin, Daniel, Lockwood, & Grant, 2006; Mercuri, Duggin, & Grant, 2005; Muswellbrook Shire Council, 2003; Polglase & Myers, 1999). Muswellbrook Council committed $400 000 to evaluating forestry as a future primary industry and the New South Wales State Government set up a working committee with the Department of Premier and Cabinet, NSW Forests, Department of Primary Industry, Department of Planning and local mining companies. Forests NSW were able to identify '30 000 hectares of mining, power station and buffer land in the Upper Hunter' suitable for potential plantation establishment (Muswellbrook Shire Council, 2007-2008). One project looked at using effluent irrigation and organic compost on mine overburden, another examined saline water on establishing plantations (Mercuri et al., 2005).

In the end, Muswellbrook’s rainfall average of 640mm per year was considered beneath the level deemed necessary for success. Rehabilitated soils were shallow and the heavy leaching of nutrients impacted on long term tree growth patterns (Polglase & Myers, 1999). Together with the need to have plantations clustered (NSW Forests, 2010), forestry lost local and political enthusiasm. The last meeting of the committee was held on May 7, 2008 and no final reports were ever written.

At the same time The National Forest Policy Statement recorded that NSW public native forests managed for multiple uses was reduced from 2.6 Mha in 1990 to 1.3 Mha by 2008 due to conversion to conservation reserves (Department of the Environment, 1994).

Modelling whole forest systems for two case studies by de Aquino et al demonstrated that when all the carbon dynamics and life cycle of wood are considered, forests managed for production over 200 years compared to conservation only, provided more GHG benefits and better long term carbon storage (de Aquino Ximenes, George, Cowie, Williams, & Kelly, 2012). This suggests that current policy directions of returning more forests to conservation could result in increased GHG emissions in the long term.
All IPCC reports have highlighted the urgency to understand more precisely the carbon cycle for different industries and forestry has received focus for its important role in climate change mitigation (Intergovernmental Panel on Climate Change, 2007, 2013). Tools to evaluate the emissions associated with the establishment and management of forests by Tucker et al (Tucker et al., 2009), have been used by NSW Forests to access the carbon flows in multiple use production forests and also concluded GHG abatement is being lost under the present policy directive that favours conservation over multiple use forest production (Department of the Environment, 1994).

There is a lot to consider if accessing forests for bioenergy:

1. Whilst for a specific site and point in time, the C stored in a forest reserved for conservation may be greater than in a harvested forest, in the long term, when the full GHG balance is considered, multiple-use production forests have significantly larger GHG abatement potential than conservation forests. Proper consideration of substitution benefits and leakage potential is critical in this assessment.

2. There is a need to explore opportunities associated with limited extraction of harvest slash (residues) for bioenergy (taking into account biodiversity and forest nutrition needs). This limited extraction has potentially large GHG mitigation benefits associated with replacing coal-based emissions from electricity generation.

3. Irrespective of the end of life path for HWPs (e.g., recycling, landfill or energy recovery systems) the GHG outcome from harvested forests will be positive compared with conservation forests.

4. Managing the forests so they grow productively is important for sustained mitigation benefit, as is ensuring timber is processed to long-life products and can be utilised to offset fossil-fuel emissions at the end of their lifespan (de Aquino Ximenes et al., 2012).

While deforestation has long been recognised as a major source of increasing C in the atmosphere, there’s been many studies assessing the difference in C uptake from young and old forests. While young forests do rapidly uptake C, it is now accepted that the C stored in old forests outweighs the speed with which new forests absorb it (Harmon, Ferrell, & Franklin, 1990; Intergovernmental Panel on Climate Change, 2007).

While old forests provide greater ecological value than new forests, the IPCC 2000 report reviewed changing land use options and concluded the best way to sequester more C was to convert arable land to agroforestry
(Intergovernmental Panel on Climate Change, 2000). That is, not just forests but forests managed with agriculture.

Calculations suggest extra carbon savings are made when forestry timber is used for long-lived products and left over wood such as branches from thinning and post harvest residues used for bioenergy (Lippke et al., 2011).

**Native Forests**

Table 4:20 shows the different types of government managed forested areas in the LGA, although Coricudgy is the only state forest with full hardwood tree removal rights. Policy management changes within all forestry sectors may provide future options for biomass supply, even if they are only short-lived.

**Table 4:20 Forestry Assets Muswellbrook LGA**

<table>
<thead>
<tr>
<th>Area (hectares)</th>
<th>Acessable standing volume t/ha (net harvest)</th>
<th>Net harvestable volume (what you can access from legal POV )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wollemi NP</td>
<td>501,700</td>
<td>0</td>
</tr>
<tr>
<td>Manobalai NR</td>
<td>3,758</td>
<td>0</td>
</tr>
<tr>
<td>Goulburn River NP</td>
<td>72296</td>
<td>0</td>
</tr>
<tr>
<td>Coricudgy SF</td>
<td>7392</td>
<td>200 tonnes single tree selection</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20 tonne ha from 10 ha per yr</td>
</tr>
</tbody>
</table>

*Note. Adapted from NSW Forestry Commission (2013)*

The Coricudgy state forest, located south west of Wollemi NP, is managed by the Western Region of NSW Forestry Corporation. The geographical position of the forest prohibits access for development in the north-eastern region of the shire. This alone makes a viable biomass supply stream seem unlikely for a bioenergy development in the Muswellbrook town area until some time when logistics become more attractive.

**Plantations**

All plantations in Muswellbrook LGA are on land owned by mining companies or power stations. A number of trial plantations were established in 1990s as part of the council’s forestry investigations and are now well established with some growth rates comparable to trees in higher rainfall zone (NSW Department of Primary Industries, 2008). Biosolids were successfully used to provide nutrients and organic matter to soil structure to facilitate tree
establishment. The largest plantation covers 40 hectares, adjoins Singleton Shire and is of mixed varieties, planted with a variety of soil amendments. These were conceived and managed as part of a NSW Forests trial in conjunction with Macquarie Generation (now AGL) and Coal and Allied Pty Ltd. Plans to thin the plantations are underway and no specific use for the thinnings has been confirmed.

**Forestry Summary**

Forestry offers the highest volume of biomass in the area but there is not a high volume of forest residues immediately available or suitable for pyrolysis due to logistical and policy constraints. If forestry management changes direction in the future and ‘productive management’ becomes an acceptable practice to mitigate GHG emissions, then more biomass from this source will likely become available.

If forestry is to become a future biomass source much can be learned from Japan’s forest policies where char making and forests have co-existed for centuries. Many Japanese researchers in the char community have felt the full brunt of the deforestation allegations often attached to char (International Symposium Utilisation of Charcoal, 2005). There has been the suggestion that for a char industry to succeed it will need to coincide with a campaign to grow forests.

**4.8 Concluding Summary**

Biomass sources need to prove they meet acceptable sustainability criteria. The abovementioned proximate biomass sources in this chapter have been classified as per Table 4:21, to check key sustainability issues. Hemp and forestry residues meet all of them. Though green waste is the most widely distributed source it is difficult to prove it will meet the disease resistance and sterility criteria, but as it is regularly collected and mulched this is unlikely to pose a serious problem for long term viability. The current reality is that there is a green waste stream that needs to be managed and this present supply is not quite sufficient for one pyrolysis plant. However, if Muswellbrook Shire accepts other council’s green waste, the supply stream will increase and become more cost effective.
Table 4:21 Local Biomass sustainability criteria

<table>
<thead>
<tr>
<th>Local Biomass Sustainability Criteria</th>
<th>Green waste</th>
<th>Hemp</th>
<th>Ag waste &amp; residues</th>
<th>Forestry residues</th>
</tr>
</thead>
<tbody>
<tr>
<td>It is not food for human consumption.</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>It should have a high yield compared to inputs.</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Have a long canopy duration.</td>
<td>?</td>
<td>✓</td>
<td>?</td>
<td>✓</td>
</tr>
<tr>
<td>Have good water efficiency use</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Provide a low moisture content at harvest</td>
<td>x</td>
<td>✓</td>
<td>✓</td>
<td>x</td>
</tr>
<tr>
<td>Be able to maximise competition with weeds</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Be easily mechanically managed</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Relatively disease resistant</td>
<td>?</td>
<td>✓</td>
<td>?</td>
<td>✓</td>
</tr>
<tr>
<td>Sterility? To prevent invasion</td>
<td>?</td>
<td>✓</td>
<td>?</td>
<td>✓</td>
</tr>
</tbody>
</table>

Note: ? Denotes unknown  X denotes no)

Green waste biomass is considered a low input biomass source because the cost of growing it is not included. All local vegetation such as grasses, both annuals and perennials, shrubs, trees and any weeds will be in the mix as it is primarily sourced from gardens, parks and urban areas. A CBC plant could facilitate better sustainable management of the green waste, ensuring it does not end up in landfill.

Table 4:22 compiles the immediate, medium and future sources of available biomass. Green waste offers the best option as an immediate source, while in the future forestry residues should offer a supply in some areas. Marginalised land due to coal mining should be the first option for planting dedicated crops for developing a new pyrolysis industry where the CBC char output could help rebuild soils.

Table 4:22 Biomass availability now and in the future

<table>
<thead>
<tr>
<th>Biomass available 2014</th>
<th>Available medium term</th>
<th>Available future</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green waste</td>
<td>Green waste</td>
<td>Green waste</td>
</tr>
<tr>
<td>Biosolids</td>
<td>Biosolids</td>
<td>Biosolids</td>
</tr>
<tr>
<td>Forestry residues</td>
<td>Forestry residues</td>
<td>Forest residues</td>
</tr>
</tbody>
</table>

By assessing biomass sources using criteria relating both to immediate sustainability and long term viability we can clearly see green waste is currently the most useful feedstock for a CBC. In the longer term industry growth will need to be supported by forestry supplies or the sustainable planting of dedicated crops grown near or on areas where the technology can
best impact soil regeneration. Viable biomass options are therefore available for current industry needs, with a clear direction for sustainable industry growth into the future.

The following chapter investigates the char output from pyrolysis, reviews char’s contribution to a sustainable future and demonstrates how it could be useful for Muswellbrook.
CHAPTER 5  BIOCHAR

‘Why so hard?’ the charcoal once said to the diamond; ‘for are we not close relations?’ Friedrich Nietzsche 1888

5.1 Biochar Introduction

In Chapter 3 the formation of char as a black porous solid created during pyrolysis was described. Its main component is elemental carbon. By considering the historical uses of char within many cultures across a variety of climates and soils a new system of restorative land practices can be developed. Turning the vision of char into a practical, viable and sustainable enterprise is an innovative challenge that needs to consider the land-use needs of the area as well as the local business, community and political environment. Despite its long history of use and the compelling evidence of its positive attributes (Lehmann, 2007b; Lehmann & Joseph, 2009a), the global production of char remains small.

Results from a voluntary worldwide survey of 110 companies by the US Biochar Initiative (USBI) in December 2012, revealed the total volume of biochar production was 390 tonnes. Over 50 per cent of the companies surveyed said char production was not the main focus of their business (Brunjes, 2012). The following year results from A Survey of Commercial Activity in the Biochar Field by the IBI suggested the annual volume of char production had risen to 827 tonnes (Jirka & Tomlinson, 2013). The main inhibiting factor for the growth of char as a marketable product is the lack of pyrolysis technology and the economics of production. The report commissioned by Climate Action Research (De Gryze et al., 2010) concluded until charmaking is economically viable the development of the industry will remain limited.

If char is to make a positive contribution to global climate change as a long term C storage method in soils or as a fossil fuel substitute, there needs to be a greater understanding of what it is and how it can be used. This chapter reviews the literature on char’s characteristics and its agronomic and environmental effects in order to understand which properties are important; what the best potential applications may be; what the status of the industry is
globally; and what opportunities in the Muswellbrook LGA show most promise in the short and longer term.

### 5.2 Nomenclature

The term ‘biochar’ is used to highlight its application to soils and to differentiate it from ‘charcoal’ or ‘char’ used for energy as heat, in blast furnaces, as colouring agents or any other industrial use. Its destiny defines its name. This can create confusion because when biochar is made the intention for its use may not be known, can change, or be used for more than one purpose.

Biochar is always a product of thermal decomposition of organic material under restricted oxygen conditions (Brown, 2009; Lehmann & Joseph, 2009a). It can be made via any type of slow pyrolysis process, such as small batch heating or with continuous processing (Bruges, 2009; Taylor, 2010). Biochar is also sometimes referred to in the literature as ‘char’ ‘charcoal’ or ‘biocarbon’.

The ‘bio’ in biochar, highlights its recent biological history as opposed to the dense carbon found in fossil fuels. Biochar is not ‘activated carbon’ where biomass has been turned into charcoal and then undergone another process, i.e. ‘activation’ with steam or chemicals at high temperatures to increase further the surface area of the charcoal. This specialist product is used largely for industrial filtration.

The International Biochar Initiative (IBI) has defined biochar as:

> Biochar is a fine-grained charcoal high in organic carbon and largely resistant to decomposition. It is produced from pyrolysis of plant and waste feedstocks. As a soil amendment biochar creates a recalcitrant soil carbon pool that is carbon-negative, serving as a net withdrawal of atmospheric carbon dioxide stored in highly recalcitrant soil carbon stocks. The enhanced nutrient retention capacity of biochar-amended soil not only reduces the total fertilizer requirements but also the climate and environmental impact of croplands (International Biochar Initiative).

### 5.3 Biochar: a long history of use

Biochar gained considerable attention after the publication of the seminal work by Wim Sombroek, *Amazonian Soils* in 1966. Thereafter his numerous publications, the development of the first Global Assessment of Human-
induced Soil Degradation (GLASOD), (Bridges & Oldeman, 1999) plus Sombroek’s political agitation, led to many others taking up the baton to better understand the historical use of charcoal in soil (Sombroek, 1966; Sombroek et al., 2002).

A ‘biochar movement’ began to develop because it was offering solutions arising from the urgent conflict of climate change. New movements respond to the big questions of the day and question legitimacy and accountability of government policy (Edwards, 2004). As Habermas points out in The Theory of Communicative Action (Habermas, 1987) how the public reflects on problems is essential to improving the theory and action of democracy.

In 2006 the global Not for Profit association the International Biochar Initiative (IBI) was established to promote the science and application of biochar to enhance food security, sequester carbon and facilitate sustainable agricultural practises. The IBI has done this by constructing a global, autonomous, accessible, primarily online space, for generating public debate. The IBI is the primary advocacy group for biochar, operating throughout thirty-three countries and driving the increase in published literature. Habermas’s phrase ‘deliberative democracy’ could be used to describe the IBI’s key focus of facilitating knowledge. This is recognised as a necessary and essential precursor to the successful uptake of new ideas, like climate change solutions. These need to be open to free reflection and discussion by the public before action can occur.

So what do we know so far?

Lehmann (2007b) essay in Nature was a turning point simplifying the explanation of the capacity of biochar to carry out multiple benefits in light of growing climate change statistics (Intergovernmental Panel on Climate Change, 2007; Lehmann, 2007b). Measuring sequestration, he argued, would be simple because of biochar’s recalcitrance. However, measuring how biochar’s properties precisely enhance soil performance is more challenging and still in its infancy (McLaughlin, Anderson, Shields, & Reed, 2009; Sohi, 2012). Evaluating biochar’s interaction with plants has also been insufficiently addressed (Cayuela, van Zwieten, Singh, & Jeffery, 2014) yet biochar research
is demonstrating that different types of biochar can stimulate soil and plant growth in a variety of positive ways (Bates, 2010; Sohi, 2012; Taylor, 2010).

Despite the fact that there is still no large-scale commercial production of biochar, research swiftly evolved into different areas.

- Its structure and physical characterisations (Krull, Swartson, Skjenstad, & McGowan, 2006; McLaughlin et al., 2009)
- Its agronomic and environmental behaviour (Van Zweiten et al., 2009) (McLeod, Slavich, & McLeod, 2010)
- Food security issues and improved domestic efficiencies (Whitman, Nicholson, Torres, & Lehmann, 2011).
- Climate change mitigation verification (De Gryze et al., 2010; McCarl, Peacocke, Chrisman, Chih-Chun, & Sands, 2009; Woolf, Amonette, Alayne Street-Perrott, Lehmann, & Joseph, 2009).

5.4 Global Biochar Projects

Many countries are testing a variety of biochars on different soils. Below is a brief outline of some of the more significant research projects undertaken to better understand the effects of biochar in soil.

**Brazil**

Field work by Lehmann (Lehmann, 2011; Lehmann & Joseph, 2009a) Glaser (Glaser, Balashov, Haumaier, Guggenberger, & Zech, 2000; Glaser, Guggenberger, & Zech, 1998) Steiner (Steiner et al., 2007) and Major (Major, Steiner, Ditommaso, Falcão, & Lehmann, 2005) have all evaluated Terra Prêta soils in situ and confirm biochar can facilitate fertility development in tropical areas and especially assist in biological improvements such as mycorrhizal growth. Biochar amendments can provide immediate short-term responses to plant growth and the evidence suggests the impacts can also be long lasting (Lehmann, 2011).

**Japan**

Japan has had a long history of charcoal making, incorporating it in many traditional agricultural activities to facilitate soil fertility (Ogawa & Yamabe, 1986). Before 2003 most of the feedstock for charcoal making in Japan was
supplied by China, until the Chinese government stopped the export of forest biomass for charcoal making on the grounds that it was leading to deforestation (International Symposium Utilisation of Charcoal, 2005). An interesting pilot project engaging a farming and town community with government and university teams began in Kameoka City, Japan in 2008. The objective was to integrate biochar into a business model that would also reduce carbon emissions (McGreevy & Shibata, 2010). It incorporated small-scale biochar production in a market garden and distributed the food with biochar labelling through sixty-nine outlets. Deodorising chicken feed mixtures with charcoal to facilitate chicken health has also proven successful (Hirowaka, 2009). While not directly agronomic these specific and successful uses are part of Japan’s unique charcoal making history and may lead to the broadening of the definition of the word biochar.

**China**

In China biochar filtration has been used to purify water successfully and help clean up the Yahagi Main River (Kito & Yoshizawa, 2005).

**Kenya**

The creation of smoke during traditional pyrolysis causes significant pollution and would not be admissible in a modern industrial setting (International Symposium Utilisation of Charcoal, 2005). Recognising this pollution potential led to significant work adjusting traditional cooking stoves (Bates, 2010). Torres-Rojas, Lehmann, Hobbs, Joseph, and Neufeldt (2011) work in Western Kenya did not assess emissions but demonstrated how low soil fertility lead to insufficient local biomass (fuel) supplies for daily cooking needs. Introducing energy efficient, less polluting (pyrolysing) combustion stoves overcame the problem and provided biochar to be used as a soil conditioner (Torres-Rojas et al., 2011). This follows the work done by Kimetu et al. (2008) who also assessed the low organic matter in Western Kenyan soils and showed that a doubling of maize yields could be achieved with additions of biochar. The question then became how to source or make the biochar.
New Zealand

New Zealand’s Biochar Research Centre at Massey University has highlighted the impacts of the development of intensive agricultural growth as global markets rapidly expand (Beukes, Gregorini, Romera, Levy, & Waghorn, 2010). New Zealand now has a different CO$_2$ emission profile than Australia and has focused on agricultural and forestry developments that account for 48 per cent of New Zealand’s emissions (New Zealand’s climate change solutions: An overview, 2007). As the NZ dairy industry proliferates, the issue of waste management also grows and this will coincide with harvestable plantation forests peaking post 2020. When harvesting occurs carbon storage will reduce. Incorporating slow pyrolysis into projected agricultural intensified areas to reduce or balance GHG emissions is their challenge.

Australia

Aboriginal camp sites identified by Downie et al. (2009) demonstrate char has been used and improved pockets of soil in Australia. In black grassland soils where aboriginal fire management had been conducted, Skjemstad, Clarke, Taylor, Oades, and Mcclure (1996) found soil carbon was 30 per cent higher than in adjacent forested soil confirming char had contributed to the organic carbon pool in many Australian soils. There has not been a culture of char additions in Australian agriculture since white settlement.

Long-term field experiments on red Ferrosol using different biochars at NSW Department of Industry and Investment, Wollongbar Agricultural Institute have tested various characteristics such as soil changes and plant growth since 2006. Pot trials using different feedstocks for biochar such as green waste on hard setting Alfisol soils show improved soil function (Chan, Van Zwieten, Meszaros, Downie, & Joseph, 2007), and paper-mill waste on Calcarosl and Ferrosol soils have revealed a range of responses with 10 t/ha additions including increased pH and increased N uptake (Van Zwieten et al., 2010). Poultry litter biochar added to hard-setting Chromosol with and without the addition of fertilizer tested radish growth and showed a 96 per cent growth with the addition of 50 t/ha biochar. This extreme result was attributed to improved N uptake due to the volume of addition and feedstock
of the biochar (Chan, Van Zwieten, Meszaros, Downie, & Joseph, 2008). CSIRO research found pesticide sorption could increase with biochar addition. This suggests chemical dose adjustments could be necessary to ensure efficacy (Kookana, 2010). All the projects in Australia have used different biochar feedstocks made for experimental purposes, not from commercial plants.

**Biochar production systems**

As the above highlights each biochar system has unique site specific needs and will operate at either a small or large scale (Lehmann & Joseph, 2009b). Small scale biochar projects draw on approaches that focus on facilitating economic improvements for lower-income groups where biochar is primarily for the kitchen garden with cooking and heating using the energy (Lehmann & Joseph, 2009b).

Biochar is not a single product and once placed in the soil will change over time. Like forest fires, biochar can leave a long trail of historical evidence, Glaser (2007) and a biochar addition may not be the only old carbon or charcoal in a soil profile (Krull et al., 2006). Bushfires also deposit carbon in soil. Different types and volume of biochar additions will create different results in different soils.

Below the physical and chemical properties of biochar are discussed to put this into perspective.

**5.5 Physical and Chemical properties**

Different types of biochar may vary greatly in their physical and chemical characteristics. These characteristics are determined by both the original feedstock and the pyrolysis conditions. According to Downie et al. (2009) the pyrolysis conditions that have the greatest impact on a biochar’s characteristics are the highest treatment temperature, residence time and pressure used. Yet despite their differences all biochars share some fundamental physical and chemical properties as listed below (Chan & Xu, 2009; Downie et al., 2009; Sohi, Lopez-Capel, Krull, & Bol, 2009):

- a large internal surface area due to pore size
• a surface area that attracts and creates microbial habitats
• the fixed carbon formed in its structure is recalcitrant
• pH which is usually alkaline

For example, laboratory analysis of two biochars, cow manure and woodchip, pyrolysed at 300°, 500° and 700°C revealed the carbon mineralization impact was only during the beginning of the incubation period and decreased quickly thereafter. The woodchip biochar pyrolysed at the higher temperature, produced a more stable organic matter and therefore a higher carbon sequestration level (Ouyang, Yu, & Zhang, 2014). This confirms other research suggesting higher pyrolysis temperatures create a more stable carbon profile with long life sequestration potential and lower agronomic value in the short term (Baldock & Smernik, 2002; Chan & Xu, 2009; Ouyang et al., 2014).

**High internal surface area**

The high internal surface area of the biochar allows it to absorb soluble organic matter, which in turn helps increase fertiliser efficiency (Chan & Xu, 2009; Downie et al., 2009; Lou et al., 2010; Warnock, Lehmann, Kuyper, Rillig, & 2007). This large surface area has been called the ‘charosphere’ (Quilliam, Glanville, Wade, & Jones, 2013) and even though the recalcitrant part of biochar may be unavailable to soil microbes, the labile compounds surrounding it are enough to positively impact the soil-plant-microbial activity, thus improving nutrient cycling and crop growth. The pore formation within the biochar reflects the cell structure of the feedstock. The porosity of biochar increases when biomass is pyrolysed between 400-600°C (Chan & Xu, 2009). The Crucible Group’s CBC pyrolyses between 500-700°C therefore is likely to guarantee high internal surface areas of their biochar.

Biochar has been shown to increase N fertiliser efficiency (Rajkovich et al., 2012). The improved N efficiency is thought to be due to biochar’s large surface area, which helps reduce leaching. Therefore the actual form, or porosity of the char is the key to accessing directly or indirectly biochar’s nutrient availability (Lehmann, 2007a).

As pyrolysis and temperature affects porosity, a process that can maintain as many nutrients as possible from the feedstock is advantageous. Pyrolysis over
500 degrees C usually leads to a 50 per cent loss of nitrogen potassium and sulphur (Major, Steiner, Downie, & Lehmann, 2009).

**Creation of microbial habitats**

Soil microbial populations have gained recognition as important fundamental processes facilitating stability and productivity in agro–ecosystems. The diversity of these communities is extensive and often drives soil health (Singh, Pandey, & Singh, 2011). Inoculation of efficient microbes has been shown to improve plant growth and quality. Native soil microbes have been identified as an important missing ingredient at some Hunter Valley mine rehabilitation sites (Castor, Nussbaumer, Ambjerg-Pedersen, & Cole, 2005; Cole et al., 2009).

Microbial communities’ ability to decompose, mineralize and release nutrients and thus increase the nutrient efficiency of plants is important if productivity gains are to be met in a future sustainable system less dependent on inputs. As organic matter is at its most useful when decaying, substances facilitating decay are useful.

Studies have indicated that biochar may increase the populations of beneficial microbes in the soil (Warnock et al., 2007). The non recalcitrant carbon in biochar attracts spores that grow into fungi, while the high internal surface area of biochar allows microbial colonisation that facilitates the growth of soil biota and therefore soil health (Ogawa & Yamabe, 1986).

How biochar affects the activity and abundance of microbes is less understood. Biochar alone could promote beneficial microbial growth by providing a suitable additional structure in the soil that triggers improved soil biology without the addition of extra inoculants (Singh, Singh, & Cowie, 2010).

Not all biochar research indicated an increase in microbial activity though and this seems to be determined by the quality of biochar added (Warnock et al., 2010). As the surface chemistry varies with the different chars this affects the organic matter volume, gasses and the soil’s ability to retain nutrients. Therefore different biochars will create different microbial habitats. Singh et al. (2011) reported that often limited plant growth was due to poor plant energy conversion and soil microbes and other biological factors may improve these physiological factors.
Effect on soil pH

Biochars are usually alkaline (>pH.7) and described as having a liming affect (Chan & Xu, 2009). Experimental rates trialled by Van Zwieten et al. (2010) demonstrated a soil pH increase of 1 could be possible in some soil types and that a pH modification could be up to one-third that of agricultural lime. Amazonian forest soils usually have a low pH and respond positively to biochar’s liming effect, as have the acidic NE New South Wales Ferrosols, where field and pot trials have taken place (Chan & Xu, 2009). The pH and cation exchange capacity (CEC) of biochar is largely influenced by the original feedstock (Gaskin, Steiner, Harris, Das, & Bibens, 2008).

Altering pH is a common agricultural practice to increase plant growth (Stotzky, 1997). Together with CEC, pH changes affect the relationship of soil fungi and bacteria. Rosenzweig and Stotzky (1980), describe how pH increases can create antagonism between different species of fungi and bacteria. Beneficial soil bacteria can be deterred by strongly acid soils that accumulate organic matter and tie up nutrients. Therefore adding soil amendments that alter pH too much can be disadvantageous for some agricultural soils (Stotzky, 1997). While the liming affects of biochar can be beneficial for acidic soils, high application rates have been shown to contribute to negative plant growth (Chan & Xu, 2009).

Carbon recalcitrance

Biochar’s stability is perhaps its most significant characteristic from which all other environmental benefits flow (Lehmann et al., 2008; Nguyen et al., 2008). The carbon stored in soil is called soil carbon or soil organic carbon (SOC). SOC is also part of soil organic matter (SOM) and includes all the other elements and various plant and animal materials at various stages of decomposition. CSIRO has identified four biologically different fractions of SOC. These are found in crop residues, particulate organic carbon, humus and recalcitrant organic carbon. The functionality of each fraction depends on the recalcitrance or stability of carbon available and these in turn are affected by water availability, soil type, and management practices (Krull, Baldock, & Skjemstad, 2003). The SOC can be categorised into three types depending on their turnover rates. There’s active, intermediate and recalcitrant, the latter
being used to describe the slowest turnover rate, which is usually the largest carbon pool around 20-40 per cent.

It is estimated that carbon stored in the world’s soils is approximately 1100 to 1600 petagrams (1PG=10^{12} KG), more than twice as much as is stored in vegetation (Kumar, 2006). As the science of carbon sequestration grows the soils of Australia are being reviewed and measured for their SOC composition in the particulate, humus and recalcitrant fractions under various agricultural practices. This is important to calculate accurately the stocks of SOC so increases can be properly measured (Sanderman et al., 2011).

As Krull et al. (2003) demonstrated, pyrolysis creates a more stable carbon in biochar compared to the original feedstock. Biochar’s potential to create a recalcitrant soil carbon pool (Sohi, Krull, Lopez-Capel, & Bol, 2010) enables it to protect the SOC.

The mineral, nutrient content and carbon base of the feedstock, as well as the temperature and heating time of pyrolysis will define both the volatile and recalcitrant components of biochar (Barrow, 2012; Sohi, Loez-Capel, Krull, & Bol, 2009). Consequently investigations into the stability of different biochars are on-going (McLaughlin et al., 2009). A review of 11 biochars by Singh et al. (2010) showed wood biochar had a higher total C and greater recalcitrance and was lower in ash and key elements compared to biochars made from manures.

Although decomposition of biochar occurs primarily when first applied to soil its long-term stability can remain high (Baldock & Smernik, 2002). This is important because if biochar is to be useful as a long-term climate change mitigation strategy, the verification of its ability to remain stable in the soil is imperative.

In Table 5:1 the compilation of research records the age of different chars soils from 13 900 yrs to 10 yrs, found in different soils. Stabilization has only been calculated via pyrolysis and not on any soil carbon interactions. The positive or negative priming effects on native soil carbon are therefore not included.
Table 5.1 Biochar Carbon Stability: Review of Research

<table>
<thead>
<tr>
<th>Publication</th>
<th>Scale of estimated MRT (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Masiello and Druffel, 1998</td>
<td>Millennial (2,400 – 13,900)</td>
</tr>
<tr>
<td>Schmidt et al., 2002</td>
<td>Millennial (1,160 – 5,040)</td>
</tr>
<tr>
<td>Cheng et al., 2006</td>
<td>Millennial (1,000)</td>
</tr>
<tr>
<td>Cheng et al., 2008</td>
<td>Millennial (1,335)</td>
</tr>
<tr>
<td>Kuziak et al., 2009</td>
<td>Millennial (2,000)</td>
</tr>
<tr>
<td>Major et al., 2010</td>
<td>Millennial (3,264)</td>
</tr>
<tr>
<td>Novak et al., 2010</td>
<td>Millennial (1,400-51,000)</td>
</tr>
<tr>
<td>Liang et al., 2008</td>
<td>Centennial to millennial (100-10,000's)</td>
</tr>
<tr>
<td>Zimmerman, 2010</td>
<td>Centennial to millennial (100-100,000)</td>
</tr>
<tr>
<td>Baldock and Smernik, 2002</td>
<td>Centennial (100-500)</td>
</tr>
<tr>
<td>Lehmann et al., 2006</td>
<td>Centennial (100's-1,000's)</td>
</tr>
<tr>
<td>Hammers et al., 2008</td>
<td>Centennial (200-600)</td>
</tr>
<tr>
<td>Schneider et al., 2011</td>
<td>Centennial (100's)</td>
</tr>
<tr>
<td>Hamer et al., 2004</td>
<td>Decadal (10's)</td>
</tr>
<tr>
<td>Nguyen et al. 2008</td>
<td>Decadal (10's)</td>
</tr>
</tbody>
</table>

Note. From the International Biochar Initiative (2013) *MRT = mean residence time

The long-term decay rate of Terra Prêta is now being calculated at greater than 1000 years (Cheng et al., 2006; Laird, 2008; Lehmann, 2007a) and the stabilised SOC in ancient soils has been attributed to biochar additions (Glaser et al., 1998).

Biochar addition to subsoils has been found to be more stable than topsoils (Rumpel & Kögel-Knabner, 2011). This is thought to be because the deeper the soil the less the microbial activity, suggesting that if sequestration is the main intention of biochar addition the deeper the application the better. Simply adding biochar may not provide agronomic gains but it will always offer an increase in soil carbon to be measured against an atmospheric CO₂-e emission.

Spokas et al. (2012) examined 44 published articles using a variety of biochar feedstock and noted that only half showed positive yield increases, with the other 50 per cent showing no improvement or even negative yield responses. The variation of the feedstock confirmed that not all biochars are created equal and the need to match the type of biochar specifically within each agronomic setting is important. Spokas (2010) suggests that the molar ratio of oxygen to carbon (O:C) could provide a more robust indicator of biochars’ stability than pyrolysis temperature and feedstock. A molar ratio lower than 0.2 appears to provide a minimum 1000 year biochar half life.
5.6 Agronomic Effects

There have been wide variety of results demonstrating biochar’s effects (Sohi, 2012). Proving these benefits is not easy with so much variation in the properties of different biochars. One of the key messages highlighted in the 2009 book *Biochar for Environmental Management* (Lehmann & Joseph, 2009a) is the repeated statement, ‘is not well understood’. That said, there is a developing understanding and acceptance of some core positive agronomic biochar effects.

**Improved fertiliser efficiency**

One of the key questions regarding biochar is ‘when plant growth improves with biochar additions is it because of the biochar structure or because the biochar was nutrient rich with elements embedded in it?’ After all a nutrient rich feedstock is likely to produce a nutrient rich biochar (Gaskin et al., 2007; Gaskin et al., 2008). Pyrolysing high nutrient feedstocks like manures or food waste is beneficial when biochar rather than gas is needed. In this instance the nutrient in the feedstock becomes attached to the biochar’s surface during the pyrolysis process. Woody feedstocks on the other hand generally produce a lower nutrient biochar (Amonette & Joseph, 2009).

Bagreev, Bandosz, and Locke (2001) showed that when pyrolysis temperature increased from 400-800°C, the C and N content decreased from 3.8 to 1.6 per cent, suggesting that the N becomes incorporated into the carbon matrix of the biochar thereby potentially limiting its availability to plants. Chan and Xu (2009) also tested the pyrolysis temperature variations impact on porosity of biochars and concluded that pyrolysis temperatures higher than 400°C increased surface area and decreased nutrient availability.

**Water holding capacity**

Biochar’s ability to facilitate the soil’s capacity to hold water is measured as the available water capacity (AWC) which is the amount of water held in soil between its field capacity and the permanent wilting point. Increases in AWC due to biochar additions have been reported by (Laird, 2008). The high water holding capacity of biochar particles could be especially important for many shallow Australian soils especially those in low rainfall areas, although not
every type of soil reacts positively to biochar additions. Burns (2014) showed that biochar additions to Western Australian soils improved AWC, while New South Wales North East ferrosols were not significantly affected. Most biochar trials in Australia demonstrate how the source of biomass and temperatures of pyrolysis create significantly different chars, which can impact differently on soil’s water holding capacity.

Risks

Biochar applications may also have negative impacts in plant growth, the environment and human health (Biederman & Harpole, 2013; Jeffery, Verheijena, van der Veldea, & Bastosc, 2011). When the pyrolysis process increases above 750 degrees C and has a long residence time, the formation of polycyclic aromatic hydrocarbons (PAH) can occur (Shackley & Sohi, 2011). These have been reported as being carcinogenic, mutagenic and/or teratogenic.

Contaminated biomass such as creosote treated timbers also risk PAH formation (Zhurinsh, Zandersons, & Dobele, 2005). Feedstock with high chlorine levels pyrolysed at high temperatures can form dioxin (Shackley & Sohi, 2011). Therefore careful feedstock selection and limiting pyrolysis temperatures can ensure dangerous levels of PAH and dioxins are prevented. Their formation is unlikely in a CBC where the pyrolysis temperature is typically less than 700°C.

Mukherjee and Lal (2014) focused on reviewing and compiling the negative effects of biochar additions in the published literature. These included reports where reduced soil quality, crop yield and increases in soil gas emissions were identified.

Toxicants in biochar may be located in two potential areas: those in the feedstock as heavy metals, polychlorinated biphenols and those created during the thermochemical process of pyrolysis such as polycyclic aromatic hydrocarbons (PAH) and dioxins. Some biochars have reported high heavy metal content when sewage and tannery sludge was pyrolysed.

For biochar to be considered safe it will need to meet eco-toxicological tests, such as the ‘earthworm avoidance test’ which is a cost effective method prescribed by OECD (Oecd, 1994). These tests have been used in some biochar
research. Acceptance of biochar usage will be dependent on meeting local regulations on human and environmental health standards. Toxicity standards in NSW are regulated by the NSW Protection of the Environment Operations (Waste) Regulation. The IBI is also assessing safety regulation in the United States.

**Compost facilitator**

The mixing of biochar with local compost production has been found to accelerate the composting process (Yoshizawa et al., 2006). Biochar mixed with elemental industrial fertilisers has become a separate area of research, which is not covered in this thesis.

**Remediation**

Kito and Yoshizawa (2005) describe how sections of the Yahagi River have been restored using a blend of soil microbes and pulverized coal. Drainage canals in the Shin River and the Futamata River also achieved increased self-purification and stench reductions with the addition of coal and microbes (Kito & Yoshizawa, 2005). It is likely that char fulfils the same functions.

Toxic pollutants, mainly heavy metals are present in mine waste (tailings) (Fellet, Marchiol, Delle Vedove, & Peressotti, 2011; Zocche et al., 2010). Maximising vegetation surround mine sites is important to reduce pollutant transfer. Biochar has been found to break down and/or lock up various heavy metals (Chan & Xu, 2009; Wang, Wang, & Ma, 2010). Sun, Lian, Liu, Zhu, and Song (2014) found Cd could be successfully immobilised from wastewater with biochar. Using biochar to manage heavy metal-rich mine waste has been shown to reduce bioavailability of pollutants and increase water and nutrient retention (Fellet et al., 2011). Biochar tested as a phytostabilisation technique at mine sites in Italy, showed pH, nutrient retention, and water holding capacity in the soil improved while the bioavailability of Cd, Pb, Tl, and Zn in the mine tailings decreased (Fellet et al., 2011). It is the porous nature of biochar that enhances the sorption of organic and inorganic contaminates. Crop straw biochars have been shown to be efficient, low cost adsorbents (Tong, Li, Yuan, & Xu, 2011). These reports indicate there is strong potential for biochar to be used as a remediation tool in the Muswellbrook LGA where so much land is disturbed.
Singh et al (2011) notes cyanobacteria fungi are especially significant in saline habitats and adapt well to increased salinity preventing potential saline wastelands. As saline and acidic soils prevail in the Hunter Valley biochar’s liming, purification and microbial facilitation may prove useful (Rajkovich et al., 2012). Sun et al (2014) indicated that crop straw biochars demonstrated unique sorption capacity to heavy metals, especially Cd. This is attributed to the surface characteristics of the biochar. Therefore a local pyrolysis/biochar industry using plant not animal manure feedstock to make low sodium biochar would likely be preferred in the Muswellbrook LGA.

5.7 Summary of characteristics and effects

The factors influencing biochars effectiveness as a soil amendment include its elemental composition, pore size, surface area, pH, density and water absorbing qualities.

If biochar can secure and extend the life of soil organic matter as researchers Steiner et al. (2007) indicate, biochar may become invaluable for building a future sustainable agricultural system. However, first there needs to be improved understanding of how biochar affects soil environments and plant productivity. So far research confirms the benefits of biochar additions to soil may be chemical, biological and physical. Positive soil attributes due to biochar addition include:

- Carbon sequestration and abatement (Krull et al., 2003; Shackley & Sohi, 2011)
- Improves cation exchange capacity (CEC) (Cheng, Lehmann, & Engelhard, 2008; Liang, Lehmann, Solomon, & Kinyangi, 2006)
- Increases microbial biomass (Hammer et al., 2014; Thies & Rilling, 2009; Van Zweiten et al., 2009)
- Increases pH (Chan & Xu, 2009)
- Improves soil structure and texture (Downie et al., 2009)
- Improves plant productivity (Cheng et al., 2008)
- Improves water holding capacity (Glaser et al., 2002; Major et al., 2009)
Harmful compounds found in biochar are likely to be derived from the feedstock and/or created during pyrolysis at high temperatures (>750°) (Shackley & Sohi, 2011)

Biochar has not been associated with negative impacts on root developments but Lehmann et al. (2011), point out that most biochar research has not focused on root development. Understanding biochar’s effects on soil fauna, beside earthworms, is even less understood (Lehmann et al., 2011).

**Review of meta analyses of biochar pot and field trials**

Several meta-analyses on a wide range of biochar trials have been conducted in recent years. Meta-analyses use statistical methods to compare individual studies in order to gain clearer understanding of any patterns or relationships between different studies. Meta-analyses are particularly important for biochar trials, where there may be considerable differences in the properties of the chars as well as the soils used, the plants grown and the climate. The results are discussed below.

Jeffery et al. (2011), reviewed 16 glasshouse and field studies and concluded the mean impact on plant growth increases was 10-15 per cent.

Biederman and Harpole (2013), analysed 371 experiments from 114 published papers and concluded small but statistically significant plant improvements were found with biochar additions as well as some positive benefits for carbon storage and ecosystem function. Biochar offered an increase in above ground productivity, crop yield, soil microbial biomass, rhizobia nodulation, plant K tissue concentrations, soil phosphorus (P), soil potassium (K), total soil nitrogen (N) and total soil carbon (C) compared to controls. However, no significant mean response to biochar was found with below ground productivity, ratio of above and below ground biomass, mycorrhizal colonization of roots, plant tissue N, soil P concentration, and soil inorganic N.

Liu et al. (2013) assessed 103 studies for crop improvements and reported on average an 11 per cent crop increase when biochar rates < 30 tonne per hectare were applied. The most positive response occurred in pot not field experiments, in acid sandy soils, suggesting pH and soil texture respond highly to biochar’s liming and soil structure effects.
Cayuela et al. (2014), focused on the mitigation of nitrous oxide emissions and reviewed 261 experimental treatments mostly derived from laboratory or greenhouse trials between 2007-2013 and found that overall biochar additions reduced nitrous oxide emissions on average by 54 per cent.

Hammond et al. (2013) conducted a small meta-analysis of 7 field trials on working farms in the UK. Three trials showed no significant (p< 0.05) effect on crop yield, two showed positive effects of 5-6 per cent, one demonstrated a 100 per cent increase and one trial had a decrease in yield. Despite this variation, the meta-analysis of effect sizes across all treatments showed a significant (p>0.05) positive effect increasing average crop yield by 0.4 tonne per hectare, with biochar application rates of 20 tonne per hectare giving the best results.

In summary, the main findings from the meta-analyses above show that biochar generally had a positive impact on plant productivity but there were instances where improvements were not statistically significant and some studies showed negative impacts.

5.8 The Crucible Group’s CBC Char

The Crucible Group’s CBC has been described in Chapter 3. Wood waste has been the main feedstock used for most of their experimental trials. During pyrolysis different sections of the biomass break down as higher temperatures are reached. The hemicellulose will break down first, followed by the cellulose with lignans being last. In feedstock with a higher lignin component, such as forest and sawmill wastes, the char yield is maximised (Demirbas, 2004).

The temperature reached during pyrolysis defines the volume and type of char produced. The higher the temperature during pyrolysis the more gas is produced and the recalcitrance of the char is increased (Downie et al., 2009). Each dry tonne equivalent (dte) of biomass pyrolysed in the CBC will produce approximately 350 kg of char. As the CBC system produces three separate outputs, gas, water and char, the char produced is dry. Some water may be added to the char as it exits the system for the purposes of cooling, dust suppression and avoiding spontaneous combustion.

Trial results at Vales Point power station have analysed char primarily for its energy value. The total calorific value of the char is slightly greater than local
coal. Table 5:2 shows the fixed carbon percentage is higher for char than coal. This is interesting as this solid combustible residue is also the most recalcitrant component and will be an important factor when calculating carbon sequestration values.

**Table 5:2 Comparison of NSW black coal and TCG’s char**

<table>
<thead>
<tr>
<th></th>
<th>NSW black coal</th>
<th>TCG char</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ash</td>
<td>15.6</td>
<td>1.1</td>
</tr>
<tr>
<td>Volatile matter</td>
<td>28.4</td>
<td>30.8</td>
</tr>
<tr>
<td>Fixed carbon</td>
<td>53.6</td>
<td>63.8</td>
</tr>
<tr>
<td>Carbon</td>
<td>83.6</td>
<td>80.4</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>4.91</td>
<td>2.88</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>1.98</td>
<td>0.36</td>
</tr>
<tr>
<td>Sulphur</td>
<td>0.76</td>
<td>0.03</td>
</tr>
<tr>
<td>Oxygen</td>
<td>8.8</td>
<td>16.36</td>
</tr>
<tr>
<td>Gross Calorific Value</td>
<td>27.91</td>
<td>28.1</td>
</tr>
</tbody>
</table>

*Note. Adapted from The Crucible Group 2013*

Feedstock selection and the CBC process conditions can be adjusted to affect gas, char and liquid production.

### 5.9 Biochar Key Issues

The historical uses, biochar projects, the physical and chemical characteristic plus the agronomic effects have been outlined above. The question now is how can this interesting diverse product with its capacity to improve soils and sequester carbon be integrated into an existing business system.

#### 5.9.1 NSW Local Government Policy

Muswellbrook’s geographic position makes it a strategic rail junction for the movement of coal, not just for the mines within its boundaries but also for the north and west coalfields. The rail infrastructure is interlinked with stockpiling terminals and loading capabilities along its tracks, is upgraded and well developed in the area (Australian Rail Track Corporation, 2012). Rail use is expected to be primarily for coal until 2025. Thereafter good infrastructure remains for future transport needs. Biomass and biochar are potential alternative commodities.
Two points in particular in Muswellbrook Shire’s Coal Mining Land Use Strategy highlight future planning considerations.

Provision needs to be made for the diversification of land uses within the Shire, particularly ensuring that once mining has ceased compatible land use activities can re-establish and add to the Shire’s diversity and economic base.

Rehabilitation of land post mining should set the platform for future land use, recreation opportunities, and provide for opportunities to strengthen the district’s biodiversity resource (Muswellbrook Shire Council, 2014).

Although local governments adhere to a myriad of different state and federal legislative requirements they can also define specific regulations in their own policies. In 2012 Muswellbrook Shire Council included biochar as a soil amendment in their Land Use Development Strategy.

The rehabilitation plan for each coal mining proposal must include a soil rehabilitation and enhancement plan (or make further commitment for the development of such a plan) that considers, amongst other things, the use of biochar as a soil ameliorant and as a form of carbon sequestration, as well as any other appropriate ameliorant including the use of sterile or temporary cover plantings (Pg. 7)(Muswellbrook Shire Council, 2014).

This inclusion gives recognition to the fact that the rehabilitation area will be extensive after 75 million tonnes per annum of coal is extracted by 2025.

The coal mining approval and extension process continues to evolve and different mines have different compliance procedures. The consent authority for Muswellbrook Coal Mine, the oldest mine in the area, and AGL’s Bayswater and Liddell power stations, the biggest coal fired power stations in NSW, is Muswellbrook Council. This unique arrangement has evolved from earlier planning instruments where local decisions were conducted locally. This is advantageous for Muswellbrook Council to drive economic transition post coal.

5.9.2 Carbon Farming Initiative

The Australian voluntary Carbon Farming Initiative (CFI) legislated on August 23, 2011, began on December 8, 2011 but was amended on November 24, 2014 and will be automatically transferred to the Emissions Reduction Fund. A full list of these regulations and proclamations can be obtained from the Federal Government website ComLaw where they are regularly updated.
The purpose of this legislation was to facilitate the sequestration of carbon or reduce GHG emissions. To understand what can be achieved under this legislation there is an agreed list of activities that are admissible and a list identifying prohibited activities. These are called the Positive and Negative Lists. An action like ploughing a paddock with a disk plough is determined to be a regular, common agricultural activity and is therefore deemed to be negative. In other words it is not part of an improved action to make it positive and therefore not accepted as a method to sequester carbon or reduce emissions.

As slow pyrolysis is a new technology and biochar a new by-product, both activities go beyond common practice and therefore qualify to be on the Positive List. The legislation aims to facilitate innovation with the Positive and Negative lists being flexible. Once an action becomes common it will move off the Positive List and on to the Negative List. Three types of agricultural emissions avoidance are eligible as projects; these include agricultural emission avoidance, introduced animal emissions avoidance and landfill legacy emissions avoidance.

This will be the first time in Australia’s history when a ‘good’ agricultural action will be able to generate a carbon credit that is saleable in its own right, regardless of the product produced from the land. Essentially it is a new income stream. Presently there is no approved methodology incorporating biochar and until biochar production has increased there is unlikely to be one.

Our present Industrial Agricultural system rarely penalises bad agricultural practices. Prosecutions for illegal native vegetation clearance have been negligible (Bartle, 2003). Some illegal clearing has been deemed as deliberate breaches of the law (New South Wales. Office of the Auditor General (NSW OAG), 2006). While laws on the one hand advocate positive carbon sequestration practices, long-standing agricultural habits are unlikely to change quickly. Accepting and complying to new regulations has already proved to be a challenge (New South Wales. Office of the Auditor General (NSW OAG), 2006).

Now with the Carbon Farming Initiative and the Direct Action Plan in place (further discussed in Chapter 8) it will be possible, with innovation, to turn a
‘bad’ practise into a ‘good’ one, create a credit and make money over and above the sale of the product produced. How this changes behaviour is yet to be seen. Success of such a system can only be judged by how much carbon is eventually sequestered or emissions avoided. Each approved project needs to create its own methodology to prove its intentions, recognizing how different management protocols, rates and timing, in any agricultural system will sequester carbon.

An independent expert committee, Domestic Offsets Integrity Committee, has been established to review and approve all methodologies. At the time of writing there are 22 different methodologies approved in the three categories

- Agriculture (livestock, soil carbon, fertilisers, feral animals)
- Vegetation (regrowth, reforestation, avoided clearing and avoided harvest)

The register of offsets projects, managed by the Clean Energy Regulator (Australian Government. Clean Energy Regulator) has no biochar projects. Most are landfill legacy avoidance projects. Each Australian carbon credit unit (ACCU) is equal to one tonne of carbon dioxide equivalent (CO2-e). As projects continue the ACCU’s are accumulated and published in quarterly reports by the Clean Energy Regulator, as part of the Carbon Credits (Carbon Farming Initiative) Act 2011.

The importance of the CFI as part of Australia’s climate change mitigation efforts has grown since its introduction, especially as land use change is further recognised as the second most significant cause of CO2 emissions after fossil fuel use (Mackey et al., 2013; Olofsson & Hickler, 2008). Avoiding and reducing land carbon emissions is likely to remain an important area of mitigation focus on all sides of politics. Although the CFI was a Labor government initiative, the concept of project based mitigation schemes with offset certification is also central to the Coalition government’s Direct Action Plan.

Soil development can also build carbon in a slow, organic way. Biochar addition on the other hand can provide a tangible volume from which to measure the carbon offset immediately. Perhaps most significantly, if claims
that the carbon from Terra Prêta soils once applied 1000 years ago are still sequestered are correct, then it is credible to argue that carbon sequestered as biochar will meet the permanence clause of 100 years in any CFI project.

Offsetting and reducing are two words frequently confused in the debate to clarify biochar’s true value. As Lal (2004) points out, the effectiveness of the C sequestration in soil is generally not achieved for long under most circumstances. The problem of accurately measuring C in the soil has been one of the biggest obstacles in developing methodologies to confirm soil carbon’s longevity and thus prove it can legitimately generate carbon offsets (Reilly et al., 1996). Knowing soils store carbon is one thing, keeping it there is another (Gifford, 2009). If Terra Prêta soils can be stable for a long time, in some cases for hundreds of years (Glaser et al., 1998; Glaser et al., 2002) can biochar do the same for Australia’s soils? While soil carbon can be increased during basic good agricultural management techniques (Lal, 2004), the issue has been the soil’s ability to keep the carbon sequestered for the 100 year CFI requirement if it is to participate in any carbon trading business. While not every soil is equal, biochar offers a promising secure carbon sequestrations option (De Gryze et al., 2010).

5.9.3 Anticipating the price

Applying biochar to soil is a permanent action and it is not accurate to compare this to fertilizer addition. It is a Capital Asset, more akin to a farmer building a dam or shearing shed.

The price of biochar will be adjusted when new technology can produce it cost effectively. The average biochar sale price of $US2480 per tonne was calculated from the International Biochar Initiative 2014 survey results (Jirka & Tomlinson, 2013). This high market price has been driven by research requirements and does not reflect the likely future commercial wholesale or retail price. It would be economically prohibitive for most agricultural applications in Muswellbrook.

The high price IBI identified is for a variety of biochar types both plain and mixed with fertilisers. The USBI has recorded even higher retail biochar prices from 12c/kg to $6/kg ($US6000 per tonne) (Brunjes, 2012).
Commercially biochar will satisfy different needs, be manufactured from different feedstocks and be priced differently. A consistent wholesale and retail price of biochar is unlikely to be realised until a consistent volume can be produced. The biochar price will be affected by the price potential of all the pyrolysis outputs, especially the gas product, which may or may not be able to earn carbon or renewable energy credits (a political factor) and the water product (which has an uncertain market value in Australia). Price of outputs plus the primary energy saved will ultimately define the profitable price needed to market biochar. Locating the most viable market entrance point for biochar will be defined by the existing surrounding enterprises; horticultural, broadacre, or industrial. As Muswellbrook is a coal industry hub it is likely biochar’s entry point could involve the mining sector.

The development of bioenergy in general has been driven by potential profits in the bio–oil market. This is an industry not presently active in Muswellbrook LGA nor is it projected to be in the future (Buchan Consulting, 2011). Agriculture on the other hand is present in the region. This was the dominant industry before coal mining, and is projected to be increasingly relevant in the future. However, agriculture is globally functioning with low profit margins and biochar as a soil amendment will need to find a cheaper price entry point.

5.9.4 Above ground storage

As discussed in Chapter 4 Pyrolysis, the establishment of a pyrolysis system depends on how the three outputs are to be used.

A CBC will produce approximately 350 kg of biochar from every tonne of feedstock. Or, one plant will produce 3500 tonne of biochar during one year of continuous processing. Therefore storage of biochar at the plant site can be a limiting factor if the biochar is not regularly removed. An important issue to consider first is what happens immediately to the biochar when it leaves the pyrolysis extruder? Where will it go?

If retailing the biochar is to be undertaken from the pyrolysis site then a bigger carbon embodied concrete area will be required. Storing freshly made biochar, with its low packing density, is challenging for two main reasons.
• It is fine, poses a potential dust health risk and requires specific material handling systems management.
• If stored in large heaps, spontaneous combustion is a potential risk.

The biochar storage, transport and value adding option to retail or wholesale could define the final cost of any project. The Crucible Group has purchased a briquetting machine, which will soon be commissioned for the purpose of developing stored and transported char products. This will subsequently be augmented by a pelletising option.

5.9.5 Application

The process of applying biochar on its own straight from a pyrolyser to soil is un-developed, with broadcasting, banding, and pelletising under investigation (Blackwell, Riethmuller, & Collins, 2009). As freshly made biochar is fine, often dusty, difficult to transport and apply, the volume to hectare variations and the required machinery to apply can be very different.

The application of solid and liquid mineral fertilisers is a specialist section within the agricultural sector with machinery and safety requirements constantly being developed and updated. The heterogeneous nature of biochar challenges the development of one application system. Traditional use in Japan overcame dust and spontaneous combustion by often mixing charcoal with manures and rice husks, creating a mineral based fertilizer that also reduced the odour of the manure (Ogawa, 2009). Mixing biochar with fertiliser and/or compost has the benefit of combining two inputs thus facilitating application efficiencies.

Pelletising biochar has been discussed as a useful secondary development, along the lines of the wood pellet industry to facilitate handling, transport and application. As an increased financial and energy cost, pelletising will need to be accounted for when measuring biochar’s full carbon mitigation capacity. Wood pellets, sometimes referred to as densified biomass fuels, has increased in importance throughout Europe as a bioenergy feedstock (Thek & Obernherger, 2004). The most important advantage of pellets is the improved handling capacity. Pelletising production has been shown to be most cost effective with larger plant capacities where efficient heat recovery can be achieved. The cost differential with dry or wet feedstock can also be significant.
Pelletising biochar could become a component of biochar’s future handling as it would allow existing agricultural machinery to be used during broad acre applications. Machinery suitable for granular fertilisers, either with a pneumatic delivery system or disc spreaders, would be appropriate (Ippolito, Laird, & Busscher, 2012). According to an FAO report, wood pellet production has increased 10 fold since 2002, primarily because new policies target renewable energy and bioenergy options (FAO (Food and Agriculture Organization of the United Nations), 2012). The European Commission projects that 27 % of renewable energy will come from wood pellets by 2030 largely due to power stations converting to biomass fuels.

Pelletising biomass prior to pyrolysis may change the form of the biochar from the converter. The most significant issue is the maintenance of the porosity of the biochar during the process to ensure microbial habit is not destroyed via compaction.

5.9.6 Salinity

Salinity is a growing problem the world over and as agricultural productivity increases, underground and surface water supplies have been negatively manipulated. Part of the Hunter River system is based on a marine geology, which is naturally saline. Now coal extraction is changing the saline balance and will continue to do so after mine closure (Day, 1986; Hancock, Wright, & De Silva, 2004). Aquatic biota in the Hunter River system has already been stressed by rising salinity (Muschal, 2006).

Mass-balance modelling by Hancock et al (2004), shows salinity in the Hunter Valley is likely to increase over time as evaporation concentrates salt in the voids making salinity one of the biggest unknown issues facing the region post coal mining. Pockets of high salinity are recorded across the region and managed accordingly (Muswellbrook Shire Council, 2011c).

The Hunter River has a Salinity Trading Scheme whereby saline water is monitored with dam controls and the legal right to dump saline water into the Hunter River during high flows. This trading system relies on the management by private companies until mine closure is carried out. How the Hunter Valley’s salinity will be managed in the long term is not decided.
Research by Mercuri et al. (2005) and funded by Muswellbrook Shire Council in 2003-4, experimented with growing trees with saline mine water and municipal green waste. It was found that tree growth was hindered by the poor soil nutrient in the mining substrates together with low rainfall. However, irrigation with saline mine water improved overall tree survival and did not negatively impact on above ground biomass volume. *Eucalyptus occidentalis* performed significantly better than other species with saline irrigation, compost and biosolids, although tree form was poor. The growth rates were not of a commercial standard suggesting plantation forestry for the wood sector is unlikely to be a future industry on disturbed mining lands. Growing trees for a coppicing biomass supply requires different wood standards and was not accessed. The use of saline water on mine sites for tree biomass establishment and production looks promising from this trial. As the reduction of saline wastewater on mine sites is an on-going management issue, using this water for tree production would seem sensible.

### 5.10 Discussion

**The development of biochar standards**

Despite the fact that there is no established biochar industry the IBI has been developing biochar product standards and a certification program that operates in Canada and the USA. These standards aim to set a benchmark for minimum standards of biochar only. They do not evaluate effectiveness of the biochar, include biochar-fertilizer mixes, address sustainability or GHG emissions.

The *IBI Biochar Standards* ensure that biochar materials intended for application to soils meet minimal physicochemical properties and pass tests designed to identify the presence of certain potential toxicants. (Pg 7)

Recognising the need to eventually meet global product standards, this is a necessary step in the establishment of biochar as a credible and useful soil amendment. As more research is undertaken it is expected that biochar standards will be constantly updated. Presently these are found on the IBI web site (International Biochar Initiative).
How it is made does matter

Small pyrolysis plants that do not capture gas have the potential to release toxic gases if contaminated biomass is used. Furthermore, the GHG emissions cannot be calculated. As mixed feedstocks are usually used in these operations, monitoring controls over feedstock is difficult. There also cannot be a clear assessment of the biochar characteristics, as each batch will vary (Joseph, 2009). The review of research demonstrates significant variability in all aspects surrounding the production of biochar, its resulting characteristics and impact on soil fertility and carbon sequestration. These include differences in feedstock, the technology system as well as the temperatures reached during biochar formation. Further variation occurs with different biochar volumes used in trials, on different soil types, growing different crops. In fact the variations are so vast that they reveal the complexity of natural systems and the difficulty in land management.

That said, the meta analysis studies considered in this thesis provide compelling overarching evidence that appropriate biochar addition to soils can improve agronomic performance. Jeffery et al. (2011) analysis of 177 experiments confirms biochar’s positive impact on acidic soils with pH increases and water holding capacity. Biederman and Harpole’s review of 371 independent studies reaffirms the liming affects and increases in above ground biomass volumes, crop yield, rhizobia nodulation. Some elemental increases are also likely with the introduction of biochar but the below ground productivity showed many variables and no significant mean response (Biederman & Harpole, 2013). Liu et al. (2013) review of 103 published studies focused on biochar soil amendments (BSA) with results showing a 11.0 per cent average increase in crop productivity with biochar amendments of <30 tonne per hectare.

Understanding the mechanism behind productivity improvements is still uncertain and is likely to remain so while pyrolysis technology is developing and the biochar remains so varied. Biochar is unlikely to ever be a singular product, therefore whether it offers a nutrient directly or indirectly will vary and may be a one-off offer for plant growth.
Significantly biochar should not be viewed as a fertiliser, but as an amendment to facilitate biological soil health and uptake of fertilisers. It is biochar’s carbon and form that can facilitate biological processes that make it so useful.

**Biochar for Muswellbrook**

As global biochar projects reveal, the manufacturing of char has been primarily driven by the need for cheap fuel for domestic cook stoves. In Muswellbrook LGA the need is quite different, there is no demand for cook stoves but a growing demand to rehabilitate disturbed lands post mining. Research testing biochar’s ability to improve soil health is particularly important for mine rehabilitation.

Especially important is the research showing biochar’s ability to help clean up contaminated soil. For instance field trials in New Zealand have demonstrated biochar can assist in remediating arsenic-contaminated soil (Gregory, Anderson, Camps Arbestain, & McManus, 2014).

The review of literature, in particular the meta analysis and the recent thesis by Burns (2014), shows that while most research in soil improvements with the addition of biochar has been concluded via pot trials there is evidence that biochar additions to poorly structured soils will incorporate into the soil after time. Artificially elevated landforms such as overburden piles on coal mines is a profound land modification (Isbell, 2003). Soil disturbance due to coal mining will by 2025, impact thousands of hectares across Muswellbrook.

As Table 5:3 shows, the area impacted by mining in the Muswellbrook LGA is extensive, growing and will require significant land rehabilitation. Insufficient topsoil is often responsible for low plant establishment rates during mine rehabilitation (NSW Department of Mineral Resources, 1999). According to (Daynes, 2010) arbuscular mycorrhizal (AM) fungi, helps facilitate the development of functioning topside on coalmine overburden. As biochar additions help develop strong microbial habitats (Warnock et al., 2007) biochar addition is likely to assist soil function and plant establishment on mine sites.
Table 5:3 Mining Impact Areas in Muswellbrook Local Government Area

<table>
<thead>
<tr>
<th>Coal Mining Areas</th>
<th>2009/10 Square Kilometre</th>
<th>2010/11 Square Kilometre</th>
<th>2011/2012 Square Kilometre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cleared</td>
<td>6.88</td>
<td>8.53</td>
<td>4.52</td>
</tr>
<tr>
<td>Active Mining</td>
<td>14.92</td>
<td>17.95</td>
<td>19.36</td>
</tr>
<tr>
<td>Emplacement</td>
<td>19.01</td>
<td>20.94</td>
<td>23.27</td>
</tr>
<tr>
<td>Rehabilitated</td>
<td>1.16</td>
<td>0.96</td>
<td>2.16</td>
</tr>
<tr>
<td>Change in total active mining</td>
<td>NA</td>
<td>15%</td>
<td>10%</td>
</tr>
<tr>
<td>Rehabilitation to clearing ratio</td>
<td>0.2</td>
<td>0.1</td>
<td>0.5</td>
</tr>
<tr>
<td>Total Active</td>
<td>33.93</td>
<td>38.89</td>
<td>42.64</td>
</tr>
<tr>
<td>Approved disturbance</td>
<td>173</td>
<td>174.09</td>
<td>174.09</td>
</tr>
</tbody>
</table>

**Note.** Adapted from Muswellbrook Shire Council 2013

The existing coalmines at Muswellbrook have between them years of legal operations and plans to extend the operations are under review with the NSW government (NSW Planning and Environment) and new mines are being proposed. This confirms that the task of mine rehabilitation in the area will be carried out for decades.

After so much soil disturbance in the Muswellbrook LGA, biochar may provide an opportunity to build the soils of the future in the region and invest in long term solutions that incorporate establishing new industry, new land management principles as well as carbon sequestration. As the Garnaut report highlighted in 2011, if Australia is to count on biosequestration to curb carbon emissions, ensuring the carbon once sequestered stays in the ground is a major benefit of integrating slow pyrolysis with its biochar output (Garnaut, 2011). The critical issue of permanence is more easily measured with a biochar application than a basic land management change (Macintosh & Waugh, 2012).

While the world tries to create a system where rewards for developing soil carbon is meant to occur alongside existing agricultural activities, Muswellbrook provides a unique opportunity to create new systems that expand on existing agricultural know-how with the opportunity of engaging new technology to quickly build soil, rehabilitate land, provide renewable energy and develop a renewable energy economic platform.
5.11 Summary

Biochar is a diverse product with two core advantages: the sequestering of carbon and the improvement of soil quality and productivity. However, the lack of cost effective technology to make it has limited biochar development. Consequently it is not a standardised developed product with surrounding industry, but rather a movement. The Crucible Group’s CBC could unlock this potential and turn a movement into an industry.

Much of the overseas research used to analyse char’s benefits refer to char made in small scale and domestic pyrolysis machines. In Australia the biochar used in most of the pot and field trials was made by Best Technologies in their NSW test facility with a biomass processing capacity of 200kg per hour. This company has since become inactive. It is possible that the char qualities of the CBC product are different to the char used in pot and field trials by other organisations. During this early technology development stage where standards are still being set, general soil improvements with biochar are achievable but specific crop volumes, product quality, protein levels or fertilizer use comparisons are harder to achieve.

As the meta-analyses by Jeffery et al. (2011) and Biederman and Harpole (2013) show, most of the published studies evaluating plant growth due to biochar addition were conducted on pot trials. Evidence that biochar improved soils in the field has been from studies primarily conducted on acidic soils.

The compelling proposition that biochar could be a positive part of mine restoration is based on the fact that reinstating functioning soil post coal mining is essential to ensure future local land use options. Biochar may assist key land issues on Muswellbrook’s mine sites such as improving seed germination rates and facilitating microbial habitats and help reduce water and soil salinity.

The pyrolysis liquid product and experimental field trials with biochar discussed in the following chapters are an attempt to begin to fill in a key gap in the technology’s existing research and development. Variations in biochar research and the lack of biochar testing with pyrolysis liquid, another key pyrolysis output, triggered the idea to conduct local Hunter Valley trials. It
was hypothesized that biochar together with pyrolysis liquid product could offer further soil improvement. Though the methodological issues described above in terms of standardised inputs apply, the trials aimed to start the analysis of the potential char/liquid treatments and are revolutionary because they capitalise on both biochar’s core advantages, simultaneously sequester carbon and aid soil regeneration.
CHAPTER 6 Pyrolysis Liquid

“Humanity has fabricated the illusion that somehow we can get by without biodiversity” Achim Steiner, Executive Director, United Nations Environment Programme 2010

6.1 Introduction

The continuous biomass convertor breaks down biomass into short-chained molecules and produces a gas, char and liquid during the thermal decomposition process. A condensate is obtained when the gas is cooled. This liquid has many names: wood vinegar, wood pyrolysis liquid, wood distillate, smoke water, mokusaka, pyrolygic acid and pyrolysis liquid, the latter being the name chosen for discussion in this chapter.

Pyrolysis liquids can contain up to 200 different organic compounds (Yoshimoto, Huang, & Liu, 1994). The major components are carboxylic acids, including formic, acetic, propionic and butyric acids acid and these create the acidity of the liquid. In addition there are commonly lesser quantities of methanol acetone, methyl acetone, acetaldehyde, allyl alcohol, furan and furfural are common (Demirbas, 2002). The liquid usually has a strong smoky aroma.

At the boutique end, the development of products that are therapeutically natural has risen with the increase in the certification of organic cosmetics (Australian Certified Organic). In the future pyrolysing specific plants for their pyrolysis liquid characteristics will likely increase as the demand for bio-based chemical replacements increase. Ma et al. (2013) for instance, tested Rosmarinus officinalis leaves; fresh, air dried and the leaves after essential oil distillation, for antioxidant properties. The leaves were pyrolysed at different heating rates to test anti oxidant and free radical scavenging activity. Fine-tuning the pyrolysis process for these specialist pyrolysis liquids is unlikely to be the feature of a continuous biomass converter, where large volumes of biomass are needed. Therefore there is likely to be a high variance with the price point of pyrolysis liquids. The most expensive are specialized biomass such as Rosmarinus with the lesser value liquids, those from green waste.
6.2 Chemical Constituents

As biomass is fundamentally made up of three components; cellulose, hemicelluloses and lignin, these different characteristics define the characteristics of the pyrolysis liquids (Soltes & Elder, 1978). Cellulose is the most common component of biomass producing the gas, whereas lignans only convert 12 per cent to gas, while 51-66 per cent will divert to char, and 14-15 per cent into tars. Therefore it is common to find the pyrolysis liquid volume to vary between 13 to 28 per cent. The acidic nature of the liquid due to the presence of organic acids is derived mainly from the hemicelluloses component of the feedstock. Acetic acid is usually the most valuable recoverable component of the liquid and the quality will vary depending on the species pyrolysed.

A review of the chemical constituents of some wood pyrolysis liquids have been conducted by Yatagai, Nishimoto, Hori, Ohira, and Shibata (2002) and (Yoshimoto et al., 1994). Table 6:1 shows the total organics range from 8.1 % with pinus species to 28.8 % with eucalyptus. These northern hemisphere eucalyptuses showed higher acetic acid 7.8 % compared to wood pyrolysed in the continuous biomass converter, where the range is usually around 2-3 %. This is interesting because most analysis of pyrolysis liquids in the literature is made from northern hemisphere deciduous hardwood timbers. The FAO also notes that eucalyptus wood often has a lower yield of the acetic acid component than other timbers. As the continuous biomass converter incorporates tar cracking within the reactor, the tar fraction of the condensate is much lower than reported above for typical pyrolysis conditions. Also, the organics and acetic acid levels are substantially higher than CBC pyrolysis liquid, which is predominantly made up of the ‘middle layer’ (i.e. pyroligneous acid).

Table 6:1 Organic compounds of some pyrolysis liquids (%)

<table>
<thead>
<tr>
<th>Tree Species</th>
<th>Pinus sp</th>
<th>Quercus sp.</th>
<th>Eucalyptus sp.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total organics</td>
<td>8.1</td>
<td>16</td>
<td>28.8</td>
</tr>
<tr>
<td>Acetic acid</td>
<td>3.9</td>
<td>8.0</td>
<td>7.8</td>
</tr>
<tr>
<td>methanol</td>
<td>0.7</td>
<td>0.9</td>
<td>0.0</td>
</tr>
</tbody>
</table>

*Note. Adapted from Yatagai (1988) and Yoshimoto pg 811 (1994)*
As mixed eucalyptus wood waste has been the primary biomass source used in The Crucible Group’s commercial development, most water analysis has been carried out using this feedstock.

Table 6:2 shows the analysis of pyrolysis liquid made by TCG conducted by Robert Carr & Associates PTY LTD (Laboratory) (Robert Carr and Associates) in October 2013. Results of analyses lower than the Limit of Reporting (LOR) are not included. This pyrolysis liquid has a pH of 2.52 and is dominated by the volatile acid, Acetic Acid at 16 300mg/L. Together with this acid are the numerous smoke compounds.

Table 6:2 Physical characteristics of pyrolysis liquid made from timber mill hardwood waste

<table>
<thead>
<tr>
<th>Compound</th>
<th>Unit ug/L</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetic Acid</td>
<td>Mg/L</td>
<td>16,300</td>
</tr>
<tr>
<td>Suspended solids</td>
<td>Mg/L</td>
<td>7</td>
</tr>
<tr>
<td>Monocyclic Aromatic</td>
<td>ug/L</td>
<td></td>
</tr>
<tr>
<td>Hydrescarbons</td>
<td></td>
<td></td>
</tr>
<tr>
<td>calcium</td>
<td>Mg/L</td>
<td>2</td>
</tr>
<tr>
<td>Magnesium</td>
<td>Mg/L</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Sodium</td>
<td>Mg/L</td>
<td>4</td>
</tr>
<tr>
<td>potassium</td>
<td>Mg/L</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Total recoverable mercury by FIMS</td>
<td>Mg/L</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

Note: Adapted from Robert Carr and Associates Pty Ltd (Laboratory) 2013.

6.3 Creation of Pyrolysis Liquids

The pyrolysis liquid collected from the continuous biomass converter is referred to as a ‘raw pyrolysis liquid’. Its consistency and complexity depends upon the feedstock and process conditions during pyrolysis.

Most research testing the characteristics of pyrolysis liquids in the literature is on product made under laboratory conditions or with small home made kilns, using a variety of feedstock. The pyrolysis liquid is usually settled for up to six months before being used or tested. After the liquid has settled, it is common for the oil and tar fractions to separate into three distinct layers. A sedimentation tar will sink to the bottom, a middle layer contains the water-soluble component and on the top a thin layer of oil, usually containing some wood tar, will float. The pyrolysis liquids can accept the addition of water but the smoke chemicals cannot be dissolved in water. The pyrolysis oils
suspended in the water are usually unstable (Sadaka, 2009). Separating the three different components within the raw pyrolysis liquid can also be carried out using equipment.

### 6.4 Historical and Local Uses

Before pyrolysis liquids found an agricultural use, the tarry materials and liquids made by pyrolysis of pinewood were used historically for waterproofing and caulking, as recorded throughout many archaeological sites (Colombini, Giachi, Modugno, Pallecchi, & Ribechini, 2003). Birch bark pitch, made by a simple thermal process, was in use 80,000 years ago in Europe as adhesives (Mazza et al., 2006).

Few botanical insecticides are used in industrial agriculture today (Isman, 2006), with neem, pyrethrum and rotenone being the most common botanical insecticides. The development of pyrolysis liquids as a local home made green chemical in Asia is extensive, especially in Japan and Thailand (Burnette, 2010). Green chemicals are based on the principles that reduce or eliminate hazardous substances during the manufacturing process (Anastas & Warner, 1998). Ogawa and Okimori (2010) points out that pyroligneous liquids have predominantly been used in biomass rich landscapes where farmers already use various kinds of kilns for charcoal making for household use. Some small kiln operators have been heating wood specifically to get the liquid to use as a green chemical, usually because synthetic chemicals are either not available or too expensive (Burnette, 2010). Local commercial charcoal producers primarily sell charcoal to local restaurants but there is also a small export market. Today farmers, scientists and industrialists are finding new ways of using pyrolysis liquids and tars as wood preservatives, fungicides and herbicides (Tiilikala, Fagernas, & Tiilikala, 2010). Applications as fertiliser, fungicide or herbicide either separately or simultaneously are different to the precise recommendations of industrial chemicals where dosage and intention define success.

### 6.5 Agronomic effects

With so many variations in production of pyrolysis liquids, dosage comparisons are inconclusive. The network of small landowners in Asia using
pyrolysis liquids does not adhere to official standards governing its application. There appears to be no systematic dilution rate so understanding volumes and rates is difficult. Decisions regarding dilution seem to depend on cultural agricultural practices and trial and error with different crops. Dilution rates as low as 1:800 have shown increases in total plant dry weight, fruit number, fresh fruit weight, dry fruit weight and significant (P <01) enhanced total soluble solutes of fruit. Some experiments have included comparisons with chemical fertilisers and shown pyrolysis liquids to be better than industrial chemicals for achieving higher plant growth (Mungkunkamchao, Kesmala, Pimratch, Toomsan, & Jothityangkoon, 2013).

Standards are presently under review in Thailand and Japan. Meanwhile, both the Thai and Japanese governments have officially declared pyrolysis liquids to be safe for the environment (Burnette, 2010). Safe handling of chemicals is a worldwide issue with each country implementing various standards to ensure human and ecosystem protection. Australian regulations require a farmer to have a certificate proving chemical training before purchasing most farm herbicides and pesticides. The incorrect handling of pesticides in Thailand has been a problem the government and the FAO have been attempting to rectify with education programs (Poblap & Silkavute, 2001).

The application of home made pyrolysis liquids on crops or direct to soil is often done without analysis of its chemical constituents. Yet these are now being promoted in local communities in an attempt to reduce dependence on commercial industrial chemicals (Mungkunkamchao et al., 2013). Sometimes seeds are soaked. In some pot trials the soil is soaked. Agricultural soil borne problems are treated with the spraying of pyrolysis liquid on the soil immediately prior planting, whereas air born infestations may require spraying on plants during different times of growth. All vary the concentration ratio with H2O.

**Seed Germination**

A variety of pyrolysis liquids have been proven to be seed germination promoters (Lange & Boucher, 1990; Light, Burger, & van Staden, 2005; Mu, Uehara, & T, 2003). The promotion of seed germination by smoke has a long history and is not limited to fire prone ecosystems (Light et al., 2005). As
Pyrolysis liquids include up to 200 smoke chemicals they have been used in horticulture as a germination cue. The chemical identity of the germination cue has been identified as 3-methyl-2H-furol (Light et al., 2005).

Many Australian native plants require fire to facilitate germination and the use of aerosol smoke and smoke water has also been shown to increase seed germination – in some instances up to 85% - on mine sites in Western Australia (Roche, Koch, & K, 1997). Plant-derived smoke is a germination cue in many horticultural species and has been tested with positive results on lettuce, watercress, honewort and chrysanthemum (Mu et al., 2003). However, the correct dilution is important to secure positive results.

Baxter, Van Staden, Granger, and Brown (1994), showed there was a positive germination response to smoke extracts on Australian redgrass *Themeda triandra*, both at optimum and sub-optimum germination temperatures. These trials suggest a future use for pyrolysis liquids for seed germination will likely increase.

**Root development**

Three pear cultivars (*Pyrus pyrifolia* Nakai) were tested with pyrolysis liquid and found shoot multiplication was inhibited yet root development was enhanced. Increasing root volume and strength are important for commercial tree crops (Kadota, Hirano, & Imizu, 2002).

**General plant growth**

Pyrolysis liquids made from different feedstock have proven to be general plant growth enhancers (Chalermsan & Peerapan, 2009).

According to Mungkunkamchao et al. (2013) when pyrolysis liquids are used on tomatoes either as a foliar spray or soil application there is no significant difference in effects and both improve crop yields, which suggests there will be multiple ways in which liquids can be applied.

As the research of (Pagnakorn, Watanasorn, Kuntha, & Chuenchooklin, 2010) shows, the diversity of options with experimental treatments is endless when considering the local plants available in each ecosystem. Many experiments test pyrolysis liquids together with both industrial and biological fertilisers
(Burnette, 2010; Kim, Seo, Lee, & Lee, 2008; Mungkunkamchao et al., 2013; Tipparak, Jothityangkoon, & Polthanee, 2007; Zhou & Lang, 2008).

The criteria defining improved plant growth are also varied and described differently in the literature. This may be because descriptors for fresh food are described differently within cultures. For instance Zhou and Lang (2008) found two varieties of cabbages had improved overall yield and ‘quality’ but do not say precisely in what way; were they sweeter, harder, greener, unmarked?

Steiner, Das, Garcia, Förster, and Zech (2008) found mixing pyrolysis liquid with char on low nutrient soils improved ‘plant growth’. However plant growth does not always lead to crop yield. Field trials on celery in China only noticed improved growth when pyrolysis liquid was sprayed on the plant, not the soil (QuanYuan et al., 2009).

**Insecticide**

Using local plants to make effective biological products may be effective for many agricultural needs. Specific uses as bio-pesticide/insecticide have been observed. The effect of pyrolysis liquid specifically as an insecticide varies with different pests, plants, dilution rates and pyrolysis feedstock.

An assortment of biological liquids made from neem, derris, citronella, grass, tobacco, turmeric and molasses together with pyrolysis liquid, were tested on soybeans in a field trial in Thailand. The pyrolysis liquid alone provided the highest significant efficacy of reducing pest infestation (at level of confidence 95% by DMRT method), while the fermented liquid bio-fertiliser increased crop growth and yield of soybeans Pagnakorn et al. (2010).

Pagnakorn et al. (2010) also tested different dosages of liquids mixed with herbs and spices on soybeans and found the highest pest repellent effect was achieved with unblended pyrolysis liquid. While pyrolysis liquid made from Coconut shells has shown to have strong positive responses to control termites and mealy bugs (Wititsiri, 2011). Yatagai et al. (2002) suggests the termiticidal activity is found primarily in the acetic acid profile, but that other acids are responsible for the different levels of termiticidal effects.

Kim et al. (2008) tested effects on plant-hoppers using pyrolysis liquid alone and pyrolysis liquid mixed with chemical insecticides. When used alone there
was no effect, but when mixed with pesticides improved the function and kill rate of the pesticide, suggesting a synergistic effect on the industrial insecticide activity.

**Fungicide**

Controlling pathogenic fungal growth is an important agricultural activity within many horticultural and orchard systems. Different pathogenic fungi negatively impact on a number of fruit crops, causing blotches (*Alternaria mali*) root rot (*Rhizoctonia solani*) and fruit and blossom death (*Choanephora cucurbitarum*). Pyrolysis liquid made from coconut shells, bamboo and eucalyptus biomass have shown positive anti-fungal properties, possibly due to the high level of phenolic compounds (Tiilikala et al., 2010). Velmurugan, Han, and Lee (2009) tested these phenolic compounds specifically to understand effects on sapstaining fungi (a problem in the timber industry) and concluded that the acetic acid had limited influence as an anti-fungal agent while the phenols showed a significant contribution. Pyrolysis liquid from coconut shells has been shown to have a high phenol component, suggesting further refinement could create multiple products (Mela, Arkeman, Noor, & Achsani, 2013), as phenols are an important precursor for the manufacture of drugs, chemicals and plastics.

**Soil microbial activity**

There are a variety of ways to measure soil microbial activity: directly via enzyme assays, nitrification rates, soil respiration rates and indirectly using indicators such as soil organic carbon levels and microbial biomass organic carbon testing. Because soil microbiology is complex, defining the effects from pyrolysis liquids has often tested specific components within soil profiles. However, measuring total microbial activity, including bacterial and fungal quantities has been conducted on some pyrolysis liquids. Rui, Wei, Zhibin, Chao, and Xiaojuan (2014), found the quantity of soil microbes increased using dilutions of 1:300 and 1:500. The quantity of soil bacteria increased 21.37% using the dilution rate of 1:300 and 73.39% using the weaker 1:500 while fungi populations decreased by 38%, with twenty types of plant pathogens also decreasing. Overall the soil microbial composition was not changed but the soil population did, suggesting good bacteria were not
negatively effected by pyrolysis liquid and the balance of bacteria to fungal pathogens can be enhanced.

This follows Steiner et al. (2008) greenhouse trials that tested the effects on soil microbial levels using char and locally made pyrolysis liquid and found microbes metabolised the organics in the pyrolysis liquids. This suggests that if the pyrolysis liquid is less diluted when used with char, it may become an effective insecticide (biocide) and control nematodes whereas weak dilutions could improve growth of soil microorganism.

Zhai, He, Wang, and Guo (2010) made three different wood vinegars from corn stover, pine cones and walnut branches. All were analysed for anti microbial activities and found to have inhibitory effects on twenty different plant pathogens. These experiments indicate that when adjusting the feedstock and pyrolysis liquid volumes it is possible to change soil microbiology.

**Animal feed supplement**

Japan has a long tradition of feeding charcoal and pyrolysis liquid to animals (Ogawa, 2009). The feeding value of pyrolysis liquid has been undertaken with different animals. Due to the acidic characteristics of pyrolysis liquid it is believed to promote animal digestion by increasing nutrient adsorption. Pyrolysis liquid’s potential ability to reduce alkaline carcinogens, enhance absorption of calcium and magnesium and increase blood circulation can reduce the presence of harmful intestinal protozoa such as *Cryptosporidium parvum oocyst*, and thereby reduce diarrhoea. For instance, when pyrolysis liquids were fed to chickens together with charcoal, intestinal villi was managed better and animal health improved (Samanya & Yamauchi, 2001).

Choi, Shinde, Kwon, Song, and Chae (2009) experimented with wood vinegar as a feed supplement for piglets and found digestibility of dry matter improved. Tiilikkala et al. (2010) reported piglet health improved in various experiments. Trials by (Wang, Wang, Wang, Zhang, & Dai, 2012), using bamboo pyrolysis liquid to test faecal bacteria communities in piglets did not lead to improved weight gains but faecal bacteria diversity was less in piglets on antibiotics than pyrolysis liquids This suggests that bamboo pyrolysis liquid could be a potential additive as an antibiotic alternative for piglets.
Soil remediation

Ameliorating degraded lands is a global ambition (Eswaran, Lal, & Reich, 2001). Hagner, Penttinena, Tiilikala, and Setälää (2013) tested the capacity of wood vinegar to reduce glyphosate (Roundup) leaching. Although glyphosate is one of the most commonly used herbicides its impact on ecosystem health is not well understood (Hagner et al., 2013). A pot experiment explored if biochar or pyrolysis liquid alone or combined affected glyphosate leaching. The addition of biochar did decrease leaching from the soil but the lowest recorded leaching was with biochar and pyrolysis liquid together.

Heavy metal extraction

Improving bio remediation of contaminated wood and in particular CCA treated timbers (copper Cu, chromium Cr, arsenic As.) is important for environmental health as most of the metals deposit in the soil (Choi, Kim, et al., 2012). Long term management of this wood waste will be important during the next few decades as these timbers continue to leach heavy metals (Mercer & Frostick, 2012). Choi, Ahn, and Kim (2012), found high concentrations of pyrolysis liquid was successful in extracting 86.3% of chromium, 95.7% of copper and 92.7% of arsenic from CCA-treated wood. This industrial use could become an important step in developing improved resource re-use, thus limiting landfill contaminants.

Medicinal and Pharmaceutical applications

Immune compromised conditions where fungal infestations have been hard to control may benefit from specialised concentrated pyrolysis liquids. Malaysian Rhizophora apiculata has been shown to be fungi static in low concentrations and fungicidal in high concentrations. When the volatile components of the liquid were removed it was proven to reduce some of the volatile components fungal infections such as candidiasis, which affects skin and human mucosa (Ibrahim, Kassim, Sheh-Hong, & Rusli, 2013). Farmers in the Philippines refer to pyrolysis liquid as mokusaku water. Mokusaku is also the name used in Japan to describe folk medicine, where there is a tradition of using refined pyrolysis liquids to treat eczema (Ikegami, Sekine, & Fujii, 1998).
Specifically pyrolysis liquid made from *Rosmarinus officinalis* has high antioxidant qualities (Ma et al., 2013) as does bamboo feedstock (Chang, Zhao, Ni, & Wo, 2004). The antioxidant capacity of pyrolysis liquids have been identified and tested in vivo by (Cai, Jiang, Ren, & He, 2012) who showed pyrolysis liquid increased the lifespan of worms. It is thought the phenol component of the pyrolysis liquid is largely responsible for its antioxidant qualities as these are known to have free radical scavenging abilities (Mela et al., 2013).

Extraction techniques such as distillation or solvent extraction have been conducted by (Wang, Weigang Lin, Wenli Song, & Yao, 2010) to develop improved processes. The acetol has been separated from the pyrolysis liquid and used for medicine synthesis. It is likely that the unique use of pyrolysis liquids will require a high level of refinement.

**Toxicity**

Although Japan and Thailand have officially declared unrefined pyrolysis liquids safe for the environment, there is a small risk that misuse could have deleterious effects to aquatic ecosystems if used in excess. This is due to the low percentage of toxic substances that may be found in some pyrolysis liquids such as poly aromatic hydrocarbons (PAH) and benzene (Souza, Re-Poppi, & Raposo, 2012).

In 2014 a trial was established to confirm the levels of these organic compounds, such as benzene and Total Petroleum Hydrocarbons present in the raw pyrolysis liquid. This was carried out at the continuous biomass converter demonstration site at Vales Point power station, where the pyrolysis liquid could be disposed in the existing ash dam.

To simulate the annual pyrolysis liquid production to be added to the outflow from the ash dam, 0.05% of pyrolysis liquid was mixed with ash dam water in 20 L containers and left exposed to atmospheric conditions for 30 days.

Table 6:3 shows the calculated levels of BTEX (Benzene, Toluene, Ethylbenzene and Xylenes) and Total Petroleum Hydrocarbons (covering the C6 to C36 fractions) in the ash dam water at steady state, based on the
experimental results, modelling of ash dam flows and volumes, and the half life of the organics (see discussion below).

Various regulatory guidelines for organics are also shown. (All values are in µg/L). The ash dam water with pyrolysis liquid additions meets these guidelines.

- ANZECC trigger values for marine water, 99% level of protection of species
- ANZECC trigger values for freshwater, 99% level of protection of species
- Guidelines for Assessing and Managing Petroleum Hydrocarbons Sites in New Zealand; Tier 1 Ground Water Acceptance Criteria, potable water
- Guidelines for Assessing and Managing Petroleum Hydrocarbons Sites in New Zealand; Tier 1 Ground Water Acceptance Criteria, irrigation water
- Guidelines for Assessing and Managing Petroleum Hydrocarbons Sites in New Zealand; Tier 1 Ground Water Acceptance Criteria, stock water
- Sewer Disposal Pollutant Limits NSW; Oil and grease

Table 6:3 Organic compounds in the continuous biomass converter pyrolysis liquid in ash dam outflow water

<table>
<thead>
<tr>
<th>Organic Component</th>
<th>Calculated Steady State Composition of Ash Dam Outflow Water (µg/L)</th>
<th>Regulatory Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene</td>
<td>0.13</td>
<td>10</td>
</tr>
<tr>
<td>Toluene</td>
<td>0.07</td>
<td>800</td>
</tr>
<tr>
<td>Ethylbenzene</td>
<td>&lt;2</td>
<td>300</td>
</tr>
<tr>
<td>meta&amp;para-Xylene</td>
<td>&lt;2</td>
<td>140</td>
</tr>
<tr>
<td>ortho-Xylene</td>
<td>&lt;2</td>
<td>200</td>
</tr>
<tr>
<td>Total Xylenes</td>
<td>&lt;2</td>
<td>600</td>
</tr>
<tr>
<td>Naphthalene</td>
<td>2.9</td>
<td>50</td>
</tr>
</tbody>
</table>

| TPH                |                                                               |                 |
|--------------------|                                                               |                 |
| C6 to C9           | 11                                                            | 18,000 |
| C10 to C14         | 204                                                           | 350 | 1,800 | 4,000 |
| C15 to C28         | 44                                                            | 5,300 |
| C29 to C36         | <50                                                           |                 |
| C10 to C36 sum     | 259                                                           | 50,000 |

Note. Adapted from Robert Carr and Associates P/L 2014

This is not simply a question of dilution. The organics in the pyrolysis liquid can be expected to degrade through the effects of sunlight, oxidation, chemical reactions and biological degradation. In order to demonstrate this and establish the half-life of these organic species, a trial was conducted using
concentrations 100 times higher and leaving them exposed to the atmospheric elements for an extended time period. This allowed for more accurate analysis of the half-life of the individual organic species. Figure 6:1 and Figure 6:2 summarise the measurements with all the organics reducing quite rapidly in concentration, with half-lives in the range of 4 to 14 days. This clearly confirms that the organics in the pyrolysis liquid are not persistent chemicals and can be treated as biodegradable.

Figure 6:1 Measurements of half-life of BTEX and Naphthalene organic species in pyrolysis liquid after exposure to atmospheric elements for 30 days
Figure 6.2 Measurement of C6-C36 fraction of organic species in pyrolysis liquid after exposure to atmospheric elements for 30 days

6.6 Summary

The continuous biomass converter will produce approximately 4000m3 of pyrolysis liquid per 10 000 tonne of biomass. The liquid is unique to this pyrolysis system creating a third output, together with char and gas to be monetised.

This large water-handling requirement will be an important consideration when designing a plant. Many of the components of pyrolysis liquids are important for bio-processing and can be used in a multitude of ways. The liquid produced will be in a raw form and may need further processing as most of the pyrolysed liquid use in industry and agriculture have focused on the water based component after it has been separated from the tar and oils. This ‘middle layer’ is the predominant constituent of the CBC pyrolysis liquid.

Although pyrolysis liquids are fundamentally made up of the same components, different biomass sources yield different acid types. For example, Ratanapisit, Apiraksakul, Rerngnarong, Chungsiriporn, and Bunyakarn (2009), demonstrated rubber wood yielded higher methanol levels than other woods. The literature review demonstrates a variety of biomass sources have been
tested for a number of different agronomic effects and shown to be a cost effective tool to facilitate plant and soil health. The historical use of different pyrolysis liquids, across multiple cultures signifies that it is a product of value. Therefore matching the pyrolysis liquid use to a specific valuable end product will be the challenge and the opportunity.

Biomass as a source of renewable energy and non-persistent agri-chemicals is important for the transition to a sustainable bio-based economy. Pyrolysis liquids are often homemade ‘green’ pesticides where the chemical components, application rates and techniques vary from farm to farm. They are not regulated like industrial pesticides that must be registered for specific uses on specific crops with legally binding safety and withholding periods. With over 38 000 chemicals in use in modern agriculture, many which have not been tested for health, safety and environmental risks (Australian Government Department of Health), there is likely to be some capacity where pyrolysis liquids can help build ecological resilience without the environmental persistence of many agri-chemicals.

There is considerable variation in the rate and style of application of pyrolysis liquids and no consistent commercial dilution and application rates as prescribed for registered chemicals. Reports suggest that strong dilutions are usually used as a pesticide/fungicide, while weaker dilutions are applied as a plant growth stimulant or soil conditioner. This variation and diversity of application will likely place challenges on registering pyrolysis liquids as an agricultural or veterinary product by the Australian Government. Australian Pesticides and Veterinary Medicines Authority APVMA). Registrations of chemicals refer to specific uses and the above review indicates those options are vast.

From The Natural Step’s ‘Backcasting’ point of view ‘the systemic accumulation in the biosphere of industrial substances foreign to nature’ will be curtailed and stopped only when sustainable systems are in place. Pyrolysis liquid may help facilitate damaged ecologies because it is a non-residual tool to help break the cycle of toxic substances accumulating in the biosphere. Toxic substances need to be managed in closed loops, or phased out rather than recycled. Although there may be toxic substances present in pyrolysis liquids, these are organic-based biodegradable molecules.
Muswellbrook LGA has large areas of degraded land due to coal mining where ongoing salinity management is required and biodiversity loss and soil structure needs repair. Integration of a continuous biomass converter needs to build on industrial ecology, and the local and regional ambitions of the community, in collaboration with the normal business profile. Therefore developing a fully integrated ‘closed loop’ production and consumption system to produce and manage enough biomass for the life of a project requires defining the use for all products.

Could there be a local market for the pyrolysis liquid direct from the plant site in its raw form? Could it be used advantageously on Hunter Valley soils? With these questions in mind it was decided to conduct an experiment using both biochar and raw pyrolysis liquid to test its impact on local soils. These experimental investigations are described in the next chapter.
CHAPTER 7  EXPERIMENTAL INVESTIGATIONS

“We delight in the beauty of the butterfly, but rarely admit the changes it has gone through to achieve that beauty.” – Maya Angelou

7.1 Introduction

This chapter examines biochar and pyrolysis liquid in soil. While research has shown a myriad of uses for biochar and pyrolysis liquids, these products produced by the continuous biomass converter have not been applied to soils to test their agronomic effects, either singularly or in combination. To get some practical experience with these two outputs for use in the study area for either agriculture or mining rehabilitation, an experiment was established to test agronomic effects and establish potential dosage parameters for future trials.

The testing of biochar’s agronomic effects have primarily been conducted via greenhouse pot trials (Biederman & Harpole, 2013; Jeffery et al., 2011). Most field trials have been carried out in tropical and semi tropical soils (Hammond et al., 2013; Lehmann & Joseph, 2009a), in Indonesia on volcanic ash loam (Ogawa & Yamabe, 1986) in Colombia on savanna oxisol (Major, Rondon, Molina, Riha, & Lehmann, 2010), on Brazil’s Zanthic ferrosol (Steiner et al., 2007) and in Kenya on ultisol soils (Kimetu et al., 2008). The field trials in the UK have tested wood biochar on different soils in their temperate climate, in areas with high rainfall. In Australia, most biochar field trials, testing an assortment of feedstocks have been conducted on semi tropical ferrosols in New South Wales (Van Zweiten, Kimber, Sinclair, Chan, & Downie, 2008) and in the Western Australian wheat belt on Haplic Xerosol, a sandy loam (Blackwell et al., 2007).

In the Upper Hunter Valley soils vary from alluvial to black cracking types. Therefore testing TCG’s biochar and pyrolysis liquids in conditions specific to the region’s soils and weather conditions was necessary to evaluate possible local applications. Two important industries that could utilise these products as soil amendments, agriculture and mine rehabilitation sites, have diverse soil foundations and structure. To start the assessment process it was decided to conduct the first trial on farmland. This fits the thesis’s strategic interest in developing future sustainable land management systems, and accepts
government directives that present mined lands will undertake some agricultural activity in the future (NSW Department of Mineral Resources, 1999).

The literature review on pyrolysis liquid field trials as described in Chapter 6 revealed the manufacture of the liquid applied in research trials was usually made from small pyrolysis kilns, where consistency of product is unlikely due to variations in temperatures reached during pyrolysis. The CBC technology will produce 400 litres per tonne DW biomass of pyrolysis liquid. The chemical characteristics will vary according to the biomass feedstock but the process will produce a consistent product.

Research has analysed the effectiveness of pyrolysis liquid for:

- improving soil biology (Mungkunkamchao et al., 2013; QuanYuan et al., 2009)
- influence on soil organisms (Steiner et al., 2008)
- as a pesticide, herbicide, fungicide (Jung, 2007; Yoshimoto et al., 1994)
- growth promoters (Kadota & Niimi, 2004; Yatagai & Unrinin, 1989)
- germination (Mu et al., 2003)
- anti-viral properties (Marumoto et al., 2012)

This thesis maintains that pyrolysis liquid is a valuable, yet undervalued product that is unproven for many agricultural applications outside small local farming use. Therefore defining applications and dosage will be essential to build confidence in the product.

There is also no agreed preferred application rate for biochar in general, although higher plant nutrient availability and nutrient retention have been proven with the addition of biochar, indicating high volumes can be beneficial in some instances (Glaser et al., 2002). But will biochar be of use in a well-structured fertile rudosol soil? Will it help grow more or better quality plants? Or will the best application for biochar in the region be on the poor structured soils in coal mine reclamation zones?

Soil and vegetation damage to the original above and below ground ecosystem caused during the mining process can be extreme. Mine rehabilitation sites often have low pH values and poor structure which can limit root development
and the establishment of plants (Shrestha & Lal, 2007). Rebuilding soils during rehabilitation depends not just on the original elemental availability of nutrients but also on the germination, establishment and management of pastures and trees on the rehabilitated land (Akala & Lal, 2001).

Significantly, Smernik (2009) reported that the movement of organic compounds may be assisted by biochar in disturbed soils. This could be the most important benefit of biochar in these soils because the loss of soil organic carbon (SOC) can be a limiting factor during mine rehabilitation (Akala & Lal, 2001; Eswaran et al., 2001).

While nature will eventually recolonise the disturbed land, primary succession on raw substrates can take centuries to complete (Bradshaw, 2000). Time, climate, soil characteristics, vegetation and management will ultimately define the rate of SOC sequestration once rehabilitation begins. Biochar and PA are amendments to aid the effectiveness of soil rehabilitation. Harley (2010) noted there were no examples of biochar used in mine reclamation to confirm an overall improved ecosystem function with biochar. As Table 7:1 shows the limiting factors impacting on mine rehabilitation can be divided into three core categories, physical, nutritional and toxicological, each area with unique problems. The data in Table 7:1 supports the hypothesis that biochar could assist soil function on mine sites because the biochar literature has already proved there is a positive interplay between biochar particles, plants and soil that contributes to microbial habitat and increase CEC of soils. Therefore biochar with or without PA could influence mine affected soils across the three areas of concern, physical characteristics, nutritional availability and soil and water quality via toxicological concerns.
To start getting some experience in both farming and coal mine affected lands in the local area, a two-hectare coalmine rehabilitation trial to test both biochar and pyrolysis liquid in situ has been planned. This trial had to be postponed due to delays in the rehabilitation schedule of the mine in response to the downturn in the market. Meanwhile the farm field trial was carried out to test above ground biomass growth impacts using pyrolysis liquid and biochar.

### 7.1.1 Biochar and Pyrolysis Liquid Farm Field Trial Design

The objective of this preliminary study was to quantify the responses of hardwood biochar and pyrolysis liquid (PA) amendments to an organically managed sandy loam, Stratic Rudosol, agricultural soil growing cowpeas, *Vigna unguiculata v. Red Caloona*. The trial was used to compare above ground biomass volumes and determine if there was a response of biochar addition to crop yield; a response to PA; and, or, an interaction between PA and biochar. This randomized field trial was undertaken during the summer of 2012-13.

Cowpeas grown in Australia during summer are usually used for animal feed, green manure crops, or converted into hay or silage and used as mulch for weed control. This leguminous plant has been an important crop in developing soil fertility via its nitrogen fixing capacity in sustainable farming systems (Njoku & Muoneke, 2008). However, most cowpea crops grown in the world are a versatile human food consumed as a green leafy vegetable, as well as a green...
and dried bean. As this crop was grown for cattle fodder the focus was on measuring above ground biomass growth, the crops' nutritional leaf and dried bean potential was not evaluated.

### 7.1.2 Study Location

The experiment was undertaken on Elmswood Farm, Gundy, New South Wales, 31°59.273'E. 151°00.335'N in the region of the Upper Hunter Valley. The Paddock is referred to as River Flat No 1. The previous crop on this site was a mixture of annuals, native perennials and the summer dominant couch grass, *Cynodon dactylon*. Although the plot was not lasered to ensure a low gradient to ensure good water drainage, it was visually flat. Annual district rainfall is estimated to be 620mm.

The pre-treatment soil on the site recorded a pH 6.7 (neutral), total organic carbon (TOC%) 1.18, bulk density (t/m$^3$) 11.41, moisture content (MC%) 9, gravel material (>2mm) 16%.

### 7.1.3 Experimental materials

Biochar was produced in 2012 by TCG at the Vales Point CBC demonstration plant. The biomass feedstock was hardwood shavings, a residue from sawmills in coastal New South Wales, north of the Hunter Valley. The application rates of 5 t/ha and 10 t/ha biochar were chosen because it was expected to be of sufficient volume to record a difference in cow pea growth and also because these volumes could be affordable if applied commercially.

The literature review showed that pyrolysis liquid is often diluted from between 1:100, to the weaker 1:1000 solutions, which is considered strong enough to create a biological response to improve soil biology (Burnette, 2010). While the pyrolysis liquid has the same acid profile as most of the small kiln types, there are less organics. It is thought that the continuous biomass converter process breaks down more of the tars thus creating a lower organic fraction in the liquid product. If this is correct, the pyrolysis liquid application to soil could be tolerated at a much higher dosage. Considering this, the liquid was diluted 20:1. This provided a strong dose and enough volume to ensure uniform spraying over the soil of each plot.
Choi et al. (2009) suggests that the strength of a dilution can dictate the use of the pyrolysis liquid with strong dilutions for pesticide use and weaker dilutions facilitating development of soil biology.

(In the lead up to field trial, 100 % strength of PA was sprayed on couch grass, until it was thoroughly wet, around the steel posts at the site. The grass was temporarily killed. Further local experiments suggested that when used at 100 % strength plant kill at 2 leaf stage occurred, but at 4 leaf + stage there was an inconsistent response. It is beyond the scope of this thesis to further consider high strength pyrolysis liquid as a weed killer.)

7.1.4 Experimental methods

A randomised design was selected using 6 treatments and 4 replications.

(PA = Pyrolysis liquids and refers to the pyrolygneous acid component of the liquid)

A. Control
B. Biochar @ 5 t/ha
C. Biochar @ 10 t/ha
D. PA @ 200 ltr/ha + Biochar @ 5 t/ha
E. PA @ 200litr/ha + Biochar @ 10 t/ha
F. PA @ 200ltr/ha

Each plot was measured 4X4 metres and allocated to randomised positions as seen in Figure 7:1 Twelve plots were located on each side of a four metre pathway. Around the outside and central pathway, slashing was undertaken to facilitate access, control weeds and limit shading.

```
C F C D E D D E A B B C
PATHWAY
E A B F D C B A A F F E
```

Figure 7:1 Cowpea Field Trial Layout
7.1.5 Crop management

Paddock preparation began in July 2012, under Australian Certified Organic - Biodynamic approved methods (Australian Certified Organic). No artificial fertilisers or chemicals had been used on the paddock since 1986. Cattle and sheep grazed the area prior ploughing to a grass height of 20cm. On October 27th, 2012, animals were removed from the paddock and locked out of the trial area.

The paddock was scarified using an Agrowplow AP10, (7 tynes mounted on a 100x100x6mm frame) to an approximate depth of 30cm in both directions on 4th November 2012. Weeds were allowed to die naturally and a few days later the whole area was diamond harrowed to create a smooth seedbed. No added fertiliser was applied to the soil or crop.

The amendments were all measured and spread on top of the soil by hand on December 8, 2012. The pyrolysis liquid was sprayed after the biochar was spread using a back-pac with a hand pump. The cowpeas were planted the following day, December 9, using a Caldow SA-11 Grasssliner seeder and planted at a rate of 10 kg/ha. The cowpeas were not inoculated.

Immediately after sowing, the crop was irrigated using 10 inch aluminum pipes providing 1ML/ha water from the unregulated Pages River. (Note that ‘unregulated’ refers to the river not being managed by a dam. When there is <1 ML/Day, irrigation is banned. This is called ‘cease-to-pump.’) Three weeks later the crop was again irrigated with 1ML/ha. In the middle of the trial the Pages River became subject to a cease-to-pump order prohibiting the crop from being fully irrigated to maximize development.

7.1.6 Data collection

The above ground biomass was hand harvested on two separate areas twice. The first harvest was undertaken and expected to be the only harvest as the weather indicated the crop had reached its maximum biomass phase and was starting to set seed. A 50cm square frame was used to randomly harvest each plot. The cowpeas were not separated from the weeds. The weights represent total above-ground biomass growing in the quadrant, including all weeds, in the order of 10 per cent. The crop was cut to stubble of 10cm.
The first sample was carried out on February 17, 2013.

Shortly afterwards there was substantial rainfall and it became apparent the crop was reviving. It was decided to continue the trial and conduct a second harvest, on a different section of each plot on March 6, 2013.

Volumes were weighed on site. Fresh weights were converted to a tonnes per hectare basis (10,000m²=1 ha).

Dry weights were measured the following day using the NSW DPI microwave technique for drying which is the common technique used by hay farmers. Wet weight samples were measured, dried at 60-90 °C for 48 hrs or until weight stopped falling.

The trial was managed in two stages to reflect the different weather conditions. Sampling was conducted twice, midway and at the end. This was because the first phase was in drought conditions and the second phase quite wet. Mean volumes were compared using a 2 factorial ANOVA model to examine the effect of the addition of pyrolysis liquid and biochar and their potential interaction. No allowance has been made for multiple dependant variables.

Statistical analysis was undertaken using JMP (Version 11.0 SAS Institute Inc, 2012).

7.1.7 Results and Discussion

The experiment was characterised by changing weather conditions with November and December 2012 being exceptionally dry.

Bureau of Meteorology data from the Scone weather station, the closest official measuring station to the field trial, approximately 21 kilometres away, registered temperatures as high as 44.2 with evaporation exceeding rainfall in November and December. Although cowpeas are considered drought tolerant, erratic death of some plants was observed while weeds germinated and thrived in the crop.

At the first sampling, February 17, cowpea growth was at an estimated 10% flowering capacity. Renewed plant vigour suggested a second sample alongside the original sample would provide a valuable comparison and was conducted
March 6. Mean fresh weights for both periods and mean dry weights for both periods were examined.

The crop endured extreme heat during its growing phase with renewed vigour during the last 10 days of growth. Between February 21-March 3, 2013 there were 10 days of precipitation, with variations between .2mm to 33mm. This was an intensive warm moist growing phase after the first sampling was conducted.

Controlling for differences in drought and wet conditions, for fresh crops, pyrolysis liquid had no effect but biochar had a significant effect \(F=11.5606 \ p<001\) as did their interaction \(F=3.749 \ p=.0273\). This was because mean yields from the crop with 5 t/ha biochar and pyrolysis liquid was slightly lower than 5 t/ha biochar without pyrolysis liquid \[\text{diff} = 5.78 \ 95\% \text{CI} (0.05, 11.50)\], but the reverse was shown with 10 t/ha biochar. Mean yields from the crop with 10 t/ha biochar and pyrolysis liquid appeared the highest, and were significantly higher than with pyrolysis liquid and no biochar \[\text{diff} = 6.49, \ 95\% \text{CI} (0.76, 12.21)\] and pyrolysis liquid and 5 t/ha biochar \[\text{diff} = 10.03 \ 95\% \text{CI} (4.30, 15.75)\]. This means pyrolysis liquid had a negative effect at 5 t/ha biochar level, and a positive effect at the 10 t/ha biochar level, controlling for drought and wet conditions.

Similarly, controlling for differences in drought and wet conditions, for dried crops, pyrolysis liquid had no effect but biochar had a significant effect \(F=15.7191 \ p<.001\), and their interaction was not significant. Again, crops with pyrolysis liquid and 10 t/ha biochar appear to have the highest yield, though the addition of pyrolysis liquid did not make a significant difference. Yields from crops with 10 t/ha biochar were significantly higher than both crops with 5 t/ha biochar \[\text{diff} = 2.88 \ 95\% \text{CI} (1.43, 4.31)\] and 10 t/ha biochar \[\text{diff} = 3.00 \ 95\% \text{CI} (1.56, 4.44)\]. Addition of 5 t/ha biochar made no difference to the mean yield compared to no biochar.

This could have been because more water had already been applied with the pyrolysis liquid prior to irrigation and rain or because the extra soil moisture activated the treatments and further diluted the pyrolysis liquid. Either reason indicates that the pyrolysis liquid application did not harm plant growth and the pyrolysis liquid strength was not a problem. No other signs of plant stress,
other than drought were observed. Although there were two sample periods, the trial was continuous. The second sample measured the total growth over the two stages of the trial.

Table 7:2 Full results of Cowpeas Sampling

<table>
<thead>
<tr>
<th>Plot</th>
<th>Treatment</th>
<th>FW (tonnes per ha)</th>
<th>DW (tonnes per ha)</th>
<th>FW (tonnes per ha)</th>
<th>DW (tonnes per ha)</th>
<th>Biochar</th>
<th>Pyrolysis Liquid (PA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>A</td>
<td>35.2</td>
<td>11.2</td>
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<td>26.8</td>
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<td>43.2</td>
<td>10.8</td>
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<td>0</td>
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<td>20</td>
<td>A</td>
<td>26.2</td>
<td>9.2</td>
<td>47.2</td>
<td>10.8</td>
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<td>26.4</td>
<td>9.6</td>
<td>41.6</td>
<td>10.4</td>
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<td>0</td>
</tr>
<tr>
<td>10</td>
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<td>31.6</td>
<td>10.8</td>
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<td>10.1</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>11</td>
<td>B</td>
<td>32.1</td>
<td>10.8</td>
<td>41.2</td>
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<td>C</td>
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</tr>
<tr>
<td>4</td>
<td>D</td>
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<td>1</td>
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<tr>
<td>6</td>
<td>D</td>
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<tr>
<td>7</td>
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<td>25.6</td>
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</tr>
<tr>
<td>17</td>
<td>D</td>
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<td>5</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
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<td>9.2</td>
<td>48.4</td>
<td>18.4</td>
<td>10</td>
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</tr>
<tr>
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<tr>
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<td>1</td>
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<td>40.4</td>
<td>9.6</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

For the trial as a whole, covering both stages of growth, the maximum yield was with treatment E, the combined application of char (10 t/ha) and pyrolysis liquid (200:l/ha), as shown in Figure 7:3.

Therefore, while the 10 t/ha biochar + pyrolysis liquid addition looks different there was no significant difference due to the addition of pyrolysis liquid. The difference in yield is likely to be due to the addition of biochar.
As Figure 7:2 shows, the average growth of biomass during the dry spell (17/2/2013) was fairly uniform with little difference in growth performance for all treatments, although the maximum growth recorded during this period was the combined application of char (10 t/ha) and pyrolysis liquid (PA) (200L/ha). At this stage the difference is quite small and not statistically significant to the control. In a water depleted area, it looked like nothing was very different. Moisture was likely to be the limiting factor.
By the time the trial was finished, bigger differences between the various treatments had occurred. Figure 7:3 shows the results from the second sample (6/3/2013) after rain where growth increases were substantial. The ANOVA statistical analysis showed the biochar at 10 t/ha to have made a significant difference while the pyrolysis liquid (PA) did not.

This suggests that under normal agronomic conditions where the weather can dictate final success, a biochar addition of 10 t/ha can increase biomass volume during periods of dry and wet conditions. This is important for land managers who adjust crop harvest management and the final end use: for instance, a failing crop can be used for animal feed in situ, converted to hay, ploughed back into the ground providing organic matter, or left as a ground cover and soil protector. These results are relevant when considering Australia’s dry agricultural conditions where extreme weather events and rainfall unpredictability have increased. Bureau of Meteorology records from Scone during the last ten years have recorded dry, hot summers, which in turn inhibit dryland summer pastures and crops.

The results confirmed the continuous biomass converter’s pyrolysis liquid can be tolerated at higher dilutions than pyrolysis liquids made via small kiln...
production where tar and other organic ingredients may be present at higher concentrations and therefore require more dilution.

7.1.8 Field Trial Conclusion

Because of its embryonic nature, the slow pyrolysis industry needs to build confidence in the products produced. This preliminary trial has provided insight into local opportunities for biochar and pyrolysis liquid. By the end of the trial, the pyrolysis liquid and char behaved differently under moist and dry conditions. In terms of statistical differences only the 10 t/ha biochar treatment was significant.

This trial, grounded in the Tom Farrell Institute, Newcastle University’s mission to develop ‘regional solutions for a sustainable future’ led to discussions with Muswellbrook Coal Company (MCC). It was decided a research project across two hectares of mine rehabilitation would be carried out to further study biochar and pyrolysis liquid application. This would enable both amendments to be tested across the two types of soils in the region.

(Note. After the cowpea field trial was concluded (Lashari et al., 2013) investigated poultry manure biochar and a pyrolyzine solution specifically to test the effects on the salinity of Entisol soil in Central China. Poultry manure biochar, a mineral rich biochar, was applied at 12 t/ha, together with pyrolysis liquid 0.15 t/ha. This is a different treatment than used in this thesis’s trial, albeit at quite similar application rates. It is interesting to see these products specifically tested for salinity reduction. The trials recorded wheat production over a two year cropping cycle and found salinity and pH readings were lowered, especially after the second year. This is a promising result for the salinity issue confronting the Upper Hunter Valley.)

7.2 Biochar and Pyrolysis Water Rehabilitation Pot Trial

In preparation for the rehabilitation trial at Muswellbrook Coal Mine soils were collected on site and tested for fundamental characteristics.

During the winter of 2013, these soil samples were used to conduct a pot trial to investigate the most beneficial application rates of biochar and pyrolysis
liquid for the rehabilitated soil profile (N Herbertson, personal communication). White clover, *trifolium repens* was used as the test crop.

Results showed a positive indication that char and pyrolysis liquid additions to MCC rehabilitation soils could improve germination, plant growth and some soil properties. There was a clear trend showing germination rates improved with char additions with all results being higher than the control. Of particular interest was the high germination rates using biochar but the opposite trend towards germination with the pyrolysis liquid additions, indicating if they are too high there may be a negative affect on germination. Therefore keeping the dilution lower would seem most beneficial.

The increase in soil carbon was in direct relation to the amount of char added. There was no apparent effect from biochar on the plant available phosphorus (P), but of particular interest was that the increase in P availability was statistically higher than the control when pyrolysis liquid was added.

To explore the strength of dilution of the pyrolysis liquid, it was increased by one third to test effectiveness, as well as low dilutions. As these treatments were mixed with reclaimed soil, it was also considered important to test higher volumes of biochar to determine if there were any plant or soil improvements.

The pyrolysis liquid (PA) plus biochar provided the best plant growth. This pot trial confirms the likelihood that both pyrolysis liquid and biochar can be used facilitate soil health and plant growth and that the continuous biomass converter’s pyrolysis liquid is effective at higher dosages. However, there is still inconclusive evidence that pyrolysis liquid is beneficial over and above the effects of the biochar.

### 7.3 Summary

These preliminary trials, the biochar farm field trial and the mine rehabilitation pot trial, have helped build the practical experience needed to better understand biochar rates and pyrolysis liquid dosages. The field and pot trial helped confirm a Muswellbrook Coal Company rehabilitation field trial design where three treatments will be analysed:

- Standard MCC rehab mix (control)
Char addition, at the rate of 10 t per ha

Combined char at the rate of 10 t per ha + pyrolysis liquid addition at 2L per ha

As mining and farming are carried out at the same time and alongside each other across the region it has been important to examine both industries to understand what the best applications are and where the best place to start is. A biochar-based slow pyrolysis industry will develop where the demand is deemed strongest.

The options for using both pyrolysis liquid and biochar in the region have been explored and provide a promising start to the utilisation of these products for sustainable agriculture and regenerative land practices in the Hunter. Whilst the use of pyrolysis liquid is established in Asian agriculture, the market is small in Australia. If a biochar-based industry is to emerge in the region it will depend not just on the technology, but also the geography, the local business community, social perspectives and especially the need for the products.
CHAPTER 8 DISCUSSION

“The fuel of the future is going to come from fruit like that sumac out by the road, or from apples, weeds, sawdust – almost anything.” Henry Ford, New York Times 1925

8.1 Introduction

This chapter brings together the opportunities and constraints regarding early adoption of the continuous biomass converter technology and how Muswellbrook could integrate slow pyrolysis into its existing energy sector and live up to the town’s corporate motto ‘bursting with energy’ in more sustainable ways. Muswellbrook has a history of radical land use change beginning in the early 19th century when the area was first cleared, native vegetation removed and introduced species became dominant with the first phase of agriculture. Subsequently, mid 20th century to the present saw the development and expansion of open cut coal mining. During both phases significant negative impacts to land and water use occurred (Story et al., 1963). Inevitably a new land use change phase will emerge as the coal industry restructures and eventually ends. This will largely be a land-repair stage and in a policy and legislative framework, will hopefully recognise soil’s capacity to draw down atmospheric carbon as part of our climate change mitigation responsibilities. It is a move away from the extreme disturbances caused by mining and the subtle ecological damage caused by agriculture.

The sustainability methodology used in this thesis, as described in Chapter 2, is primarily based on The Natural Step (TNS) framework with its five-level hierarchy and backcasting approach. The previous chapters have outlined the case study area, the historical evolution of land and water use. These ideas constitute the boundaries of the existing system in Muswellbrook and represent Level 1 of the TNS (the system).

Defining a sustainable vision for Muswellbrook LGA, identifying existing biomass resources and introducing slow pyrolysis technology concepts with its input requirements and output supplies is Level 2 of TNS (principles of sustainability). These earlier chapters represent the first two steps in backcasting from success; Step A (vision) and Step B (current reality).
This chapter addresses the strategies and actions needed to achieve the vision and represents Level 3 (strategies) and Level 4 (actions) in TNS hierarchy. This includes the technical strategies and the process principles that will underpin the transition to more ecologically sustainable development. Thus this chapter, together with Chapter 7 Experimental Investigations, represents the next two backcasting steps. Step C (future options) and Step D (pathways).

These will be discussed within the framework of three themes.

Environmental Sustainability
- The sustainable parameters, including land, water and social implications.

Economic Sustainability
- A financial assessment based on core assumptions at market prices during 2014, post removal of the carbon tax.

Technology Adoption
- Requirements to get to stage one of the commercialisation of this new technology.

Only after these three challenges are met and new industry systems and protocols established can the tools needed for monitoring and reporting progress Level 5 (metrics) be fully defined. Therefore this chapter does not address metrics.

8.2 Environmental Sustainability

The sustainable vision for a future Muswellbrook area throughout this research accepts that in the past humans have damaged the regional ecology to a very significant extent as a result of operations in agriculture, mining and energy. Before white settlement there was no chemical intensive agriculture because Indigenous farming was conducted at a local level using water and fire as the main tools. Previous government support for clearing the riparian zone along the major river, the Hunter, and most of its tributaries, building dams, diverting streams and over allocating irrigation licenses have led to decreased river health. Government support, funding and institutional arrangements also established and oversaw the present coal based energy
sector and its water usage and management plans. In addition major secondary infrastructure investments such as port facilities, rail and road services have been built with public and private funds to service these sectors. Such decisions have had unexpected and wide-spread consequences impacting on local land use and economies while supporting businesses with high carbon emission footprints.

The future is not and cannot be a return to the past. Therefore a vision for sustainable land management would be a new concept for both Australian agriculture and the energy sector. It will not be impacting on a virgin landscape. It is not a land restructure selectively rearranging healthy resources, because soils and riparian zones have been depleted and most are in need of added nutrients and improved soil structure to ensure production. Tools such as animals may also be needed to manipulate grasses and facilitate plant growth in areas. With water supplies decreasing, and environmental damage so complex the sustainable vision needs to be benchmarked not against the present reality but against a new agricultural paradigm integrated with the energy sector.

The burden of proof placed on renewable energy systems to meet sustainability criteria must recognise that resources are currently shared with many production systems that are not sustainable. It is unreasonable to expect renewable energy systems to carry all the costs and the burden of proof for the new vision. In the Muswellbrook area unsustainable systems are not only the coal and power sector but include carbon emitting agricultural practices. The latter includes overgrazing, chemical intense cropping, inefficient irrigation and the extensive unmeasured losses of biodiversity.

Figure 8:1 illustrates how a CBC plant within the study area can interact and support sustainable land practises and societal values. This presents a symbiotic relationship between the CBC and land use, where the land is the source of feedstock and the char and pyrolysis liquid have beneficial land applications. The gas, converted to electricity is a source of renewable energy. (A sustainable vision incorporates the concept that fundamental human needs are permanent needs, such as those defined by Max-Neef (1992). Subsistence, Protection, Affection, Understanding, Participation, Recreation, Creativity, Identify and Freedom are at the centre of building sustainable societal values.)
Figure 8.1 The Continuous Biomass Converter within a sustainable framework

The capacity for biomass sources to grow in volume will be improved if the ecology of the future resource base improves. Therefore while green waste is the immediate option as a biomass source, the future may also include other residues, waste streams and energy crops as the char and pyrolysis liquid enhance land use and further develop biomass resources in the region.

The components of understanding a sustainable vision include:

- Water use requirements and availability in the area
- The meaning of evolving land use changes
- Bioenergy within the Food Versus Fuel debate
- Creation of marginal land by agriculture
- Creation of marginal land by mining
- New ideas
  - Animals eating char and pyrolysis liquid
  - Energy crops
  - Genetically modified biomass
- Unique challenges for Muswellbrook
8.2.1 Water use requirements and availability in the area

The integration between water management and the energy sector is stark in the Hunter Valley. It involves factors such as the diversion of the headwaters of the Barnard River into the Hunter River system to secure more water, the building of multiple dams along the Hunter River to control water supply, over allocation of aquifers and unregulated feeder streams. The shift to a management strategy of regulated water access going to the highest bidder has meant that the energy sector has come to dominate water use in the Hunter River system. In the future, the inevitable decline of the coal-based energy sectors, both mining for export and local electricity production, will have direct flow on effects on water access and possible new uses.

While the concern of land use change is common when assessing sustainable bioenergy projects (Berndes et al., 2011; Plevin, O’Hare, Jones, Torn, & Gibbs, 2010), water use change is of equal concern in the Upper Hunter (Healthy Rivers Commission of New South Wales, 2002). Collectively the water management of the coal and power sector in Muswellbrook involves five coalmines with individual water management plans, plus two power stations, Liddell and Bayswater (now operated by AGL and formerly by Macquarie Generation). The latter is not just an on site management system, but an extensive integrated engineering project set up to ensure water security.
The water infrastructure developed over the years to maintain water security for two coal fired power stations is shown in Figure 8:2. The overall design includes the weir to access, via diversion, the headwaters of the Barnard River at the northern head of the Hunter River. This vast plan ensures AGL maintains 80% of its 72 000ML water access at all times. The volume of water needed is managed with dams and an array of different delivery systems reducing risk of any one particular water access failure. All licenses within the water package can be adjusted at any time. This extensive system demonstrates well the previous political commitment to energy security as this infrastructure was put in place when the power stations were under public ownership. The New South Wales government, in line with the trend across
Australian jurisdictions, no longer perceives its role is to be owner and provider of energy delivery (NSW Auditor-General, 2011). The evolving privatisation of energy assets, suggests that future energy security will be re-distributed, incorporating a suite of privately owned renewable energy providers (AGL Energy Ltd, 2013; Diesendorf, 2014; Reeves, 2011). Future power generation infrastructure is therefore likely to need and use less water as renewable systems increase their contribution. Hydropower is the only system dependent on large water inputs. The continuous biomass converter does not have high water needs for production. Therefore water access and water infrastructure as demonstrated in Figure 8:2 would not be required.

Water directly used in power stations to make electricity is one aspect of local water use. The other is the need to extract or manage water to mine the coal used in the power stations. Table 8:1 shows the variety of licences used by the 5 local coalmines and power stations. To give a sense of scale to this potential water availability for agriculture and biomass production, a lucerne or hemp crop requires 6ML per hectare. Therefore the 102 103 ML presently tied up in the energy sector could liberate enough water for 17 000 hectares of crops.

Table 8:1 Power and Coal Industry water use

<table>
<thead>
<tr>
<th>Power and Coal sector</th>
<th>Water Access Hunter River High and General (ML)</th>
<th>Ground Water (ML)</th>
<th>Water Storage (ML)</th>
</tr>
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<td>AGL</td>
<td>72 000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mt Arthur</td>
<td>7 938</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bengalla</td>
<td>1 000</td>
<td>125</td>
<td>642</td>
</tr>
<tr>
<td>Muswellbrook Coal</td>
<td>8 000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drayton</td>
<td>959</td>
<td></td>
<td>6 444</td>
</tr>
<tr>
<td>Mangoolla</td>
<td>4 996</td>
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</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>102,103 ML</strong></td>
<td>**664 **</td>
<td><strong>6 444</strong></td>
</tr>
</tbody>
</table>

*Note. Adapted from AEMR and Annual Reports (2012)*

Each mine is managed to its own specific water plan. It is common for the plans to be constantly adjusted. For example, Bengalla Coal Mine’s (BCM) 2012 Water Sharing Plan notes water seepage variations. All coalmines consume underground water during the process of mining and as a consequence water constantly seeps into the pits, both underground and open cut. The inflow predictions are assessed using special monitors. These seepages are licensed under Part 5 License (20BL169798) issued under the
Water Act 1912. BCM can use up to 125 ML/per year of this groundwater seepage from the coal seam and hardrock aquifers (Bengalla Mining Company Pty Ltd, 2012).

Water use variations are also influenced by the weather. As an example, Table 8:2 shows Mt Arthur Coal during 2012 did not need to pump water from the Hunter River even though it has a license to do so (McLaughlin, 2012). However this water was not available for reallocation to other industries to use and therefore the current licensing regime inhibits the development of other opportunities.

Table 8:2 Mount Arthur Coal Water Use (ML) 2012

<table>
<thead>
<tr>
<th></th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pumped from the Hunter River</td>
<td>0.0</td>
</tr>
<tr>
<td>Treated effluent from MSC</td>
<td>375.2</td>
</tr>
<tr>
<td>Rainfall and runoff captured from site</td>
<td>3,124.5</td>
</tr>
<tr>
<td>Groundwater reporting to open cut pits</td>
<td>210.0</td>
</tr>
<tr>
<td>Potable water</td>
<td>18.0</td>
</tr>
<tr>
<td>Total</td>
<td>3,727.7</td>
</tr>
</tbody>
</table>

Note. Adapted from Mt Arthur Coal Mine 2012 AEMR

Mine water balances in Table 8:3, show that at times water outputs can actually be higher than inputs.

Table 8:3 Mount Arthur Coal Water Outputs (ML) 2012

<table>
<thead>
<tr>
<th></th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHPP</td>
<td>2,302.1</td>
</tr>
<tr>
<td>Tailings and coarse reject</td>
<td></td>
</tr>
<tr>
<td>Product</td>
<td>66.6</td>
</tr>
<tr>
<td>Stockpile sprays</td>
<td>9.0</td>
</tr>
<tr>
<td>Water carts</td>
<td>1,248.0</td>
</tr>
<tr>
<td>Industrial area water use</td>
<td>531.8</td>
</tr>
<tr>
<td>Potable water consumption</td>
<td>18.0</td>
</tr>
<tr>
<td>Discharge under Hunter River Salinity Trading Scheme</td>
<td>87.5</td>
</tr>
<tr>
<td>Open water evaporation</td>
<td>511.7</td>
</tr>
<tr>
<td>Total</td>
<td>4,774.7</td>
</tr>
</tbody>
</table>

Note. Adapted from Mt Arthur Coal Mine, 2012 AEMR

Each mine is required to produce a final-void water balance model. This includes all projected inflows into the void lake, rainfall, runoff and seepage from the wall and surrounding catchment, plus seepage from groundwater and overburden infiltration. However the long-term behaviour of a final void’s inflow and outflow balance is unknown. Inflows are estimated based on water movement levels during the course of mining. For instance Mt Arthur’s 2012 prediction of groundwater inflows into their final void is estimated to be
1.4ML/day. How these flow rates will adjust during post mine recovery is likely to vary according to the water level. Therefore there is a risk of long-term soil water loss from mine disturbance.

As open cut coalmines expand the natural catchment area for water flow is reduced. The volume and flow of water draining into coal pits is likely to change as the design of the mines change. Therefore measuring water volume and quality while the mining sector is operating does not offer clear indicators of water volume and quality after mine closure. Water balance and final void design have become important issues during the New South Wales, Planning Assessments of mine approvals and modifications (Planning Assessment Commission, 2013). So the key questions are:

- Will there be more or less water for agriculture after the mining sector moves out?
- What will be the price of water?
- What will be its quality?

As shown in Table 8:4 Muswellbrook Shire Council monitors the quality of Hunter River water for the community and publishes a weekly report. While industry is the main user the same water supply is also required for municipal and recreation use. These water samples indicate Hunter River water suitable for primary contact use (i.e. swimming) has been as low as 12 per cent in 2009-10 and secondary contact (i.e. river sports such as fishing and canoeing) plus stock water quality was in 2011-12 at 78 per cent. Flow levels, heavy rainfall and flooding are largely responsible for increases in turbidity along the river. Flooding across mine sites adds to this problem. The fact that the river is unsuitable for primary use most of the time has changed the way the river is used by the general public. Ensuring a healthy river system for the future is challenged by so much soil disturbance due to mining along feeder streams of the Hunter River. No longer is the Hunter a ‘passively meandering gravel-bed river of moderate sinuosity and relatively uniform channel width’, as (Hoyle, Brooks, Brierley, Fryirs, & Lander, 2008) points out in a review of 8 kilometres of the Hunter River. It is officially classified as ‘disturbed’ (Department of Environment and Conservation NSW, 2004) and underdoing profound ecological changes.
Water management within the mining sector is extensive and must comply via numerous annual plans such as; Site Water Management Plan, Surface Water Monitoring Program, Site Water Balance, Surface and Ground Water Response Plan (Environmental Protection Authority; McLaughlin, 2012). However, the collective impact on river flow levels and health remains unknown as the management plans are primarily about monitoring actions and outputs not ecosystem impacts.

One issue that plagues the industry as coal profitably slides (2007 thermal coal price rose to >$100 per tonne, 2014 prices average $63) is the potential for mines to be locked in operational limbo and managed under a protracted ‘care and maintenance’ phase rather than be officially finally closed. This could hinder rehabilitation plans and limit future water availability. Environmental repairs need long time frames. For example, the government sponsored decisions along the entire Hunter river system for many decades (to remove woody debris, clear native trees and replace them with willows, enlarge channels that increased velocity) simply did not recognise the contribution that debris, trees and the curvature of the streams made to river health. It has been estimated that it will take >100 years for the Hunter River to regain its healthy resilience (Erskine & Webb, 2003). When considering water issues, it is clear we are presently nowhere near the sustainable vision.

In conclusion, while it is expected that in the future more water will become available for new industries, volumes and quality will not be fully understood until mine closure plans are defined and water requirements during the ‘care and maintenance’ phases are finalised.
8.2.2 The meaning of evolving land use changes

Gone are the days when agriculture meant simply providing basic food and fibre. Agriculture is a sector with an increasing number of purposes as well as the resource base from which we access health and nutrition. Food, nutrition, biodiversity goals of conservation, wild foods and ethno pharmacology concerns are all part of agricultural land use decision-making (Heywood, 2011).

Land use changes are not only local environmental issues but also part of global climate change mitigation. Land Use Changes (LUC) undertaken to reduce GHG emissions can be Direct Land use Change (DLUC) and Indirect Land Use Change (ILUC) (International Energy Agency (IEA), 2007) (Intergovernmental Panel on Climate Change, 2013). Most ILUC related emissions can be unobservable and its measurement ‘approximate at best,’ thus measuring GHG emissions from ILUC is highly uncertain with a very wide error band (Plevin et al., 2010). If the ILUC is the most uncertain component of GHG accounting a Net Displacement Factor (NDF), becomes hard to justify. Land displacement factors involve many subjective choices for all land managers. With so much variance should the full impact of ILUC including emissions be omitted from analysis of bioenergy and be assigned a value of zero? Presently those in favour of bioenergy place at the low end any negative impacts from ILUC while those opposed focus on the high end. With such disagreement neither can be proved correct (Plevin et al., 2010).

Over the last two decades agriculture in Muswellbrook was fragmented due to DLC and ILUC brought on by agricultural structural changes, commodity prices and the growth of the coal-mining sector. One of the biggest ILUC in the study area has been transfer of ownership from local farmers to mining companies. One coal mine can consume up to 20 farms with various agricultural activities such as dairying, haymaking, beef production, fat lambs, wool, grapes and vegetables. A different ILUC could improve this negative outcome.

Documents confirm the present Australian agricultural system is responsible for soil erosion, salinity, water misuse and over allocation, desertification and pollution (Erskine & Webb, 2003; Story et al., 1963; White, 1997). Why then
does land use change and bioenergy engender such resistance? If biomass can be produced cost effectively then the opportunity to improve agricultural land management could increase.

This dilemma of where to position LUC has focused attention on bioenergy biomass only being allocated to marginal and idle land where assumptions of ILUC can at least be low. But this argument omits the fact that whatever is grown anywhere uses resources of some kind. Just because an ILUC has occurred the end result may not be negative. If a bioenergy crop can be produced cost effectively then the opportunity to improve agricultural land management will be increased. An ILUC could advantage land management.

When GHG emissions are included in ILUC calculations they often reflect changes projected against the historical pattern of land use. In Australia this may mean inappropriate historical land use. These historical activities are an inadequate benchmark from which to judge change from the present situation and land use.

Bioenergy crops are expected to meet very high sustainability criteria to ensure they

- Improve carbon balances
- Preserve or improve biodiversity
- Efficiently use water
- Improve soil functionality

These are important consideration but the ability to carry out business and achieve these goals is not isolated from other current and competing land activities in the area. Rather than focusing on biomass destined for bioenergy as a LUC agent it perhaps should be viewed as a farm diversification option. A biomass crop could be grown at a different time to the main farm enterprise to minimise conflict of equipment or staff.

Countries such as Germany have found compatibility with bioenergy, where farm businesses have diversified, engaged with the energy sector and found compatible needs (Plieninger, Bens, & Hützl, 2006). Policies show that the different biomass plants and residues can be integrated into existing agricultural businesses across all land and soil types.
Unlike Australia, Germany’s over arching land use principle takes into consideration the fact that farms are multi purpose operations. If agricultural policies do not incorporate bioenergy needs, biomass supplies will remain destined to only being available from waste streams and/or grown and harvested on marginal ‘waste’ lands (Oxfam International, 2007; Pimentel et al., 1992).

8.2.3 Bioenergy within the Food Versus Fuel Debate

The current dominant industrial agriculture model with its dependence on fossil fuel inputs is unlikely to become the low emission industry needed for a sustainable future (Howden et al., 2007). Although agricultural productivity has increased during the past five decades because of improved plant varieties, fertilisers, irrigation systems, pesticides and herbicides, many farm practices have caused ecological degradation (Pretty, 1999). It is important that a biomass and char based system not become another problem but part of the solution.

Putting more pressure on already over stretched agricultural land has been a major concern when discussing biomass production (Bryan et al., 2008; Carneiro & Ferreira, 2012). However, this view assumes that the way we have been using agricultural land is good, sustainable and worth preserving. This is not necessarily the case. Land utilisation is best facilitated with appropriate machinery for the size of plot. When fossil fuel based energy reserves are considered, the long-term availability of fossil fuel based fertiliser and transport costs will be limiting factors for industrial agriculture. Labour remains an abundant resource globally and should be re-valued and not de-valued as is the case in industrial agricultural models (Pimentel, Berardi, & Fast, 1983).

The loss of soil carbon is not only an Australian problem. It occurs globally on all soil types and is the result of industrial agriculture practices outlined above (Pretty, 1999). Global research on industrial agricultural systems’ impact on soils indicates that soil organic matter and soil carbon are inevitably lost during intensive cultivation (Pretty, 1999). For instance wheat production on rich vertisols soils in New South Wales has led to 32% loss in soil organic carbon and an average 49% loss in mineralised nitrogen compared to native
grasslands and significantly lowered water stability (Chan, Hodgson, & Bowman, 1995).

Central to the Food versus Fuel debate is a narrative primarily about growing food crops for ethanol and diesel. It has been called ‘bio-fuelling poverty’ (Oxfam International, 2007), and a ‘crime against humanity,’ (Monboit, 2007; Ziegler, 2013) to grow food plants only to be converted to run vehicles. Pimentel (2007) also suggests biofuels are inefficient and that cost analysis by the ethanol industry is wrong. Attitudes to first generation biofuels are a hurdle to overcome when promoting the positive aspects of bioenergy. This reinforces the need for the industry to be integrated into the agricultural as well as the energy sector. Although slow pyrolysis is not a biofuel production system being part of the bioenergy sector means it faces the same sustainability questions and therefore can raise concerns about food security.

All people at all times wish physical and economic access to sufficient, safe and nutritious food to meet dietary needs and food preferences for an active and healthy life (FAO (Food and Agriculture Organisation of the United Nations), 1996). Australia is the world’s 14th largest food exporter and one of only 15 net exporters of food in the world, yet domestic food security has become an important political issue. In 2009-10 Australia’s food surplus, including produced and manufactured food was worth $14.2 billion. Our agriculture also grows the ingredients to build the nation’s biggest manufacturing sector – food manufacturing (DAFF, 2011).

Despite droughts and floods, Australian agriculture meets local needs and has developed as an export based industry. On average, 60-70% of total production is exported. Therefore domestic food security is unlikely to be threatened. (A high Australian dollar has been blamed for the ongoing decrease in exports of grain, meat and wine with the exception of sugar, which still enjoys a high commodity price).

The concept of food security is often calculated as part of national security (Falvey, 2010). When food security is a national security issue food should be grown as close as possible to where it is needed. Australian Agriculture does this with the sector spread across all states. Although the value of Australia’s agricultural production has risen, the percentage of GDP is decreasing and in
2009-10 was only 2.8%. Employment in agricultural is also down 12% over the past decade (DAFF, 2011).

While first generation bio fuels were food crops, primarily soybeans and corn, there was no measurable impact on feedstock prices. It was feared that biofuels would push the price of food up as it competed with natural resources. World Bank 2008 report suggested the main factor leading to a rise in food prices was the increase in land growing biofuels. Now that second generation, non-food crops are being developed, it is less likely that a global or national price rise threat will occur (Ajanovic, 2011).

Using land and water for any bioenergy project is not a simple land use conversion argument with simple direct land use change as discussed above. All land is not equal. Water supplies vary not only geographically but also seasonally, cyclically and in response to climate change. Furthermore food supply needs vary globally with trade and fashions in food are in constant flux. The main issue is, can the existing land and water supplies be sustainably managed to incorporate new demands and climatic trends?

For Australia food security is more about the level of engagement with the food security of the world. FAO figures indicate the world’s population is expected to be 9.1 billion by 2050 with 70 per cent of people living in cities. Most of this population increase is in under-developed nations. While it is estimated that Earth does have enough land to feed this number of people, it is unclear what and where food will be grown. The new resource base will be a multifunctional system where food, fibre, fuel, and carbon sequestration co-exist (FAO (Food and Agriculture Organisation of the United Nations), 2009). Designing this system will be conducted region by region. Accessing waste streams such as green waste or growing biomass in Muswellbrook poses no immediate threat to national food security and is unlikely to drive a rise in food prices.

Incorporating marginal land, idle land, less productive areas and opportunistic harvests could become a valid part of a biomass supply chain in the future (Tilman, Hill, & Lehman, 2006) and these same areas could be improved with char and pyrolysis liquids.

Bioenergy is viewed differently in the social sustainability prism with projects frequently being associated with the redevelopment of rural areas and in
particular jobs growth (Plieninger et al., 2006; Sims, Hastings, Schlamadinger, Taylor, & Smith, 2006). For this to happen though the concept and uptake of bioenergy needs to be embraced in sectors other than agriculture and energy if it is to achieve the social support it needs to thrive. The trade-off between food, fuel, carbon and fibre will be unique in each landscape. While food crops and second generation energy crops are the two biomass categories most under review, a third biomass supply of ‘high-diversity mixtures of plants grown with low inputs on agriculturally degraded land’ as described by (Tilman et al., 2006) could be applied to Muswellbrook.

Land use changes in Europe and the US due to the uptake of bioenergy have been described as ‘major’, over ‘short timescales’, (Dauber, Jones, & Stout, 2010), or ‘expanding rapidly’ (Campbell, Lobell, Genova, & Field, 2008) but these models are based on concerns with the use of first generation biofuels because these remain relatively easy to scale up. In Muswellbrook where rehabilitation is a major future task the focus would more likely be on the immediate energy use for the CBC gas, and local land use for char and pyrolysis liquid outputs. This could ultimately increase food production in the area not decrease it.

8.2.4 The creation of marginal land by agriculture

Reference to a ‘sustainable agricultural framework’ is very different to the present industrial agricultural system dependent on fossil fuels.

Industrial agriculture in this thesis means agriculture reliant on:

- the manufacture of synthetic fertilisers
- increasing farm sizes
- mechanisation
- increasing distance food travels to consumer
- reduction in soil carbon

A definition of sustainable agriculture on the other hand is:

- cyclical in its use of resources
- does not rely on synthetic fertilisers
- can be profitable at a smaller scale
• does not rely on ever increasing large scale machinery
• promotes local distribution first
• sequesters soil carbon.

Based on a broad acre approach, Australia’s industrial agricultural systems have focused on using large-scale mechanical equipment. It is allegedly science-based yet has degraded essential ecosystem services. This failed system is unlikely to provide us with a regenerative agricultural model. Industrial agriculture’s assumption about economies of scale is also questionable. Large farms can use more energy than smaller ones (Singh & Miglani, 1976). Estimations suggest industrial agriculture on average consumes 50 times the energy input of traditional agriculture (Jones et al., 2011).

Recognizing that industrial agriculture is not sustainable is the first step in appreciating that land management is multi-factorial and a farmer allocating some prime agricultural land to biomass production does not necessarily mean food production loss.

There is a growing literature on the value of small, traditional farms, where not only the economic value of production is included in assessments but also the cultural and ecological benefits (Joly, 2005; Schumacher, 1974; Tuomisto, Hodge, Riordan, & Macdonald, 2012). Evidence suggests small carefully managed farms are more productive, have fewer input costs and are often overlooked by politicians and agricultural planners in favour of ‘big farm’ policy. The opposing claim that productivity and technology gains will be able to deliver adequate food for the growing population remains the industrial agricultural mantra (Godfray et al., 2010B; Heywood, 2011).

Yet many Australian farms are already marginal businesses. Were it not for financial aid many would fail. Recognising the need to integrate industry within existing structures is important to take advantage of the local resources such as labour, technology, and surrounding infrastructure. Bioenergy may offer profit if it involves existing farms, effective capital investment and can utilise existing service industries.

The concept of marginal lands within the bioenergy debate can be viewed through two different lenses; a place to grow biomass and a place that needs
biochar and pyrolysis liquid to assist soil and landscape recovery. The literature often cites the view that the most sustainable land to grow biomass is ‘marginal’ land because ‘high quality’ land should be reserved for food production. (Carneiro & Ferreira, 2012; Evans, Strezov, & Evans, 2010; Tilman, 1999; Tilman et al., 2006). This flawed argument does not incorporate the needs of a whole farm systems management approach to agriculture and how different agricultural activities can support each other. Also marginal land can become so due to poor agricultural practices. Marginal land usually produces marginal incomes. Yet these less-fertile soils are expected to supply a secure biomass supply.

The FAO suggests the word marginal should not be based purely on a land classification.

It is recognized more explicitly that marginal lands constitute a moving target. There are drawbacks to defining them in terms of biophysical and economic yields since both their physical and economic yields can be altered by on-site investments and exogenous institutional factors affecting markets, prices, resource entitlements, etc. Further, due to spatial variability, farmers may have access to both marginal and favoured lands which could clearly modify their management systems. Thus, soil and climatic domains, although relevant, in most cases are likely to be outweighed by qualifying variables in determining the research approach. (FAO (Food and Agriculture Organisation of the United Nations), 1999)

Marginality of land can be human induced as the growing salinity area of Australia demonstrates and the overburden rehabilitation sites across Muswellbrook so clearly show. Such lands are not likely to be the areas where productive agriculture or maximizing biomass per hectare can be achieved unless. The FAO, as per below, outlines important considerations:

- use -what is marginal in one sector may not be in another
- natural biophysical characteristics - can be altered by investment
- location relative to infrastructure such as roads, railroads, harbours, and cities can completely alter the economic returns from land nearby
- institutional and policy context influences access to land, water, credit, markets, therefore outside inputs can completely alter the economics of land use
- size of land holdings - from a cattle producer’s perspective, land is not marginal, even though the biophysical yield per ha may be low
• technology development creates change - Jojoba development in arid environments; acid tolerant rice in the Cerrados of Brazil
• advantages of niche opportunities - spices, flowers, vegetables, special fibres

Land can move into and out of marginal status depending on any or all of the above factors *(FAO (Food and Agriculture Organisation of the United Nations), 1999)*. Therefore it makes sense to view ‘marginal land’ in the Muswellbrook LGA in terms of a defined position but a temporary situation thus recognising the opportunities for rehabilitation on mined land.

Identifying and measuring marginal lands has improved with recent GPS technology. *Campbell et al.* (2008), reported that using what they called a ‘new global, spatially explicit estimate of abandoned agriculture’ estimated Australia had a large marginal area largely because abandoned agriculture and idle land were included as marginal.

All plants no matter why, where or how they are grown require basic nutrition. A biomass crop cannot be expected to grow on marginal land with no nutrient support. Furthermore cost analysis indicates that when there is less harvestable crop per hectare the less likely it is to be financially viable. Occasional opportunity harvests may best utilize biomass on marginal lands and these will be dictated by the weather. Surprisingly while woody biomass from trees and C4 grasses offer very different classes of biomass both are advocated to be grown on marginal land (Chivers & Henry, 2011).

The OECD (1993) claimed the absolute energy consumption per hectare of agricultural land increased by 39% from 1970 to 1989. Fossil fuel inputs directly and indirectly have led to agriculture becoming less energy efficient. There are no specific figures relating to fertiliser use in the study area but when considering national figures, fertiliser was applied to 46.7 million hectares of agricultural land across Australia, an increase of 6% of fertilised agricultural land compared to 2009-10 (Australian Bureau of Statistics, 2011-12). Increasing fertiliser use will increase climate change emissions. To build soil fertility without fossil fuel inputs and reduce GHG emissions is the challenge. Bioenergy crops must not increase inorganic fertiliser use in the process. Therefore it would be advantageous if char and pyrolysis liquid could
facilitate the reduction of inorganic fertiliser dependency to help build a different soil-fertiliser-carbon sequestration model.

When viewed within a national framework Muswellbrook covers all land use types, especially the different types of agricultural activities from irrigation to Dryland grazing as shown in Table 8:5.

Table 8:5 Summary of Australian Land Use

<table>
<thead>
<tr>
<th>Australian Land Use</th>
<th>Area ('000 hectares)</th>
<th>Per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dryland Livestock Grazing</td>
<td>442,874</td>
<td>57.6</td>
</tr>
<tr>
<td>Minimal use</td>
<td>117,225</td>
<td>15.3</td>
</tr>
<tr>
<td>Other protected areas including Indigenous uses</td>
<td>98,094</td>
<td>12.8</td>
</tr>
<tr>
<td>Nature Conservation</td>
<td>52,707</td>
<td>6.9</td>
</tr>
<tr>
<td>Dryland Agriculture</td>
<td>23,799</td>
<td>3.1</td>
</tr>
<tr>
<td>Timber Production</td>
<td>15,175</td>
<td>2.0</td>
</tr>
<tr>
<td>Water</td>
<td>13,487</td>
<td>1.8</td>
</tr>
<tr>
<td>Irrigated Agriculture</td>
<td>2,814</td>
<td>0.4</td>
</tr>
<tr>
<td>Intensive uses</td>
<td>2,445</td>
<td>0.3</td>
</tr>
<tr>
<td>Unknown</td>
<td>230</td>
<td>0.0</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>768,850</strong></td>
<td><strong>100.0</strong></td>
</tr>
</tbody>
</table>

Note. 2001/02 Land Use of Australia dataset, Version 3, Bureau of Rural Sciences, Canberra (2006)

The consequences of poor land use were highlighted at the world’s first conference on Biofortification in 2010. Micronutrients across most soil sectors have been reduced suggesting that the mining of the soil rather than its development has been taking place. Ensuring soil micro nutrients are not depleted is part of ensuring crop nutrition. Effective stewardship of our long-term soil resource must not be compromised if we are seeking sustainable agricultural practices. The enrichment of staple food crops with essential micronutrients is part of the plan to get the agricultural sector to prioritize nutrition but biomass production does not place this as important. Not all areas can be premier food producing regions. Therefore Muswellbrook could focus on producing products where food nutrients are not central to agronomic requirements.

History has shown, and Australia’s highly successful Landcare movement confirms, that local communities are often the best at assessing, monitoring and conserving biodiversity on both private and public lands (Lockie, 2004). Traditional agricultural systems and home gardens are also important
components in preserving biodiversity. They are also important potential providers of biomass.

Sustainable farming systems that integrate trees with cropping and grazing have shown accumulation of 0.3-0.6tC per hectare in soils. Newly designed and managed landscapes that include native wildlife such as kangaroos and wallabies as alternative grazing animals to livestock may also help reduce methane emissions (Pretty & Ball, 2001). Native soil turning animals, such as bandicoots, bettongs and potoroos are often called ‘ecosystem engineers’ and will also naturally spread char like earthworms.

Improving land use is not just a question of agricultural management with its droughts and floods. It must address how our large land mass, and variety of activities as outlined in Table 8:5 can support our modest population with food, fibre while continuing to provide an export income and grow the fuel for a renewable energy sector. Growing biomass on marginal land may be perceived as useful because it is not accessing prime land where food should be grown. However marginal land will have lower productivity and this may prohibit profitability, as harvesting and transport costs generally remain the same regardless of yield. If marginal land could generate new income it may also facilitate building biodiversity. As highlighted in chapter 4, hemp is one plant that has already shown it can enhance the growth of the following crop.

Skinner, Sanderson, Tracy, and Dell (2006) conducted important qualitative research with graziers regarding the uptake of new land management practises. Prior to holistic management training only 9% of the respondents admitted to considering biodiversity in their business decisions. Afterwards all of them considered this and reported increased observations in biodiversity on their farms once they began monitoring. Learning about ecosystem services is the first stage in driving change and reducing the creation of marginal land via agriculture, just as learning about the options with char and pyrolysis liquid will be important to begin the process of integrating these products into new agricultural systems

8.2.5 The creation of marginal land by mining

Marginal land in Muswellbrook has mostly been created by land use change activities by the coalmining sector. Sharing natural resources in the
Muswellbrook LGA is recognised as an area of conflict for the mining sector. Analysis qualifying benefits for water use in mining areas has been shown to improve when mining companies are more engaged (Sontera, Morana, & Barretta, 2013). Coordinating the cumulative impacts of the mining sector has not been undertaken because mines are assessed on an individual basis. Reputational risk regarding damaging water resources is high for the mining sector (Sontera et al., 2013). New investments must reach the most sustainable outcomes possible and limit adverse impacts on non mining industries. The NSW Government and mining companies have agreed on principles for temporary and final rehabilitation with five-year goals:

Goal 1 To decrease the time that disturbed areas are left without final or temporary cover, recognising that different mining operations are at different points in rehabilitation.

Goal 2 To achieve a consistent level of best practice, quality, integrated rehabilitation – both within the industry and with future land uses - across the Upper Hunter and to be a responsible steward of the land (Upper Hunter Mining Dialogue, 2014).

While the five local coal mines agree to undertake progressive mine rehabilitation such core issues as soil stability, vegetation cover, pollution, air quality, water flow, void size, heavy metal movement and subsidence remain unresolved factors in both the short and long term. Efforts to manage environmental risks and all activities are recorded in Annual Environment Management Reports (AEMR) documents, but the ultimate success of the present rehabilitation plans are not, and cannot be, known for decades hence.

Figure 8:3 Overburden Bengalla Coal Mine (November 2014)
As Figure 8:3 and Figure 8:4 show, the scale of landscape reshaping is significant. During the time the mine overburden is not fully rehabilitated and without vegetation it is unstable and a major contributor to the Muswellbrook monitoring stations exceeding the national air quality PM10 and PM<2.5 levels.

Figure 8:4 shows the agricultural zone adjacent to and in-between Mr Arthur and Bengalla Mines. Mining companies own this agricultural land. The land-use across most of the mine rehabilitation sites, according to the different mine rehabilitations plans, is destined for future grazing. This assumption is at the foreground of decision-making regarding rehabilitation design and plant selection. How sustainable this will be remains unknown because long-term success of rehabilitation is unknown.

Re-establishing grasslands on mine rehabilitation areas can be a long process. As there is no healthy soil structure to start with in these areas, the development of soil health and complex vegetation cover occur slowly to recreate the multiple components for ecosystem health. Conducting traditional set stocking, or uncontrolled grazing on these sites will create a different outcome to strategic grazing. Fischer et al. (2010), reported how traditional livestock grazing has threatened grasslands and damaged biodiversity in Eastern Australia on all land types. Uncontrolled grazing has become unaccepted. Rotational or strategic grazing is now the preferred grazing practise recommended by New South Wales Local Lands Services (LLS). It is also endorsed and promoted throughout New South Wales Resource Management government education programmes (NSW Department of Primary Industries). The other response to previous grazing errors is to remove livestock. This idea has been a key component in government endorsed
Property Vegetation Plans. However, removal of domesticated animals can also have unexpected negative ecological impacts (Savory, 1999), such as reducing biodiversity.

Resting land from livestock rather than complete stock removal has been found to be a key to building grassland resilience (Savory, 1999). The capacity to do this varies depending on the level of destruction to start with. A case study in the Upper Lachlan reviewing tree cover and conservation outcomes suggested two key measures were needed; reduction in fertilizer use and incentives for farmers to change grazing patterns.

In the Muswellbrook area grassland improvements are most likely achievable with short rotational grazing practices (Savory, 1999). These rotations may need to be very short in areas of mine rehabilitation where soil structure is less developed. Further biodiversity losses could occur if grazing were to be uncontrolled on newly established pastures.

Rehabilitated land is not going to be the source of biomass for bioenergy if grassland and C3 and C4 grasses are to be the main plants grown. If the land management favours biomass and not grazing, plantation timbers would be the preferred plant material over grasses. Therefore, managing plantations via thinnings and short-term rotation would provide an alternative future use for the area.

The second component of marginal land is its potential enhancement with the addition of biochar and pyrolysis liquid. In this scenario the notion of marginality is not to provide the foundation of a biomass source but to provide a site where biochar and pyrolysis liquid additions could facilitate the rebuilding of functional soils, improve agricultural productivity and sequester carbon; all part of a GHG mitigation process. There is perhaps a third way biochar and pyrolysis liquid and marginal land designed for grazing could be coordinated as the products from biomass conversion can also be beneficial animal feed ingredients.

### 8.2.6 New ideas

Incorporating a new slow pyrolysis industry into sustainable land use practises would engage multiple services in different ways. In considering
emission scenarios, Stocker (2013) points out that our mitigation efforts will become less effective if the carbon already emitted into the atmosphere is not drawn down. Otherwise future mitigation options will irrevocably shrink and disappear. Therefore a system that reduces and draws down CO₂ would be advantageous. Biochar in soil is one such option.

Reports analysing pyrolysis co-products (Galinato, Yoder, & Granatstein, 2011) conclude that for sequestration to be a profitable option there needed to be a low market price for char together with carbon offsetting. This poses a dilemma for inefficient char making technologies that would need high char prices to be viable. The dilemma can only be resolved with highly efficient and capital effective char making.

*Animals eating char and pyrolysis liquid*

Animal husbandry options have the potential to concurrently reduce GHG emissions and increase agricultural production. Char and pyrolysis liquid has been incorporated into animal feed for centuries and remains a common practice in Asia as discussed Chapter 5 and 6. Feldmann (1992) experimented with the ingestion of activated carbon in ruminants and found char assisted digestion. This suggests that if grazing is to be the main activity on marginal land, animals eating char could be a cost effective system to integrate carbon sequestration potential across the landscape. The safety assessments of feeding char to animals have primarily been conducted using activated carbon sources. These chars have been recommended as medicines for some animals. For instance, Pass and Stewart (1984) found that 500gms of activated carbon for sheep and 2kg for cattle inhibited poisoning by *lantana camara* and animals recovered.

Animal production creates non-CO₂ emissions from enteric fermentation (CH₄) and manures at the farm gate, representing 18% of total global GHG emissions (Steinfeld et al., 2006). This coincides with the global increase in meat consumption (Delgado, 2003) and the increase in Australia’s meat export (Meat and Livestock Australia (MLA), 2013).

When char is produced it presents in a powdery form. Hence the possible need to pelletise it to improve handling. One option is to use the powdery form as a feedstock rather than directly as a soil additive. This is one way of
simultaneously delivering directly the health benefits of char to stock as well as the soil naturally via faeces and dung beetles without needing to mechanically prepare soil or consider complex crop needs. Char’s adsorption qualities can bind toxic substances in the gastrointestinal tract of cattle. Feldmann (1992) studied activated carbon effects on the fermentation process of rumen flied in vitro and detected pH levels could rise 25 per cent.

Demand for animal products is increasing (Gerber et al., 2013) and while they may be methane emitting creatures they are also a tool to spread char and facilitate carbon sequestration.

Improving forage digestion is already known to reduce GHG emissions (Hristov et al., 2013). Simple measures such as different feed supplements can be effective while increasing productivity (Savory, 1991). Char is one such supplement that has been trialled to improve animal health and decrease methane emissions. Leng, Inthapanya, and Preston (2012) conducted two experiments during 2012 and found 1% of char added to feed reduced methane by 12%. Further testing with cassava feed together with char confirmed methane reduction but also led to increased weight gain in growing cattle. This confirms the hypothesis that char can improve feed conversion in the rumen. Ogawa (2009) reported how char was a common medicine in Japan for animal intestinal disorders. Then in the 1970s Japanese farmers began to mix pyrolysis liquid with the char, which seemed to improve animal health even further. Gerlach and Schmidt (2014) fed out 200-400g of char per cow per day, and found stock health and vigor improved and bad odours were reduced.

Based on stock numbers as reported in Annual Land and Stock Returns, there were 18 359 head of cattle in the Muswellbrook area in 2013. If 18 000 head of cattle receive 300g of char a day this would represent 5.4 tonne per day in total across the region. This system could spread significant quantities of char relatively easily and also more slowly, favouring natural rates of soil carbon sequestration. One of the considerations regarding the high carbon of Terra Prêta soils has been the fact that these ancient soils developed slowly over a number of years (Glaser et al., 1998; Lehmann, 2007b). The concept that one can simply apply char once to soil in a mechanical agricultural activity and achieve the same results as a slowly developing improvement with
sequestration seems unlikely. So feeding char to the soil via the gastrointestinal tracts of ruminants and allowing earthworms to assist in the spread and penetration of the char within the soil may be both more effective and practical.

In the two adjacent areas of Muswellbrook, cattle numbers are even higher with 42,167 in 2330 postcode and 62,811 head in 2337 postcode, giving a total regional grazing beef herd of over 120,000 that would be capable of consuming 36 tonne of char daily. If cattle in the Muswellbrook area and the surrounds participated and all consumed small char doses regularly (300g/d), this would represent the char product of 35,000 tonnes per annum continuous biomass conversion and an opportunity for thousands of hectares to sequester carbon. Clearly there would be a slow ramp up of such a system but the local stock numbers highlight the potential.

**Energy crops**

If Australia’s climate change policy were to focus on carbon sequestration, biomass could become more important. The principle of growing crops specifically for energy strengthens TNS framework that reinforcing existing activities to promote innovation is good. In this case the existing activity is agriculture and the continuous biomass converter innovation offers new agricultural product streams both for inputs and outputs. The present biomass sources available in Muswellbrook have been considered in Chapter 4 which concluded that in the immediate term current green waste could supply at least the first CBC scaled at 4000 – 10,000 tonne annual production.

The Hunter Valley has a long history of calling itself an energy region and Muswellbrook Shire’s logo is ‘Bursting with Energy’. A more recent phrase often used in sustainability literature is ‘energy landscape’. This is a useful term when considering energy crops because unlike first generation biofuels these crops are only destined for energy. Carneiro and Ferreira (2012) recommends the benefit of dedicated energy crops to immediately reverse external energy dependence if fossil fuels are not available. Australia does not have an energy shortage but there could be a place for these crops within a more holistic approach to sustainable land use.
In the biomass feedstock review in Chapter 4, the bulk density of the different kinds of biomass was outlined. Briefly, while grasses provide the least bulk density, they are also the most widely spread biomass source and two grasses have become leading energy crops, switchgrass (*Panicum virgatus*) and miscanthus (*Miscanthus giganteus*).

The United States set up the Bioenergy Feedstock and Development Program (BFDP) in the 1990s and focused on US native switch grass primarily because of its high yields (McLaughlin & Walsh, 1998). One five year field study on marginal land across three US states tested the net energy output, GHG emissions and yields and found switch grass produced 540 per cent more energy than it needed to grow, harvest and process into ethanol (Schmer, Vogel, Mitchell, & Perrin, 2008). This experiment showed how fertiliser use was less than recommended yet the crop yields remained high. Maximizing yields with less energy and resource input will be the key to ultimately defining the amount and type of land required.

Switchgrass and miscanthus have also been trialled to test the economics of replacing coal in power generation in the US. It was found that one harvest of switch grass proved most cost effective but without a carbon tax or other biomass economic incentives it was not competitive on price with coal (Aravindhakshan, Epplin, & Taliaferro, 2010). Lowenberg-DeBoer and López-Pereira (1990) looked at the risks of farmers switching their enterprise to growing switchgrass or tall fescue. Harvesting switchgrass in the US coincides with a period of low labour and machinery requirements. This allowed biomass crops to be integrated into existing farm operations and lowered farm income risk.

*Miscanthus giganteus* has also been tested as a potential energy crop primarily because of its low nutrient needs and low water requirements. Commercial trials across Europe and US have provided feedstock for heat, electricity as a co-firing feedstock and biofuels. In the US it is a featured plant in the Biomass Crop Assistance programme BCAP, set up as part of the 2008 US Farm Bill. As a consequence, since 2012, 18 000 acres of miscanthus has been established.
German agricultural policies have favoured *M. gigantum* a naturally occurring hybrid between *M. sinensis* and *M. sacchariflorus*. Germany aims to have 15% of its energy from biomass by 2020. Miscanthus has been widely planted with plant stands expected to last 20 years and (Dauber et al., 2010) suggests it is a better plant for promoting biodiversity, despite it not being a native to Germany.

Crop productivity of miscanthus and switchgrass has now been assessed under a variety of agronomic conditions in the EU and US (Brown, Rosenberg, Hays, Easterling, & Mearns, 2000; McLaughlin & Adams Kszos, 2005; McLaughlin & Walsh, 1998) but not in Australia. If bioenergy was mandated to increase to German levels, this might change. One negative issue with miscanthus in Australia is its relationship with Miscanthus (*Miscanthus sinensis*), which is classified as a weed in NSW, a potential weed in Victoria and a particular plant of worry in the Blue Mountains and Central tablelands. Invasiveness risk evaluation is regarded as an important first step when considering energy crops, to at least understand potential spread (Barney & DiTomaso, 2010).

Blaschke, Biberacher, Gadocha, and Schardinger (2013) points out that increasing biomass production may require a large special footprint, and defining the appropriate scale to each landscape will be essential to drive good sustainability outcomes. Yet the trials of miscanthus and switchgrass have demonstrated the large variation in crop volume, which will define the area needed. For instance, although switchgrass grows well on productive soils, a low-input, high-diversity grassland produced a third as much, but when inputs were considered was better than switchgrass (Tilman et al., 2006). Therefore, according to Tilman, using abandoned agricultural land is useful because it does not compete with fertile soils, food production or lead to further ecosystem destruction. Oddly, in Australian idle land can be depositories of plant biodiversity, precisely because they've been abandoned (Peake, 2006).

While switchgrass and miscanthus were attracting attention overseas, valuing equivalent indigenous Australian perennials were attracting attention, especially the arid zone mallee (small eucalyptus trees that regrow from rootstock after harvesting), where it has been planted and assessed in Western
Australia with promising results (Bartle & Shea, 2002; Barton, 1999; Shea, Butcher, Ritson, Bartle, & Biggs, 1998).

The FloraSearch field trials in a number of locations throughout 2004, 2005 and 2006 were to develop commercial broad scale woody perennial crops in low rainfall areas. It was thought woody perennials could be integrated into existing grazing systems for ecological benefits, improving resilience and to start a new biomass supply stream. Koojong Wattle (*Acacia saligna*), Old Man Saltbush (*Atriplex nummularia*) and Blue Mallee (*Eucalyptus polybractea*) were identified as suitable species for short-cycle woody crop biomass sources in low rainfall winter dominant areas (Hobbs et al., 2009). Other strong candidates were Sugar Gum (*E. cladocalyx*), Flat-topped Yate (*E. occidentalis*), Flooded Gum (*E. rudis*), Mallee Box (*E. porosa*), Smooth-barked York Gum (*E. loxophleba* ssp. *lissophloia*) and Rough-barked Manna Gum (*E. viminalis* ssp. *Cygnetensis*) (Hobbs et al., 2009).

The climatic areas where these plants were evaluated differ from Muswellbrook. Rainfall volume is the same but is summer dominant in the Hunter. Yet Old Man Saltbush has been promoted in the Muswellbrook area and sold by Muswellbrook Forest Nursery as a useful fodder species with high drought tolerance. Fodder shrub-based plants may be the key difference between indigenous biomass supplies in Australia and elsewhere.

The dryland agricultural area of the South Australian River Murray Corridor was surveyed for biomass potential and 360,728 ha was found to produce 3 million tonnes of green biomass per annum (Bryan et al., 2008). Transposed to Muswellbrook’s Class 4 land area and considerable biomass could be produced. This CSIRO case study covered an extensive area of southern Australia and compared agricultural (food) with first generation biofuel production, and found that while there were profits to be made growing biofuels instead of food the GHG reduction was lower when first generation biofuels were produced (Bryan, King, & Wang, 2010). It highlights the fact that one of the biggest challenges in a vast country like Australia is that food and fibre is often grown in areas where the local market is low or non-existent, hence the development of Australian agriculture as an export industry. Growing biomass close to where it is needed is one of the key points in sustainable development of bioenergy. While there are isolated areas where
bioenergy crops can be grown there may well be no need for them locally as energy needs are small. If on the other hand the purpose is export then wood based forestry biomass is more likely as its density is greater than agricultural plant material.

The other important issue with energy crops is farmer willingness to grow them. If bioenergy is to engage with the remaining agricultural sector then it will need local farmers to support the idea. Studies in France examined if growing energy crops will negatively impact on a farmer’s bottom line. Complex subsidies direct EU agriculture and changing traditional crop rotations impacts on income expectations. Thus the option of planting as a rotational crop for environmental purposes would need to be in conjunction with a contract to justify any liquidity risk (Bocquého & Jacquet, 2010). The possibility of growing energy crops in countries where labour is cheaper is not really an option for Muswellbrook land managers, as transport costs become an impediment.

The latest modelling to assess biodiversity losses due to bioenergy crops in the EU may be less applicable in areas like Muswellbrook where biodiversity losses are already so extreme on mine sites. These are government approved biodiversity losses and in many instances are offset via bio-banking agreements on land outside the LGA. The long-term consequences for Muswellbrook will be felt after mine closure when the final area of biodiversity loss is realized and by which time the mining compliance regulations will no longer apply.

Associated fuel costs represent an important weakness in the economic return of energy crop projects under the present price conditions. For instance, according to the Portuguese RES policies, a more favourable and guaranteed feed-in tariff is often required to tackle perceived risks. This suggests additional support schemes are required to attract private investors to biomass power projects based on dedicated energy crops.

The development of energy crops, especially in Germany and the United States, show *misacanthus* and *switchgrass* are valuable biomass feedstocks. Their development has evolved from policies promoting bioenergy and direct
engagement with the agricultural sector. Until an equivalent political directive applies to Australia energy crops are likely to remain undeveloped.

Genetically modified biomass

From an industrial energy point of view photosynthesis is not efficient. A plant produces enough energy for its own needs and is not designed to optimize solar energy capture (Blaustein, 2012). Therefore it has been suggested that new genetically modified (GM) plants will need to be engineered to meet the future biomass demand. PETRO (Plants Engineered To Replace Oil) are being genetically engineered to capture more energy. This is to improve the ‘feed stock – conversion’ process and use less water and fertilizer in the process.

In Australia before being deemed safe for human consumption and the environment, genetically modified GM products are reviewed by the Office of the Gene Technology Regulator. Genetically modified canola and cotton have been approved and are now grown in Australia. Other GM products such as corn and soy are imported and included as ingredients in a variety of processed foods and stock feed.

Although having been through an assessment process, GM crops remain contentious (Mellon & Rissler, 2004; Park & Phipps 2002). The level of safety for human consumption is not fully understood (Mellon & Rissler, 2004). Rissler and Mellon (1996) points out how gene silencing has the potential to inadvertently turn off non-targeted genes in people who consume them. Yet GM ingredients in food are not labelled because they are assumed to be safe for human consumption. Therefore a GM biomass crop would be likely to undergo even less assessment.

While attempts to design the perfect plant for a myriad of reasons has captured our imagination for centuries, the real impact of GM plants has only recently begun to be understood. For two decades GM crops have been promoted as crops that can reduce chemical use. Statistics show this is not the case. In fact the opposite has occurred. GM crops have lead to herbicide resistance in some plants and created glyphosate-resistant weeds (Senseman & Grey, 2014). Ultimately, chemical resistance usually leads to increased chemical use (Mellon & Rissler, 2004).
The potential for gene silencing to inadvertently turn off non-targeted genes when consumed is under debate (Mellon & Rissler, 2004; Rissler & Mellon, 1996). At the same time, the responsibility for managing environmental risks has been placed on farm workers, consumers and the environment itself (Beckie, Sikkema, Soltani, Blackshaw, & Johnson, 2014). These significant issues do suggest GM crops would not be environmentally acceptable for creating a sustainable vision for the future in Muswellbrook LGA.

Weed science has become a sub-section of agricultural research and has a strange love-hate position within the sustainable land use debate. This is because holistic management (Savory, 1999) and organic farming (Australian Certified Organic) do not consider weeds as enemies but as plants needing to be managed differently. Improving grazing and cropping systems can have immediate and significant implications in effective weed control (Major et al., 2005; Pimentel et al., 1992). The risk that more damaging chemicals may have to be used to rehabilitate the area may increase with GM crops (Park & Phipps 2002; Shiva, 2006).

The priority for Muswellbrook is to facilitate improved land stability and increase biodiversity. The risk of increasing chemical use with GM crops challenges this and does not lead to developing a sustainable land use systems. It presently does not offer an ecological advantage nor does it promote environmental stewardship.

8.2.7 Challenges for Muswellbrook

In 2010, Muswellbrook Council began to quantify local land use change. The twelve months between 2010-2011 saw the loss of 15 per cent of local agricultural land (Muswellbrook Shire Council, 2010, 2011b). Most of this was caused by coalmine expansion Table 8:6.
Trying to plan for this volume of land change was compounded by on-going negotiations to extend or open new mines. Mine projections in the Muswellbrook LGA could lead to at least 32.5Mtpa more coal being removed as Table 8:7 shows. Table 8:8 shows mining could be approved till 2039, pushing further back the time frame for mine closure and full land rehabilitation. In October 2014, Drayton South Mine was recommended by the Planning Assessment Commission not to proceed, although this decision is being legally challenged.

Table 8:6 Coal mining areas Muswellbrook LGA

<table>
<thead>
<tr>
<th></th>
<th>2009/10</th>
<th>2010/11</th>
<th>2011/2012</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Square Kilometres</td>
<td>Square Kilometres</td>
<td>Square Kilometres</td>
</tr>
<tr>
<td>Cleared</td>
<td>6.88</td>
<td>8.53</td>
<td>4.52</td>
</tr>
<tr>
<td>Active Mining</td>
<td>14.92</td>
<td>17.95</td>
<td>19.36</td>
</tr>
<tr>
<td>Emplacement</td>
<td>19.01</td>
<td>20.94</td>
<td>23.27</td>
</tr>
<tr>
<td>Rehabilitated</td>
<td>1.16</td>
<td>0.96</td>
<td>2.16</td>
</tr>
<tr>
<td>Change in total active mining</td>
<td>NA</td>
<td>15%</td>
<td>10%</td>
</tr>
<tr>
<td>Rehabilitation to clearing ratio</td>
<td>0.2</td>
<td>0.1</td>
<td>0.5</td>
</tr>
<tr>
<td>Total Active</td>
<td>33.93</td>
<td>38.89</td>
<td>42.64</td>
</tr>
<tr>
<td>Approved disturbance</td>
<td>173</td>
<td>174.09</td>
<td>174.09*</td>
</tr>
</tbody>
</table>

*Note. Adapted from Muswellbrook Shire Council 2013*

Alongside coal mining plans is competition for local resources. The Upper Hunter Diversification Reports have identified the changes in industries in the area affected by the expansion and contraction of mining (Buchan Consulting, 2011).
Table 8:9 Key industries in Muswellbrook LGA

- Coal mining
- Power generation
- Mining support
- Equine
- Wine
- Agriculture incl. beef and dairy
- Population services ie retail
- Tourism

*Note. Adapted from Muswellbrook Shire 2013*

While mining and power generation may dominate economic activities maintaining critical mass of other services is essential if the agricultural and equine businesses are to be maintained and/or for new sectors to develop. Table 8:9. Engaging with the existing businesses is advantageous for any new industry. Growing bioenergy crops as part of an existing farming system is more likely to engage farmers. This way biomass can be used as an additional cash crop while also providing other benefits such as increasing crop rotation options, breaking weed cycles, insect loads, plus environmental and biodiversity improvements.

### 8.2.8 Employment opportunities

If biochar is to have an important place improving fertiliser uptake and sequestering carbon, future engagement needs to involve a broad cross section of farmers and areas so that sustainable removal of biomass can be achieved. Future works must focus not only on emissions but also on other social relevant impacts and envisage public participation in order to ensure the farmers interest and commitment to the process.


> There is a serious capacity gap in professional and technical human resources necessary for effective land management, including both a growing shortage of qualified people and a lack of relevant skills and experience among the next generation of land managers.

It has been thought that the Carbon Farming Initiative (CFI) would lead to new management strategies on farm that would create a new skill base, as there would be the need for:
• New grazing management education and training
• New agronomy consultants
• New bio-fertilisers and health products
• New farm equipment
• New equipment based support services
• New biological science services (testing soil carbon etc.)

Precisely how the transition can take place is not clear. FAO set out guidelines on what should be encouraged.

> Give priority to projects based on small-scale farming, possibly through cooperative arrangements, where adequate arrangements are made for a combination of biofuel production and food production of own and local consumption (Social). (FAO (Food and Agriculture Organisation of the United Nations), 2008)

Australian agriculture is managed very differently than in the European Union (EU) where subsidies define what is and is not grown. It is easier to support bioenergy where the government is so entrenched with the industry. In Australia most government support has been given for natural resource management via grants, advisory services and not for production.

The coal sector in the Hunter Valley has also driven significant negative local structural changes such as:

• Road closures.
• Reduction in agricultural work force.
• Reduction in agricultural service industries.
• Increased wages that are difficult for other sectors to compete with.

These have had a direct impact on reducing employment in other areas. Now with the downturn of the industry, direct jobs losses in the Hunter coal sector including Muswellbrook, reached 2 500 during 2013-2014 according to the NSW Minerals Council.

Biomass in rural and urban areas has the potential to create jobs via the different management and transport systems that would support a slow pyrolysis facility. Bioenergy advocates stress the employment benefits for the rural sector (Domac, Richards, & Risovic, 2005; Sims et al., 2006). However, confirming precisely the main jobs created in the bioenergy sector remains
somewhat vague. There is no break down of figures for Australia’s nascent bioenergy sector yet, and figures in Germany suggested 29 000 employed across all areas of bioenergy were recognized in 2004 (Plieninger et al., 2006). Statistically analysing these employment figures is going to be difficult as the energy sector transitions to renewables. Should for instance some of the staff at a coal-fired power station be calculated as employed in the renewable sector because some of their work is carried out with the 5 per cent biomass co-firing?

The important point is that bioenergy is unlikely to lead to fewer jobs in the energy sector and possibly more jobs in the biomass component if farmers across multiple sectors become engaged.

8.3 Economic Sustainability

Regardless of the perceived direct and indirect benefits of char making in the Muswellbrook area, a continuous biomass converter industry will not emerge unless the business is financially viable.

The challenge is that firm project costs cannot be developed in advance of detailed project planning. The scale, scope and location of the plant will affect capital costs, and these are not yet determined. Biomass supply volumes and costs will have to be negotiated. The markets for two of the products, biochar and pyrolysis liquid are new and therefore prices are uncertain. Incentives for clean technology are politically volatile and generally cannot be relied upon.

In this context, the deliberations below are for strategic planning purposes. They are based on indicative, estimated costs and revenues, for a nominal 10 000 tonnes per annum facility. The assumption is that the gas will be used to generate electricity and that the char will primarily be used in land applications and that the pyrolysis liquid will be directed to the sewage water treatment plant, until more value adding applications in agriculture and rehabilitation are developed.

Political context

Since Australia ratified the Kyoto protocol in 2007, there has been fluctuating policy and pricing regarding renewable energy. Federal and state governments
have initiated, changed and closed many schemes to promote renewable energy production and use. This volatile situation is due to the failure of Australia to achieve a bipartisan approach to national Climate Change mitigation. Despite this the Renewable Energy Target (RET) supports the continuous biomass converter technology and the value of Renewable Energy Certificates (REC) generated by the plant’s electricity production. The Carbon Farming Initiative and the new Direct Action Plan also offer potential financial support (Clean Energy Regulator).

The literature on renewable energy in Europe suggest public policies such as incentives, subsidies and feed-in-tariffs have been a major driver in developing the sector (Evans et al., 2010). The Australian Clean Energy Council has suggested the same (Clean Energy Council, 2008) calculating that unless there is a price on carbon that is market driven, valuing different renewable end products is challenging and unlikely to be profitable.

Due to the fluctuating policy directions during the period of this study regarding climate change, renewable energy and carbon, it was decided to outline the capital costs, operating costs and projected income without a carbon tax or ETS to influence prices, as a conservative scenario.

Table 8:10 therefore is based on existing and articulated government policy, including income from Large Scale Generation (LGC) certificates for the generation of renewable electricity, but no income at this stage from measures that may result from the Carbon Farming Initiative or The Direct Action Plan.

Capital costs

The estimated capital cost for one continuous biomass converter processing a nominal 10 000 tonne of biomass per annum to produce gas, char and liquid products is $2M. This includes the converter and the balance of plant, such as materials handling and buildings. To generate electricity from the gas will incur an estimated additional capital cost of $1.5M to cover the gas engine and associated costs. This brings the total capital estimate for the facility to $3.5M.

Biochar is typically produced in a fine form, usually less than 1mm. If it is pelletised or briquetted on site after production this would require extra floor
space, sheds and machinery. This post-production cost has not been included. However, equipment is readily available and the additional costs can be expected to be covered by the opportunity to value add with a range of char products.

The same argument applies to the pyrolysis liquid. The capital and operating costs involved in post processing to separate the middle fraction from the oil and tar layers can be expected to be covered by the value adding on site. However because there is no immediate market for pyrolysis liquids in Australia this has been valued at $0 to ensure profitability in the short term.

*Production costs*

The continuous biomass converter and associated electricity generating plant is automated and designed to operate full time. Production costs (not including biomass) includes operations, maintenance costs and licence fees, and are estimated to be $30 per dry tonne of biomass processed.

*Biomass costs*

The most important variable in production costs is the biomass supply. For this exercise as shown in Table 8:10, biomass is costed at $20 per tonne. However it is likely that for stage one of development this biomass resource could be free if supplied by green waste, which is a cost to Council. It was decided to place a low indicative cost on the biomass because in the future it is unlikely to be a free resource. As renewable systems become more common and waste management practices effectively utilise all biological resources biomass will become more valuable. For slow pyrolysis to grow as a renewable option it will need regular supplies of biomass and free green waste will not be readily available to supply multiple CBC platforms. US and Europe literature, as discussed above, suggests growing specialist biomass will be needed in the future for bioenergy to succeed.
Table 8.10 Indicative Costs and Income for an early 10,000 tonne/annum Continuous Biomass Converter in the Muswellbrook Area

<table>
<thead>
<tr>
<th></th>
<th>Electricity &amp; Char Production</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Capital Costs ($M)</strong></td>
<td><strong>AUD</strong></td>
</tr>
<tr>
<td>CBC Pyrolyser</td>
<td>2.00</td>
</tr>
<tr>
<td>Power Plant</td>
<td>1.50</td>
</tr>
<tr>
<td><strong>TOTAL Capital Costs</strong></td>
<td><strong>3.50</strong></td>
</tr>
</tbody>
</table>

| **Operating Costs ($/t dry biomass)** | **Biomass Feedstock** | 20 |
| **Production Costs** | **50** |

| **Income ($/t dry biomass)** | **Electricity** | 77 |
| **REC** | 25 |
| **Char** | 70 |
| **Pyrolysis Liquid** | 0 |
| **TOTAL Income** | **172** |

| **EBITDA** | **$/t dry biomass** | 122 |
| **$M** | 1.22 |

| **Pay Back Period (years)** | **2.9** |

**Assumptions:**
- Energy of biomass (dry basis) 20 GJ/t
- Gas yield 8GJ per tonne biomass processed
- Efficiency of electricity generation from gas 33%
- Value of electricity $100 per MWh
- 0.77 MWh electricity generation per tonne biomass processed
- Char yield 350 kg per tonne biomass processed
- Char sale price $200 per tonne biochar
- Pyrolysis liquid yield 400 litres per tonne biomass processed
- Renewable Energy Credit: LGCs at $33 per MWh

### 8.3.1 Income

**Gas and Electricity**

Income is usually maximised if the continuous biomass converter produced gas is converted to electricity, thus making the CBC a renewable energy power station. The gas produced from one tonne of dry biomass will generate around 0.77/MWh of electricity. If the savings made by generating their own power is $100/MWh it will generate an income around $80 per tonne of biomass processed. The continuous biomass converter will produce eligible Large Scale Generation Certificates (LSC) under the Renewable Energy Certificate (REC) scheme. One LGC is equivalent to 1 MWh of renewable electricity. This
assumes there is no need for the gas to provide local industrial heat and all gas will be converted to electricity.

Char

As discussed in Chapter 5, the global production of biochar is under 1000 tonne per year and is constrained by technology conversion. Consequently there is no price benchmark for large volumes, with most biochar presently on the market packaged for the horticultural and gardening retail market. Once the volume increases and the market for agronomic use is accepted the price point will vary. There is an assumption soils need biochar (Lehmann, 2007b; Shabangu, Woolf, Fisher, Angenent, & Lehmann, 2014) therefore the true price of biochar will be influenced by three main factors: the cost of manufacture, the proven agronomic benefits and the possible rebate for sequestering carbon. Hammond et al. (2013) analysis of biochar in temperate regions showed a 0.4 t/ha increased average yield suggesting a small financial reward.

Financial comparisons of various technologies usually assume a theoretical format and often pay attention to micro technical variations to find financial gains. Shabangu et al. (2014) for instance, reviewed different types of pyrolysis conducted at different temperatures and assumed the gas could not offer financial benefits without a price of biochar at $220 per tonne. A CBC on the other hand will be able to produce biochar profitably as per Table 8:10 when biomass is priced at $20 per tonne.

The char is at least worth its energy value and with an energy content of 30 GJ per tonne that corresponds to around $100-200 per tonne, depending on whether the value comparison is with coal ($3/GJ) or natural gas ($7.50/GJ).

Pyrolysis Liquid

No income has been allocated for pyrolysis liquid. If disposed of directly no extra cost should be incurred. Water is a valuable resource and although pyrolysis liquid is primarily water it has no present value as water due to its acidity and organics. In the future further financial gains could be achieved with improved engagement with the Carbon Farming Initiative and the Direct Action Plan, metal extraction and the pyrolysed products from specialty crops.
8.3.2 Australia’s Direct Action Plan

The Direct Action Plan was passed in parliament November 2014. This new system will subsume the Carbon Farming Initiative. Instead of being market based it will provide funding for emissions reduction via a government Emissions Reduction Fund. This fund has, at the time of writing, been allocated $2.5b to pay for 400 million tonnes of CO$_2$ reductions, in order to meet Australia’s 2020 emissions reduction obligations. If all projects were deemed equal and no further funds were allocated this would mean the carbon value would be worth only $6 per tonne. This low value would not be likely to drive innovation.

The concept of the Direct Action Plan with its Emissions Reduction Fund is the opposite of the carbon tax, which required polluters to pay for their pollution. Direct Action on the other hand pays the polluters money to reduce their emissions. The price a polluter will be paid to reduce emissions will vary with each project, as the government will only fund those projects where the carbon abatement price is cheapest. The biggest polluters may elect to not participate in the system and some projects would only be likely to be developed if the carbon value was high. With a short-term low carbon price, the Renewable Energy Target becomes the main driver reducing emissions in the long-term.

8.3.3 Scaling Up

Defining the appropriate scale of a slow pyrolysis business starts from clearly knowing what is to be achieved but must comply with available ecological capacity. Scale options change more easily when distance and mobility is high. The advantage of mobility has meant broader, larger scale projects have been achievable but when carbon emissions are accounted for scalability is often reduced.

Schumacher (1974) understood that while mobility has structure, it has made it harder to define a proper scale of a business and community. For instance, the 1968 Mansholt Plan redefined European agriculture with its ambitious agenda to ensure affordable food. It accepted that improved mobility allowed for bigger farms to operate allegedly more efficiently. At the time the plan
projected 5 million hectares of agricultural land would and should be removed from production (Mansholt, 1970 Winter; Schumacher, 1974; Stead, 2007). This revolutionary restructure was not met with enthusiasm from the farmers. It was the start of agriculture being viewed politically as just another business without recognising the unique ecosystem services and biodiversity interconnections within the industry. Today the farm size in Europe remains small compared to farm sizes in Australia. It is interesting to reflect on the boldness of the Mansholt Plan where economics dominated the change, not sustainable land use and what it has achieved. In principle the pursuit of logistic efficiency leads to oligopoly as the global food processing and food retail sectors clearly shows. Many farmers in the EU remain today and most manage their land with subsidies; despite the policies to remove land from production, there have been repeated annual food surpluses.

A continuous biomass converter needs to efficiently convert solar energy without adverse environment effects. This is not always easy to gauge as conclusions shift regarding true environmental costs. Importantly, size plus conversion efficiencies ultimately define final biomass volume requirements. The CBC has been measured at around 96%, placing it as one of the most energy efficient biomass conversion systems available. Therefore the scale effect of this modular type design provides a low risk for scaling up.

Research regarding up-scaling sustainable agricultural practices has shown that intensifying productivity in some ecologically functioning systems is important to secure supplies.

### 8.3.4 Key Issues regarding pricing

**Landfill**

The New South Wales government licenses landfill waste disposal facilities. It is estimated that 1.8 tonne CO\(_2\)-e can be produced per dry tonne biomass in landfill (National Greenhouse and Energy Reporting System Measurement (NGERS), 2012). Local Government is now required to pay a levy for every tonne of waste deposited and Muswellbrook’s regional fee is $65.40 per tonne (Environmental Protection Authority). Muswellbrook has attempted to reduce the volume of green waste entering landfill by converting it into mulch for sale.
and also delivering it to coal mines for rehabilitation. Further GHG reductions and reductions in landfill fees can be achieved if biomass is diverted.

Improving waste management has also become a focus of the Emissions Reduction Fund (Australian Government, 2014a). This includes the areas of landfill gas, alternative waste treatments and improvements within wastewater treatment plants. However to access government funds allocated to emissions reductions via the Direct Action Plan any process needs to be a government approved method and the CBC system is yet to be classified as an ‘approved emission reduction process’.

_Electricity generation_

If all things were equal, the price of coal compared to biomass should dictate the renewable energy replacement technology. But the procurement fuel delivery logistics is a sub-set all to itself. A true value comparison is difficult while the price of coal is embedded in special conditions and subsidies (ACIL Tasman, 2012).

Local coal reserves originally dictated the location of New South Wales’s biggest coal-fired power stations, Bayswater and Liddell with their combined generating capacity of 4 690 MW currently providing approximately 13% of the national electricity market. Operating since 1979, they have undergone numerous upgrades during that time and used coal from a number of different local coal-mines with short and long term coal supply contracts varying over the years. The present 2013 coal contracts are with three different coal-mines.

- Mangoola (Glencoe)
- Wilpinjong (Peabody)
- Mt Arthur (BHPBilliton)

All three coalmines were approved with conditions to supply coal locally at a lower than export market price. These low prices (some may say, subsidised prices) have allowed the power stations to maintain value, build and upgrade on-site delivery facilities, generate a profit and provide income back to the state government before being sold. This may not have been possible if the market had set the price of coal. As local coal supplies have been used coal
has been sought further afield. Wilpinjong coalmine is 167 kilometres from Liddell.

When the Australian carbon tax placed a clear price on GHG emissions for polluters the carbon tax drove research to improve input efficiency and reduce emissions. Reducing emissions and saving money became an economic objective. The CBC technology was developed alongside this financial incentive and drove the concept of co-firing biochar, not the raw biomass, to make renewable electricity more efficient in a coal fired power station. With the carbon tax eliminated, will the efficiency gain be enough to justify the extra process?

Co-firing is a relevant consideration in the Muswellbrook LGA because the Council is the local consent authority for future planning developments for Bayswater and Liddell power stations. This is an advantage in coordinating the integration of new technology where multiple outcomes are required and infrastructure investments have already been undertaken.

Biomass co-firing is essentially carbon neutral. Modelling based on 1 tonne of biomass converted via a CBC would generate 1.8MWh of electricity from co-firing the char and the gas as a coal substitute (National Greenhouse and Energy Reporting System Measurement (NGERS), 2012). As Sterner and Fritsche (2011) reported, co-firing is the most cost efficient and effective biomass application for immediate GHG emission reduction.

When the carbon tax was operating at $24.15 per tonne -e emitted, Vales Point could save $10Million per annum if one CBC plant was fully operational (Australian Government. Clean Energy Regulator).

**Biomass supplies**

While the externalities of biomass energy can be high if water and chemicals are used, high NO₂, SO₂, dust and CO₂ emissions are likely to occur. (Faaij, 2008) calculated that when biomass is grown with industrial chemicals and fertilisers the cost of bio – electricity rises to 53-70mECU/kWh while coal can be produced within the range of 45-72 mECU/kWh.

While biomass transport logistics are complex (International Energy Agency (IEA), 2008), it is also true that all transport logistics are complicated. Moving
even fresh and processed food to supply the present supermarket system is complex. Ensuring correct inputs on farms is complex. The grain supply alone that supports animal feed-lotting in Australia travels vast distances. In fact one of the biggest logistical set-ups occurs in Muswellbrook LGA with the movement of coal from far afield right through the centre of town either on its way to, or from Newcastle, the biggest coal port in the world. No matter what the biomass fuel source is, the closer to the processing plant the better.

According to the latest figures climate variation is destined to increase in the future (Intergovernmental Panel on Climate Change, 2013). This will be a considerable factor in securing affordable biomass and can have a negative impact on financial confidence needed to invest in infrastructure to manage the supply distribution. Expecting a few geographical areas to secure biomass supplies would be problematic, whereas extending the area where biomass can be grown for a particular plant may reduce risk.

This is one of the core management differences as energy moves away from the geographical constraints of fossil fuel. Whereas coal, oil, shale and gas originate in defined places, biomass has the capacity to be grown over a wider geographical range, reducing exposure to weather variation that can potentially retard the biomass supply. The present agricultural system tells us a lot about existing and potential capacity. Local knowledge should not be underestimated (Kates et al., 2001), as present agricultural systems need to be integrated to develop different technologies. Moving hay to a dairy is not that much different to moving a biomass bale to a CBC.

Feedstock supply deliveries can piggyback on the agricultural sector and the coal sector.

*Biomass transport cost and logistics*

How the biomass is transported is defined by the storage capacity and position of the CBC plant. Most biomass refineries have limited storage requiring constant deliveries of fuel. Cost control of the purchase, harvesting, handling, transport and storage is essential. All components can vary. Sims et al. (2006) points out in a study of wood removed from a single forest site using seven different delivery systems for collection and transport, that a wide range of costs are incurred. The system with the highest transport cost created the
overall highest biomass cost, despite variations in handling and storage. Transport remains the hardest cost to contain (Ruiz, Juarez, Morales, Munoz, & Meendivil, 2013).

Canada has a significant forestry sector and exports biomass for energy. Their industry is not dissimilar to Australia’s coal development. Both natural reserves are greater than local need and both have been exploited primarily for export. This has lead in both instances to services overlooking local needs. For instance, in Australia the Hunter region’s rail network is designed for coal not people.

Research in systems development and natural resources show that resource use defines development. When biomass capacity is assessed locally rather than as a national commodity the best delivery system can be defined (Bouchard, Landry, & Gagnon, 2013). As each geography is unique so too is each delivery system.

**Biomass site, scale and selection**

Agricultural residues, such as hemp and prunings could become relevant additional feedstocks once the industry is developed. Methodologies testing biomass availability, such as the Bovemar model and the Biomass Logistics Computer Optimization system, indicate the most expensive part of biomass production can be the harvesting and delivery costs (Velazquez-Martí et al., 2011). Maximising biomass volume per hectare will be important in reducing the costs in the supply chain. The delivery cost of agricultural residues or wastes are likely to be the same as all other agricultural deliveries.

The Hunter Valley has a fully integrated meat industry system. Agents, graziers, abattoirs, infrastructure on farms, designated transport servicing domestic and export markets and 200 years of history. Bioenergy enjoys none of these logistic advantages. There simply is not an integrated bioenergy production system, yet both systems could use much of the same equipment to integrate resources. Around the world transportation of all energy fuels is constantly evolving and absorbing billions of dollars worth of infrastructure as it forges ahead. Therefore, until bioenergy is developed, early adoption of a continuous biomass converter using green waste as a feedstock overcomes some of the transport obstacles.
Densification of biomass includes many different techniques such as baling hay and agricultural residues, forest trimmings and pelletising. Slow pyrolysis is also considered to be part of the pre-treatment process because it can convert biomass into the energy dense char product, which has multiple end uses. The assumptions on how best to convert biomass to improve transportation and delivery efficiencies are based on energy conversion rates and most assume slow pyrolysis to be lower than the CBC’s 96%. Uslu, Faaij, and Bergman (2008) for instance, found pyrolysis energy conversion efficiency to average 64% in their analysis. Therefore it is likely that the CBC can incorporate a different cost structure because the conversion efficiency is higher. Downstream systems may need to be simultaneously developed such as pelletising the biochar to facilitate improved handling.

8.3.5 Summary

When considering The Natural Step question, Is a CBC likely to produce a sufficient return on further investment? it is important to include all financial considerations. Therefore the char sale price of $200 per tonne is based on its GJ value (the current GJ value of thermal coal and current REC) because if the char cannot be placed in the ground at this price it could find an alternative market in a power station.

As a continuous biomass converter is a multi platform system, its position within the Emissions Reduction Fund scheme will vary depending on choice as well as delivery requirements of the outputs. Financial reward via the CFI and DAP is currently primarily granted when emissions are avoided. Only a few projects offer sequestration via reforestation and afforestation projects. Slow pyrolysis is engaged with realigning systems processes where not only are emissions avoided but a draw down of CO₂ can also be achieved when char is made and secured in the ground.

For instance, in the soil carbon sector, there is already a methodology approved by the CFI whereby strategic grazing helps build soil carbon. However, there is no approved system for simply adding char to the soil to provide carbon sequestration. Especially while small-scale slow pyrolysis
systems operate outside regulatory agencies, costs involved in auditing their performance have proved a significant issue for developing methodologies.

The most significant factor influencing the financing of a continuous biomass converter is securing local affordable biomass. However, the CBC capital cost is not high when compared to coal fired power generation and this allows for a more organic growth of the technology. Investment in small, local and sustainable multipurpose systems would be a significant change in the way energy systems are funded. To establish viability in Muswellbrook the value of the green waste, char and gas will define success.

Income can be generated in a variety of ways.

- Reduction of landfill (savings)
- Supply of renewable energy production incorporated into a council business such as the waste water treatment plant being made available for RECs
- Provision of a carbon sequestration product that may be eligible for funds via the Direct Action Plan.

In the short-term, planning for income via the energy value of char, rather than a price based on the sequestration value is more appropriate until there is market development for biochar.

To progressively reduce the ecological impacts of mining and to improve ecological efficiencies a continuous biomass converter could assist in a number of ways. As the World Business Council for Sustainable Development suggests slow pyrolysis can assist by:

- Reducing toxic dispersion
- Enhancing recyclability
- Increasing the use of renewable resources
- Extending the life of soil via char additions (DeSimone & Popoff, 1997).

All of these are important to achieve zero emissions, ensuring nature’s regenerative capacity is not exceeded and the potential to redirect legacy pollution is high. Thus, a continuous biomass converter is considered a collaborative technology that integrates multiple sectors, agriculture, municipal and industry.
8.4 Technology Adoption

There is no bioenergy sector in Muswellbrook. Furthermore, as described in Chapter 3 Pyrolysis, slow pyrolysis is not a developed sector anywhere within the bioenergy sector. At a more general level, bioenergy projects across Australia presently generate approximately $400 million annually (de Aquino Ximenes et al., 2012) and ABARES has indicated bioenergy for electricity is set to increase by 2.3% by 2030. The AERA report Clean Energy Council Roadmap suggested this might be even higher (Clean Energy Council, 2008). It would therefore be fair to suggest that nationally, some forms of bioenergy such as digesters and landfill gas projects are relatively well developed.

The Clean Energy Council (2008) report states bioenergy has not developed largely because of technological constraints and the failure of the evolving global and regional political frameworks within the bioenergy industry to drive uptake. This has not been aided by the constant refrain of ‘lack of market certainty’ due to changing renewable energy policies. There are a variety of state and national renewable energy targets, unique life cycle and economic analyses and numerous integrated designs for different renewable energy systems. While the term bioenergy has come to mean many different things, the discussion below refers only to The Crucible Group’s CBC system.

While the Carbon Pollution Reduction Fund offered some solutions, its political failure to be approved and the following introduced carbon tax in 2012 only offered a short lived financial benchmark from which to calculate income. The tax’s repeal, the CFI and the new Direct Action Plan offer different means of finding entry points and income for this new technology.

Richard (2010) suggests that the development of bioenergy systems will evolve from three fundamental biomass supply chains: the local, the regional and the global. Muswellbrook is well situated to take advantage of all three.

- Locally there is a readily available green waste biomass stream.
- Muswellbrook historically has been an agricultural area that has been interactive with adjoining regions engaged with livestock and cropping and already has agricultural systems in place.
• Muswellbrook is a rail hub and central to the transportation of coal across regional New South Wales and the port of Newcastle and therefore has access to infrastructure to develop future commodity transport.

Few regions have access to such rail infrastructure as Muswellbrook. This opens up the opportunity to consider the biomass commodity market and trading opportunities. As bioenergy products are developed and specifications more clearly defined, regions that can access transport infrastructure will be most advantaged. In the immediate term, a continuous biomass converter will need to be established where there is readily available cheap biomass and green waste is the most likely biomass source for early adoption.

8.4.1 Site selection

Site selection needs to meet pre-defined site parameter criteria where human energy needs and natural vegetation are optimized. Human need for energy in a city is far greater than natural vegetation whereas in regional zones like Muswellbrook natural vegetation will be greater than human need. Either way transportation will be a major cost of production.

Biomass has a larger spatial footprint than solar as it is a ‘land-consuming form of renewable energy’ (Blaschke et al., 2013). However, the biomass cost that justifies the transport price is locked into the conversion efficiencies of the technology used. General assumptions are often reported thus:

Big plants = big biomass volumes = big distances

Small plants = small biomass volumes = small distances.

A small biomass supply can mean a more secure supply, simply because less is needed. Once a plant size increases, the consistency of biomass availability becomes much less secure, which subsequently increases risk. Small plants also offer greater flexibility in terms of biomass varieties precisely because they need less feedstock (Ruiz et al., 2013). One CBC plant using 10 000 dry tonne equivalent (dte) biomass per annum could produce around 1 MW electricity from the gas (IEA classifies this size plant as small) (International Energy Agency (IEA), 2007). The scale of a plant usually defines type of feedstock, efficiencies, as well as capital and operating costs. Viability at a small scale is...
advantageous for securing feedstock supply for one plant, i.e. 10 000 dte should be easier than securing a bigger volume in the short term.

Sustainable agricultural intensification is defined as producing more output from the same land area (Conway, Waage, & Delaney, 2010) (Godfray et al., 2010B). Ultimately it is the same soil base that will supply the plant material no matter what or where its final destination. (Pretty, 1999) has analysed many different agricultural components where drought, water and social dislocation constraints are similar. He points out that up scaling from ‘small islands of success’ is important if transformation of the agriculture sector is to be achieved. Small systems also usually denote less negative environmental impact and carry less risk. Conclusions shift regarding true environmental costs dependent on site.

8.4.2 Transport. An acceptable distance

According to Sims et al. (2006) and International Energy Agency (IEA) (2007) the site selection assessment should be based on the nature and volume of the biomass. In other words, the biomass comes first. Even nuclear power plants situated close to European and Asian cities require uranium delivery usually from a considerable distance. No energy system functions without transporting fuel. Global trade in biomass related products have seen steady growth in volume despite fluctuating prices. Acceptable distance of any fuel supply is driven by price of the feedstock.

Many arguments opposing bioenergy cite transport logistic constraints of biomass because the energy density of biomass is less than fossil fuels and therefore greater volumes are required to be transported for a given energy output. Does the fact that a greater volume of fuel needing to be moved either by road, rail or sea, mean it is automatically logistically inefficient? Not necessarily, if the biomass can be delivered cheaply enough. In regional Australia it was common for coal sources not to be near the areas requiring the electricity. Coal-fired power stations used to be built near cities and the fuel delivered to them. By the late 20th century, power stations like Bayswater and Liddell were being built close to the source of coal. Fuel is not always available adjacent to areas where energy is most needed.
8.4.3 Role of Council

The 2009 Copenhagen Climate Change conference addressed the issue of responsibility for carbon generation in different jurisdictions and how this should be reported. The NSW Local Government Act 1993, via Agenda 21 legislation provided local government with greater reporting responsibilities on top of the regular land use planning, development approval processes, subdivision applications, soil conversation and land clearance controls.

OECD members are obliged to undertake State of the Environment Reports and in 1994 the federal government set up the State of the Environment Reporting Unit (Department of the Environment, 1994). There has also been a proliferation of small Clean Development (CD) initiatives.

As each council has the right to design their own sustainability frameworks there has been a high level of incoherence, un-coordination, un-evenness and, at times, systematic undermining of projects. The good intentions of ad hoc initiatives do not always lead to CD becoming normal and mainstream (Newell, Jenner, & Baker, 2009). Critical issues for Muswellbrook LGA in the future will be the decline of the coal industry, the increased waste rock/over burden and the potential liabilities of subsidence.

There is no legal obligation for Muswellbrook LGA to report on carbon emissions exported from the area, absolving responsibility for the CO₂ generated from exports. While this is legal it is ethically weak. Turner, Munday, McGregor, and Swales (2012) analysed emissions exported from carbon intensive industries in Wales and suggested the carbon footprint for the region was not fully calculated if the economic benefits and costs from carbon intensive exports were not included. Recognising the full consequences of total emissions is essential to understand a true and full carbon footprint.

Local Government New South Wales has now outlined procedures to evaluate the best ways to mitigate climate change (Local Government New South Wales, 2014). When considering Local Government as a significant local business and employer there is much that the council is doing to mitigate its own emissions. Council has been engaged with a variety of programs to reduce its own GHG emissions. Table 8:11 highlights how since 2009 some reduction has been achieved.
Table 8:11 Muswellbrook Council Estimated GHG Emissions

<table>
<thead>
<tr>
<th>Emission Category</th>
<th>09/10</th>
<th>10/11</th>
<th>11/12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>4.918</td>
<td>5.081</td>
<td>4.776</td>
</tr>
<tr>
<td>Diesel</td>
<td>0.696</td>
<td>0.663</td>
<td>0.561</td>
</tr>
<tr>
<td>Automotive gasoline (petrol)</td>
<td>0.164</td>
<td>0.121</td>
<td>0.121</td>
</tr>
<tr>
<td>Other Fuels</td>
<td>0.026</td>
<td>0.026</td>
<td>0.023</td>
</tr>
<tr>
<td>Methane emissions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Waste Management Facility</td>
<td>14.91</td>
<td>15.700</td>
<td>13.147</td>
</tr>
<tr>
<td>Water and Waste</td>
<td>2.741</td>
<td>2.741</td>
<td>2.741</td>
</tr>
<tr>
<td>Total Methane emissions</td>
<td>17.651</td>
<td>18.441</td>
<td>15.888</td>
</tr>
<tr>
<td>Total</td>
<td>23.455</td>
<td>24.333</td>
<td>21.369</td>
</tr>
</tbody>
</table>

*Note: Adjusted Muswellbrook Council State of the Environment report (2012)*

These emission reductions do not address the consequences of being surrounded by the carbon intensive coal industry where the CO₂ exposure is calculated after the coal is exported.

There are two challenges for Muswellbrook Council regarding emissions reduction:

1. to reduce emissions from their own activities
2. to facilitate the creation of new low emission industries in the region

The location of a CBC plant in Muswellbrook will depend on the biomass availability for the life of a project, but it must also match the local energy needs, either as electricity or heat, for the area. Muswellbrook only has three Council businesses with significant energy requirements:

- Indoor swimming pool
- Regional Art Gallery
- Waste water treatment plant

The wastewater facility is likely to be the only asset to engage directly with bioenergy production primarily because although the energy needs of the pool and art gallery are significant they are not geographically placed in an appropriate area where biomass delivery could easily be carried out. There are no local manufacturing businesses requiring significant heat. Therefore it is unlikely that the gas output would be used directly for heat and would be further processed into electricity to offset council electricity purchases. This
means that the price of the gas electricity produced needs to be comparable to other renewable options and coal.

Comparing coal-fired energy with a CBC is, in some ways, irrelevant because one is large scale and stationary whereas a CBC plant is small and can create energy (heat and char) into a distributed system. But the two can be compared in relation to price. Unless there is a clear political directive as has been the case in Europe (Sjølie, Trømborg, Solberg, & Bolkesjø, 2010) viability of a CBC plant will be dependent on prices comparable to coal.

While general equilibrium models and econometric methods are used to balance the finer points of a cost analysis and comparisons with energy systems (Sjølie et al., 2010) especially GHG emissions, the primary costs need to be addressed first before a plant can operate to test such assumptions. Identifying future land and water availability and agricultural prices may be volatile while the coal sector undergoes restructure.

Raymer (2006) for instance concluded, after conducting LCA on 6 different wood energy systems, that when all the uncertainties were considered there was very little difference in the avoided GHG emissions between the different biomass sources. He concluded that the most significant differential was the technology used for the conversion.

Focusing on one CBC plant, securing enough biomass, assessing the sustainability and price of that supply and developing a market for the outputs seems a sensible start.

Green waste will engage local council as the biomass supplier and the community as the supporting supplier. The wastewater treatment plant may be able to use the electricity created, accept all the pyrolysis liquid while higher value markets are being developed and the local region could use the char produced. Therefore the full engagement with the inputs and outputs could be achieved locally. Will a continuous biomass converter be able to engage a motivated citizenry? Will it need to? In the short term, the support of local council alone may meet the immediate requirements to facilitate the coordination of inputs and outputs.
8.4.4 Regulations and Standards

Regulations are changing and integrated into legislation as climate change policies and new technologies open opportunities. A continuous biomass converter will operate under a number of legislative regulations for all sections of the operation. Compliance regulations will include federal, state and local rules overseeing:

- Biomass production
- Pyrolysis
- Transportation
- Energy
- Agricultural food and fibre sectors.

Integrating policies will help to interconnect these challenges. Broad scale clearing of native vegetation for bioenergy is prohibited in each state and territory and regulated under various state legislations. Federal and State government regulations also oversee waste management and waste-to-energy streams where local councils have the responsibility to ensure compliance. Sustainable outcomes regarding waste seek to reduce the volume going to landfill. Bioenergy projects that offer a resource recovery pathway for waste biomass are contributing to this.

As shown in Table 8:12 some specific issues outside the technology development are listed. As a continuous biomass converter will be operating 24/7 local compliance will be unique and site specific. EPA pollution rules pertaining to air, soil and water will all need to be met.

**Table 8:12 Noise Compliance**

<table>
<thead>
<tr>
<th>Noise Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Truck movements</td>
</tr>
<tr>
<td>Green waste shredder</td>
</tr>
<tr>
<td>Forklifts loading activity</td>
</tr>
<tr>
<td>Compressor</td>
</tr>
<tr>
<td>Pyrolyser</td>
</tr>
<tr>
<td>Gas engine generator</td>
</tr>
</tbody>
</table>
8.4.5 NSW Energy sector

NSW electricity sector has been facing a number of problems including aging stationary assets (Auditor-General’s Report to Parliament, 2008). The separation of electricity generation, transmission, and distribution functions into private and statutory companies is slowly evolving and remains incomplete. This separation and privatisation is part of a global trend that has been underway during the past three decades (Hughes & Tillman, 1998). Economic uncertainties surrounding coal remain high with the potential for coal-fired power stations to become future stranded investments (Nelson, Kelley, Orton, & Simshauser, 2010). Together with changing environmental regulations businesses are driven to take a short-term economic and environmental focus. Yet within today’s uncertain world co-firing is a relatively low-risk means of reducing GHG emissions, with low costs involved if the biomass can be accessed nearby at a cheap price (Hughes, 2000).

The new structures demonstrate that the old centralised control of energy delivery will not define the future energy market. This is inevitable with the increase in renewable energy supplies from wind, solar and hydro feeding into the present grid system. In 2010 the NSW state legislation clause, Protection of the Environment Operations (General) Regulations allowed timber to be used for wood products but forestry waste from native timber was legally prohibited. It was amended in 2014 to allow new biomass feedstock for bioenergy; tree heads, offcuts of trees cut for sawlogs, and trees that might otherwise be made into pulp for paper production are now available for bioenergy. This new ruling still requires the timber volume and type used for the energy sector to be registered with the NSW EPA.

8.4.6 Forests and Plantations

Forests

Dr Heather Keith ANU reports that biodiversity can be high in temperate forests, even better than the tropics, thus indicating a managed temperate forest is arguably better for biodiversity conservation. This is interesting news for places like Muswellbrook, even though Forests NSW suggests the rainfall
levels just fall short of the area being a highly productive forest area. This is despite almost half the LGA being a dedicated National Park.

There is no mature development of short-rotation forests designed for bioenergy in Australia as there is in Europe, Canada and the US. Australia can learn much from these short-rotation forests, where numerous experiments have been carried out on a variety of sites, with a variety of species, (many of them Australian natives). Projects established in the 1970s after the oil crisis provide valuable long-term observations and frequently positive ecological interdependence.

European plantations have two characteristics not applicable in Australia; there is already a coppicing tradition, and there is a need to reduce agricultural over production in light of the high cost of farm subsidies. Yet these short rotation forests demonstrate that the impacts on nature need not be disadvantageous as Trinkaus (1998) demonstrated in comparative studies of different plantations in Austria.

Forest plantations have been established the world over, are expanding and play an important role in economic development FAO (Food and Agriculture Organisation of the United Nations) (2010) the oil age probably saved some forests from the axe. The energy dense resources in forest plantations are today recognised as an essential component in building local biodiversity and ecosystem services. When forests are felled there is a one off release of carbon dioxide. At harvest time, most timber in a sustainably managed forest only utilises approximately 50-70% of the aboveground biomass for a variety of wood and energy products (Lippke et al., 2011). The remaining biomass made up of the tree crown, leaves, broken stems, dead trees and litter are usually left to decay or burnt. Until the carbon values are otherwise recognised this biomass is currently viewed by the forestry industry as an uneconomic biomass supply.

**Plantations**

A well-managed, high performing bio-energy plantation on the other hand can offer a greater opportunity to sequester carbon during its growing phase. There have been many unique surprising findings in the literature, such as willows (*Salix sp*) grown in Sweden for bioenergy being found to have a high
uptake of cadmium which improved soil health, helped clean water and build humus. It was discovered the crop needed little herbicide and did not degrade the ecosystem (Ledin, 1998).

Understory measurements, diversity and composition has shown that the *Eucalyptus* plantations overseas have provided poor habitat for their native biodiversity where Eucalyptus’s exotic status can inhibit natural forest species ability to compete (Calviño-Cancelaa M, Rubido-Baráa M, & van Ettenb J B, 2012).

While this may not be an issue in Australia, it is interesting to see the role native species play in facilitating ecosystem services and the importance of using native species to secure habitat connectivity. Eucalyptus is now ubiquitous the world over and yet few eucalyptus species are deployed in managed plantations on marginal low rainfall regions in Australia. In the early 1990s a variety of mallee plantings in the WA wheat belt were established primarily to help combat salinity. Belts of trees were integrated with existing crops and livestock production to offer marketing opportunities as wood and non wood products such as biochar, bioenergy, carbon sinks and eucalyptus oil (Bartle & Shea, 2002; OMA, 2009; Shea et al., 1998). These large plantings have also provided significant land rehabilitation benefits (Barton, 1999).

Government research by RIRDC and CSIRO have evaluated species in *low rainfall* areas in South Australia where reintroduction of tree species have facilitated improvements in dry land salinity and soil erosion (Hobbs et al., 2009). These reports, while not based in the Hunter Valley are useful in analysing ecological improvements and understanding their use as bioenergy feedstock.

Validation of native forest growth rates in Australia (Paul, Polglase, & Richards, 2003a) has been important in understanding fluctuating soil C rates over the life of plantations (Paul, Polglase, & Richards, 2003b; Polglase & Attiwill, 1992). Accurate calculations are essential to guarantee proper GHG accounting. Accumulation of soil carbon was found to increase when plantation understories included N₂-fixing species. If forest litter was included in the soil carbon calculation the total increased (Paul, Polglase, Nyakuengama, & Khanna, 2002). Research carried out in Hawaii also showed how different
Eucalyptus species, grown outside their natural rainfall criteria do not necessarily respond efficiently to coppicing (Bowersox, Schubert, Strand, & Whitesell, 1990). These studies on the performance of different native species are useful in light of bioenergy and provide much needed and useful data in order to verify sustainable supply.

Most of the native vegetation in the low-lying areas of the Hunter Valley was cleared soon after white settlement (Archer, 2007). Yet reforestation on grazing lands can have undesirable outcomes especially regarding water use and in particular the redirection of water patterns. The CSIRO conducted considerable work on stream flow impacts in different regions and concluded not all plantations have a negative impact on water movement (Brown, McMahon, Podger, & Zhang, 2006). Plantations in Muswellbrook LGA have been established on mine sites to investigate their performance in saline conditions. The trees were not designated for bioenergy and are now incorporated into the rehabilitation areas and offer small biodiversity hubs.

A silvopasture system where short rotation coppicing is undertaken can accumulate 6.62 tonnes of carbon, per hectare, per annum (Smith, Sessions, Tuers, Way, & Traver, 2012). This can be better than woodland regeneration, grassland rotations and agricultural processes, although cover cropping and crop rotations may quickly facilitate biodiversity. Forest plantations can offer complementary environmental services and produce different carbon based outputs.

The correct site choice can make all the difference regarding ecological impacts, but it is also the main factor determining economic profitability. (Husain, Rose, & Archibald, 1998) cites how hybrid poplars planted for bioenergy on marginal land in Minnesota could offer a valuable income stream and improve overall farm profitability.

Plantations created via Managed Investment Schemes (MIS) during the 1990s were established across thousands of land titles. These have been rife with failures and receiverships (Sykes, 2010). When these projects were proposed self-sufficiency in timber was viewed as a beneficial economic long-term plan. Almost no region took MIS’s without arguments about loss of community, inflating land values and biodiversity loss. In hindsight concerns that projects
were driven by tax incentives instead of product needs have been proven correct. Now, as private plantations of various sizes and quality emerge onto the sale market, it has been revealed that many plantations have never been thinned. This provides a significant bioenergy feedstock resource.

This suggests that tax incentives, while instrumental in raising the capital for planting trees, have not been a profitable way to manage long lived tree stands. Precisely where the tax incentive should be for planting biofuel based trees is undecided. It is important that trees for biofuel do not undermine the market for long lived timber products needed for the building and furniture industries and valued for their long carbon storage. Creating a hierarchy of wood uses is essential to maximise carbon mitigation.

Various Australian species for plantations under review for biofuels (Hobbs et al., 2009) were discussed in the section of energy crops. The short-rotation plantations in the Condobolin region in NSW and in SW Western Australia designed specifically for bioenergy offer insights for the Hunter Valley (Baumber, Merson, Ampt, & Diesendorf, 2011). Although these plantations are still young, having been planted this century, they have been planted with the specific intention of being harvested for bioenergy within the next decade. The measurements for carbon storage, fuel value and ultimately emissions reductions should be comparable to the Hunter Valley. According the Forests NSW water has been the main restriction in developing a forestry industry for timber in the Hunter Valley where no private commercial plantations for timber have become economically sustainable. But this may not be the case for developing woody plants for biofuels. Native and Plantation forest management is widely regulated, unlike agriculture that does not legally require farms to carry out natural resource management (NRM) plans to operate.

8.4.7 Risks

The Rural Industries Research and Development Corporation, 2009 sustainable production of biomass report says:

There appears to have been insufficient attention given to how to evaluate differing sustainability outcomes, and how to address trade-offs in the components of
Trade offs cannot be evaluated without a focus on the outputs of a technology. Assessing potential sustainable growth and extraction is only fully understood if the converted outputs are priced and identified. While one risk involved in a CBC project is financial, there is also the issue of the social license to operate. As described above, the debate whether to grow food, fibre or fuel is far from over and the fear of unintended environmental risks and food security is real.

The agricultural sector does not conduct formal compliance risk assessments on farms. Industry bodies may calculate risks but these are not part of a required farm audit. Risk evaluation in the coal sector on the other hand has established formal assessment procedures for every process undertaken.

Unlike coal mining though, which fully removes a resource, bioenergy has the capacity to grow sustainably. Therefore the assessment process and the acceptable risks of coal are fundamentally different to a bioenergy project. The loss of ecosystem function is classified as an acceptable risk during coal mining, yet is regarded as unacceptable for bioenergy (International Energy Agency (IEA), 2007).

There have been a number of coal mining pollution incidents that have drawn international attention. For example at Yallourn coal mine when the dam wall broke and the pit was flooded in Victoria (2012), the Georges River in New South Wales (2010) was cracked due to underground mine subsidence. These are incidents that would be classified as unacceptable within bioenergy sustainability frameworks and highlight the fact that managing the environment post mining is a risky business. Bats often occupy disused mines, accessing areas where heavy metals discharge into the water system. One study in Brazil found the local bat community had abnormally high levels of Al, Mn, Fe, and Ni suggesting this may cause DNA damage. Bats are useful bio indicators and can help track human health risks associated with exposure to non-essential and potentially toxic elements (Zocche et al., 2010).

While efforts are made to contain waste on mine sites throughout the Hunter Valley, history shows that mining companies are allowed to release polluted water and waste into the Hunter River system during times of high flow. (NSW
DEPT Planning 2009). (As was the case under extreme circumstances during the 2011 Queensland floods.) Heavy metals do not dissipate and tend to concentrate in the bottom of river courses.

The other risk is potential air pollution. The 2013 Upper Hunter Particle Characterisation Study by CSIRO collated the recent scientific advances regarding health impacts of particulate matter pollutions and concluded that especially for PM$_{2.5}$ there is:

- Sufficient evidence to conclude that long-term and short-term exposure causes illness and death from cardiovascular conditions, and is likely to cause respiratory conditions.
- Associations have been observed between exposure and reproductive and developmental effects (Hibberd et al., 2013).

Biomass combustion can be an important source of inhalable particulate matter smaller than 10 microns. Ensuring the biomass is free from pollutants will be essential to ensure particulate matter does not become a problem. As Baral and Malins (2014) concluded, GHG emissions were reduced by 60% in the UK transport sector when a biofuel carbon calculator was used as an LCA framework and tested in three pathways. It will be important that the GHG gains are not negated by particulate matter pollution.

### 8.4.8 Technical considerations

Slow pyrolysis offers three major pathways for biomass conversion with the pyrolytic functions varying according to the biomass used. Cellulose, hemicellulose, and lignin, are the three main components of biomass and each part breaks down differently during pyrolysis. Thus it is common to read that certain types of biomass are not suited for certain pyrolysis conversion processes. For instance one biomass source may be better for gas, another for biochar. Understanding the commercial end-product requirement and price should define the best biomass source.

A biomass based energy system that seeks to replace a specific fossil fuel application must prove it can achieve the same energy output with fewer inputs than its fossil fuel equivalent.
One of the biggest barriers for the biomass industry has been the perceived problem of its net energy production. Baseline understanding of how biomass feedstocks respond in the CBC will assist analysis. Two core issues will be needed before any full assessment of a specific biomass supply is undertaken.

1. calorific value

2. fuel quality

In the future competition for biomass sources is likely to increase, with commercial gasification plants now operating with a large variety of conversion efficiencies (Chapter 3 data shows approximately 60% efficiency) and in the transport sector 1st generation transport fuels (food based biomass, i.e. corn, soy, sugar, vegetable oils) are widely deployed as bioethanol and biodiesel. Plus 2nd generation lignocellulosic feedstocks (forestry residues, woody grasses and algae) are rapidly developing. (Chauhan, 2010; Field et al., 2008; Klass, 1998; Rosillo-Calle et al., 2007).

8.4.9 Existing infrastructure

Hunter Valley infrastructure needs as shown in Table 8:13 are based on ACIL’s Vision 2020. If the coal sector expands, infrastructure short falls are likely as rail track availability is already limited and water supplies in short supplies. This is a dilemma for the coal sector where contraction has been continuous throughout 2014 with lay offs primarily triggered by low thermal coal prices. If there is no further growth in the sector future rail investment is less likely to be needed. So in the short term there is no more space to access rail infrastructure for bioenergy, but post coal mining freight availability could be likely.

Table 8:13 Hunter Valley Infrastructure data

<table>
<thead>
<tr>
<th>Region</th>
<th>Infrastructure class</th>
<th>Current and Future Gaps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hunter Valley</td>
<td>Rail</td>
<td>Rail Infrastructure unlikely to meet growth in freight task</td>
</tr>
<tr>
<td>Hunter Valley</td>
<td>Ports</td>
<td>Lack of sufficient coal loading capacity</td>
</tr>
<tr>
<td>Hunter Valley</td>
<td>Water</td>
<td>Lack of water supplies</td>
</tr>
</tbody>
</table>

Note. Adapted from ACIL Tasman Vision 2020 Project Table 1 Summary of infrastructure requirements under growth scenario to 2020 for the Hunter Valley
8.4.10 Technical readiness and maturity

While most investment in climate change has been in various mitigation measures, there has been a growth in attention of policymakers to integrate multiple objectives in climate investments but ‘understanding many of the interactive effects are underdeveloped’ (Intergovernmental Panel on Climate Change, 2013). As shown in Table 8:14, the continuous biomass converter has undergone a series of development stages many of which interact with each other.

Table 8:14 Technology development criteria

<table>
<thead>
<tr>
<th>The Crucible Group Development Criteria</th>
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</thead>
<tbody>
<tr>
<td>Technical readiness and maturity</td>
</tr>
<tr>
<td>Performance achievements</td>
</tr>
<tr>
<td>Process capacity</td>
</tr>
<tr>
<td>Power generation</td>
</tr>
<tr>
<td>Char and pyrolysis liquid applications</td>
</tr>
<tr>
<td>Emissions</td>
</tr>
<tr>
<td>Regulatory interface</td>
</tr>
<tr>
<td>Quality, safety and environmental credits</td>
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</table>

This confirms the continuous biomass converter is presently operating at Technical Readiness Level 7, with ‘System prototyping demonstration in an operational environment’ (Australian Government, 2014b). The technology has been able to maximize all outputs and not create waste streams in the process. The management of the technology to ensure health and safety standards are met will depend on how the outputs are used. For instance, if biochar is to be pelletised and packaged at site, it will require different measures than the char being fed in a powdery form directly into industrial equipment, as such boilers or kilns.

The same issue applies to the pyrolysis liquids. If this output is to be collected and re packaged this will require a significant increase in the site’s footprint. However, if the liquid is to be sent straight into a water waste system then this process is simplified and the focus becomes one of monitoring, not the management of volume.

High water content of raw biomass has made bio-products deemed inferior to fossil fuels. The percentage of moisture in biomass can also impact on pyrolysis efficiency. The most economical way to dry any biomass is to use the
sun’s heat first. Yet there may be a necessity to dry biomass on site, for instance, using waste heat from the power generation plant.

New research focusing on producing chemicals and other by-products from biomass while simultaneously producing energy is also an expanding field, suggesting biomass’s multifunctional role is yet to be fully explored and certain to be valuable beyond energy markets (IEA, 2009).

8.4.11 Summary

The slow pyrolysis sector has been shown to be globally an embryonic industry. The integration of a new continuous biomass converter into the existing energy sector to live up to Muswellbrook’s corporate motto ‘bursting with energy’ has been explained. Impacts of the radical land use change firstly in the 19th century when the land was cleared, native vegetation removed and introduced species became dominant and, secondly in the 20th century to the present with the expansion of coal mining. During both phases negative impacts to land and water use have been reported. If a continuous biomass converter is to drive another land use change and avoid further negative land and water impacts, it will require sustainability criteria to be incorporated. These issues have been discussed within three fundamental themes.

• The sustainable parameters, including land, water and social implications
• A financial assessment based on core assumptions at market prices during 2014, post removal of the carbon tax.
• The first stage of technology adoption of this new technology.

When focusing on efficient energy and water use, total output, reduced production risk and local ecological impacts, industrial agricultural enterprises can implement expensive new technologies and benefit from tax offsets. Business success however is not guaranteed as many failed Managed Investment Schemes reveal (Sykes, 2010). Also, across OECD nations government support for agriculture is facing a downward trend.

The biomass resource base is not necessarily a limiting factor because often the poor utilisation of land and water resources is at fault (Falvey, 2010; Lappe & Collins, 1982; Osvald, 1966). Although the removal of crop residues for bioenergy is considered negative by some researchers when biomass
output is transferred to a more secure carbon pool such as char, combining improved soil management with carbon redistributed and sequestered across agricultural fields, biomass residues become complementary not competitive with other uses.

To progressively reduce the ecological impacts of mining and to improve ecological efficiencies, a continuous biomass converter would assist in a number of collaborative ways as it integrates multiple sectors, agriculture, municipal and industry. All of these are important to achieve zero emissions so nature’s regenerative capacity is not exceeded and the potential to redirect legacy pollutants is high.

• Reducing toxic dispersion
• Enhancing recyclability
• Increasing the use of renewable resources
• Extending the life of soil via char additions

Options for early adoption with income options have been outlined. Projects are most likely to be viable if they can monetise all the multiple outputs. While a facility will be uneconomic without affordable biomass availability it also needs to match the energy demand of the area. This is unique in Muswellbrook because there is a need for:

• Renewable energy to meet local targets
• Soil amendments for rehabilitation
• Development of new industries in preparation for the post coal economy
• Improved management of green waste

The Council Environmental Objectives from the Community Strategic Plan 2011-2021 states clearly the intention to “Improve long term sustainability of infrastructure assets” (Muswellbrook Shire Council, 2012a). Finding the synergistic combinations between coal and biomass are needed so biomass can be hooked into existing infrastructure.

With so much soil disturbance surrounding local coalmines, plus heavy metal contamination risks, utilising biomass close to rehabilitation sites – even if the nutrient content is not as high as other biomass sources - can offer considerable soil benefits such as carbon sequestration, moisture retention
and mycorrhizal facilitation. Thus the concept of promoting biodiversity while reducing risks of contamination and creating renewable energy would be conducted simultaneously.

The International Energy Agency (IEA) calculated that for bioenergy to produce 20% of the world’s primary energy needs by 2050, biomass production will need to increase four times (International Energy Agency (IEA), 2008). If the bulk of the biomass is to be lignocellulosic feedstocks such as green waste and energy crops then the bulk density will be lighter than if grains (first generation biofuels) are used. Containing the transportation costs of biomass delivery will be a major consideration for defining the feasibility of future projects. For biomass to replace coal for example, it will require more frequent transportation movements.

The IEA however has based these biomass requirements on conversion efficiencies of 60 per cent (International Energy Agency (IEA), 2008) and the continuous biomass converter has a conversion efficiency of around 96 per cent. Therefore the true value and efficiency of biomass requirements for the CBC is better than the baseline projections used by the IEA.

Transportation infrastructure has been developed and consolidated throughout the Hunter Valley for the coal sector and is now well situated to develop future bioenergy systems because it can utilise existing infrastructure without huge investments in road and rail to move the biomass and end products. The population density and existing businesses in the Hunter Valley presently has limited need for heat, so the gas will need to be used locally as renewable electricity. A CBC cannot be compared with present coal system because coal fired power was established for industrial and retail electricity supply only. Control and security of supply was the primary consideration. Environmental impacts, such as water usage, air pollution, salinity and legacy impacts were not a focus of former planning decisions. Nor were global climate change impacts.

Deliberations of this thesis, and the four meta-analysis reviewed indicate there is an overwhelming view that char is beneficial to soil when added as a soil ameliorant and in the process carbon is sequestered. However, the financial value in carbon sequestration remains unrealised.
Possible uses for char in the area have been identified:

- Soil conditioner for already productive soils
- Biochar as fodder – a steady process of delivering biochar
- Rehabilitation
- Assists composting processes
- Back up position where local power stations could use char as an alternative to coal

A continuous biomass converter project will have to ensure it develops sustainable land management practices, maintain carbon balances, safeguard biodiversity, water resources and soil function. These requirements are not presently required for agriculture, although water management and specific rehabilitation criteria are required with mining developments (NSW Department of Mineral Resources, 1999). Ironically sustainability management compliance applies to mining that is not sustainable but is not legally binding to potentially sustainable activities like agriculture.

The thesis has provided a strategic assessment of the continuous biomass converter system within the context of the broader bioenergy sector.

- Described the biomass necessary to operate one system.
- Identified existing land use and areas where multiple uses can be carried out.
- Evaluated the present and future biomass availability in the Muswellbrook LGA.
- Reviewed the literature of two main outputs produced, biochar and pyrolysis liquid.
- Completed a random block field experiment using biochar and pyrolysis liquid.

Alan Savory, President and Co-Founder of The Savory Institute said ‘We are a desert making people.’ This statement captures precisely the long-term implications of the human impact on Hunter Valley ecosystems. If we keep doing what we are doing more deserts are likely. Consequently there will be less biomass in the future and any biomass will be placed in the pecking order of priorities, determined by the political agenda of the day. Biomass is a
valuable store of chemical energy and a unique form of renewable solar energy. A CBC plant may assist in the understanding of this fact. Emerging technologies are worth taking seriously. Redesigning the future energy market will be a change that takes many steps.
CHAPTER 9  CONCLUSION

This thesis firstly explored linkages between the physical reality of the biomass availability, the infrastructure development options available in the Muswellbrook study area and the government directives to incorporate energy efficiency and GHG mitigation. It outlined:

- The biomass needed for one continuous biomass converter
- The conversion technology itself, including all outputs
- Defined char and pyrolysis liquid as unique products produced during the process and tested the products in the study area.

During the course of research it became clear that for biomass to become an acceptable fuel with the social license to proceed there needed to be a greater understanding of its full potential and all the outputs produced. Alongside the national discourse on sustainable agriculture, agricultural residues have been positioned as a significant component in soil protection. Campaigns to stop burning stubble, the promotion of green manuring crops to build organic/plant matter into soil profiles have all placed agricultural residues in a different light, where they are no longer perceived as waste but an important component for building better soils. Biomass cannot be subjected to a simple either/or replacement comparison with coal. Coal extraction provides no GHG mitigation or soil development.

The various requirements for technology uptake and the biomass supply chains using a sustainability lens concluded:

- The most appropriate avenue to introduce the technology is via local government engagement with GHG emission reduction goals
- The necessary biomass feedstock can be acquired via the ongoing green waste stream collected by Council
- The most cost effective place for early adoption is near a wastewater treatment plant so all the pyrolysis liquid can be directed into the water system. This is important while the market for pyrolysis liquids develops.
9.1.1 Global Relevance

The thesis accepts that the need for a global decision for reversing climate change and that globalisation of economic and cultural life is irrefutable. Like all organisms humans are modifying their environment. No ecosystem today is considered to be without some pervasive human influence. The rate of change is increasingly technologically driven, expanding in scope and type of modification, and the rearranging the earth’s biology threatens the survival of many species. It is estimated that up to a half of the earth’s land surface has now undergone some kind of human transformation (Vitousek et al., 1997). That said, local decisions that have global consequences are made in light of unique and specific access to local financial, cultural and natural resources. Local decisions to adjust natural resource management in Muswellbrook LGA to reduce GHG emissions will be but one step in an ever-changing redevelopment of land use.

Together with the background knowledge that a 40% increase in human population is expected by 2050, and the net primary plant production is fixed by planetary constraints, the situation is urgent. This may not prove a problem for the future when one considers that grain production has more than doubled over the past 5 decades yet only used 9% more land. Redirecting some plants into char production could expand the present carbon stocks to facilitate more plant growth. For biomass to be used for carbon abatement, char needs to become a preferred option and must prove its agronomic benefits. The price and value of carbon abatement will only be clarified once a price for carbon is understood and/or traded. What is necessary immediately is to start incorporating bioenergy into the agricultural systems of the future. Although plants dominated fuel use before fossil fuels, incorporating plants back into the energy sector should not be seen as a step back into the past.

A continuous biomass converter will have an impact on the complexity of the agricultural systems presently in existence. How we value land and what we expect to get out of it is a core question. Clearing vegetation and using fossil fuel inputs in agriculture are two of the biggest activities responsible for GHG emissions. The future growing and cutting or clearing of vegetation even if the clearing is temporary needs to become an acceptable land management concept. At present there is a cultural perception that using forest reserves is
negative. Even establishing enough controlled experiments to evaluate the risks to prove otherwise is difficult.

Muswellbrook LGA’s ability to move swiftly to a more sustainable economic future while relying on the coal sector for short-term economic development is the challenge. A new industry needs to be established sooner rather than later to minimise social upheaval. Muswellbrook LGA residents who work in or around and live adjacent to coal mines have first hand knowledge of many of coal mining impacts; air quality, water use, safety regulations and cultural connections. Perhaps this is why 60% of people working in the local five coalmines chose not to live in the area.

The fact that State of the Environment reports shifted from annual to occasional reporting indicates the incorporation of ecological thinking is still an inadequate part of the political planning process.

9.1.2 Future work

There are several areas where future work could build on the results of this thesis. For instance, to assist in early adoption of a new technology it is necessary to find value in all the products produced. It is also necessary to understand how the technology can be placed within the rapidly changing climate change policies, because if income cannot be received from the products it may be generated from energy savings or renewable energy certificates.

Future research focusing on pyrolysis liquid could help develop an Australian market and assist in the long term with the reduction of agricultural chemical use. Testing the pyrolysis liquid against specific local weeds at various dilutions will assist defining usage parameters.

While economic feasibility was demonstrated to be possible with this thesis, further studies identifying and developing markets for the outputs produced will be necessary to up-scale. This thesis has laid the foundations for further holistic research and development to position Muswellbrook for a positive future in the post coal era.
9.1.3 Final Conclusion

This thesis invokes a future idea against the current reality of the present energy system. New competition for resources and new market opportunities could drive change in the rural economy of Muswellbrook. Depending on how these changes are managed there is the potential to improve economic diversification after coal mine closures with a continuous biomass converter. The advantage is its flexibility, not only regarding its inputs but also its outputs. It can be a cost effective system covering a moderately small area. The scope to enhance local livelihoods directly and indirectly via this new technology uptake remains considerable.

Key issues are likely to be competition for land and the expansion of new outputs – char, pyrolysis liquids and gas. The opportunity to develop bioenergy crops will be facilitated by the establishment of the technology in the region. The positive and negative effects of a CBC in Muswellbrook are listed in Table 9:1.

### Table 9:1 Positive and Negative attributes of a continuous biomass converter

<table>
<thead>
<tr>
<th>Positive</th>
<th>Negative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Help meet local RET</td>
<td>New therefore risky</td>
</tr>
<tr>
<td>Provide energy savings</td>
<td>Must ensure a sustainable biomass supply</td>
</tr>
<tr>
<td>Create new economic development</td>
<td>Possibility of social opposition</td>
</tr>
<tr>
<td>Create direct and indirect jobs</td>
<td></td>
</tr>
<tr>
<td>Diversify local energy supply</td>
<td></td>
</tr>
<tr>
<td>Assist land rehabilitation</td>
<td></td>
</tr>
<tr>
<td>Sequester C in soil</td>
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</table>

Muswellbrook LGA provides some key advantages for being an early adopter of this technology.

- It is presently a wealthy shire with a strong economy
- Local government is willing to lead
- Urgent need to consider the local economy post coal
- Has two major coal fired power stations in the region
- the CBC demonstration plant at Delta Electricity is a local reference site.

Indications are there could be further downstream business, such as pelletising the biochar, or on selling of pyrolysis liquid. Muswellbrook could integrate a CBC into existing businesses and this is a key factor for early
adoption as recommended by RIRDC. While the NSW Department of Planning oversees mine rehabilitation developments, individual mine plans are flexible and constantly adjusted. Muswellbrook Shire has defined its Mining Rehabilitation Policy (Muswellbrook Shire Council, 2011a), to include new interpretations on final void design and the use of biochar for rehabilitation. This local government document is part of the broadening considerations in final rehabilitation negotiations, and an indicator of the development of collaborative management.

The complexity of issues surrounding establishment of a project include the efficient use and income of the outputs as well as access to biomass supply. A bioenergy policy option including slow pyrolysis has not previously been available to councils. Therefore using green waste for energy, and the soil amendment benefits of char have not previously been under review.

This thesis has bought together the fundamental components of a new slow pyrolysis system, called a continuous biomass converter, for consideration. The thesis provides proof that the pyrolysis liquid output has economic value. It also confirms that biochar could be advantaged when applied with pyrolysis liquid, even in good quality soils. The thesis identifies local areas where early adoption of the technology could take place and where the outputs could be used. Although future use of the outputs needs further market development, there is an opportunity where energy savings can be achieved and biochar applications used either for mine rehabilitation or used as a coal substitute. Although using char in a coal fired power station for energy does offer renewable energy certificates, it does not in the long-term facilitate the development of a sustainable rural economy.

It is becoming apparent that successful innovation uptake is rarely the inevitable consequence of a linear one-directional approach with new technology simply usurping the role of the old. It is multi-factorial, requiring institutional, attitudinal and perhaps legislative changes to encourage commercial production. As the recent history of transformational technology from Silicon Valley attests even the mysterious element of luck has to be factored in.
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