21

Taking Biochar to Market: Some Essential Concepts for Commercial Success

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Introduction

The apparently beneficial properties of biochar (see Chapters 2 to 6 and 12) seem to support immediate investment to bring biochar to full commercialization. Certainly, there are those 'true believers' or 'early adopters' who will invest in the commercial opportunities related to biochar before it is fully proven or established, usually with smaller, but strategic investments. These pioneers are important and must be encouraged; but the biochar sector will need to attract and rely on more traditional sources of investment in order to secure its future for the long term.

For this to happen, the tangible properties and benefits of biochar will need to be presented in a commercially logical context. All of the remarkable properties of biochar need to be verified and taken to market and all the commercial promise and demonstrable benefits presented to potential customers as a viable and cost-effective offer. However, within the context of a carbon (C)-constrained environment, there is potential for over-enthusiastic exploitation that could damage or delay the medium-term commercial prospects for biochar. This has occurred most recently in the first-generation liquid biofuels sector, where the rush to produce the biodiesel and ethanol products neglected to address the genuine sustainability of the actual methods of supply and production for these materials (Giampietro and Ulgiati, 2005). The biochar sector would do well to analyse and understand this experience in order to avoid similar pitfalls and inform a more sustainable commercialization pathway. This is discussed in more detail below in the section on 'Lessons from the first-generation liquid biofuels sector'.

Biochar is positioned to be presented to the market as an important element of the climate change agenda and the new-found attention to sustainability (Mathews, 2008b) as society readjusts the agricultural and industrial practices of the past 200 years. Biochar stands to play a crucial role in the future re-evaluation of biomass as an essential resource in a C-constrained world and will therefore be featured in a number of seemingly disparate agendas, including:

- the urban waste agenda – as the objective moves from waste management to systematic resource recovery and inherent resource value retention (Rhyner et al, 1995);
- the agricultural inputs or supplements sector – as the full C impacts of high-nutrient fertilizers are recognized (Dittrick, 2007);
- the agricultural residues and by-products sector – as land scarcity stimulates the need to optimize the sustainable values of these materials (Tilman et al, 2001);
- the pulp, paper and forest products sector – as by-products, wastes and residues are reassessed as potential profit centres;
- the animal husbandry sector (including biosolids) – as wastes, emissions and effluents are appreciated for their full inherent resource value (Fleming et al, 1998);
- the biofuels sector – as sustainable yields and sources of biomass are applied to the provision of this essential product (Giampietro and Ulgiati, 2005);
- the petrochemical sector – as it is obliged to secure sustainable C-based feedstocks in the face of dwindling fossil fuel reserves;
- the metallurgical industries – as they seek sustainable sources of reductants;
- the stationary energy sector – as it adapts to a C-constrained future and the trend towards optimizing localized or distributed low-carbon energy sources.

Sustainable biochar production is possible (Lehmann, 2007), even probable, as a primary or secondary product for these fast-changing sectors, which will significantly affect the development and commercialization of the biochar sector. Within this framework, the biochar sector will need to demonstrate to the investment community that it is a secure investment and that all risks are strategically managed, and that it will not fail to deliver on the early promise.

The biochar sector could encounter significant long-term challenges if, in the rush to secure research and development funding or early stage project or technology funding, a much more strategic, structured and focused set of principles are not adopted and adhered to. These principles, which are discussed below, derive from the immutable concepts of sustainability that have created the platform for the commercial opportunity in the first place (O'Connell et al, 2005).

Finally, for the biochar sector to reach its full commercial potential, a considerable level of vertical integration along the entire value supply chain (Tan, 2001) will be essential until the sector is sufficiently established and matures to the point where it allows greater levels of individuality, specialization and niche sophistication. The full value/supply chain that could result in sustainable supply and demand for biochar includes, at a minimum, sustainable land-use issues, sustainable biomass yield, constantly evolving technologies, informed customer demand, government policy, intervention or support, a stable global C price signal, and marketing and distribution channels. In a mature sector, each facet can and should undergo incremental development and improvement; but in nascent sectors, such as the entire biochar production and application sector, there are few established protocols, relationships and common understandings.

Because the emerging biochar sector is entirely new, change is the only constant for all stakeholders along the value chain. Commercialization of the sector therefore calls for a widely supported roadmap that can be developed as a consensus document. Its purpose would be to both facilitate the initial success of the sector and to hasten a level of maturity that would encourage sophistication, dynamism and optimization sooner than if the sector left these issues completely to chance.

A roadmap of this type is beyond the scope of this chapter. However, the process would involve a comprehensive review of where the market potential of biochar is, including a detailed customer-segmentation evaluation. An accompanying gap analysis would highlight all the actions and initiatives necessary to attract the capital markets or, in the case of government funding, direct the investment necessary to take biochar to market. Rather than taking a rose-coloured view of biochar and its apparent properties and potential, this chapter examines the opportunities at each stage from the viewpoint of a conservative investor.

It has already been noted that not all investors are conservative and totally risk averse. In fact, some specialize in bold early investment positions. However, the capital required for biochar to reach its full potential as a global product and commodity will require support from the mainstream investment community.

It is also an essential precondition for the successful commercialization of biomass products, in general, and biochar, in particular, that the sustainability context is properly understood, since it is a major driver for the new industry and provides the foundations for a valuable and structured offer to the market. The following will concentrate on summarizing the sustainability and climate change issues and agendas; the inherent properties of biomass and the position that biochar has within that framework; and, finally, the fundamental issues that biochar commercialization should systematically address.

Biochar's positioning in the sustainability and climate change agendas

The commercial properties of biochar have a basic value in a 'business as usual' economy – properties such as tangible soil productivity improvements, even a C sequestration value in jurisdictions where such values are recognized; but these same basic properties have a much greater commercial value in an economy that is proactively managed to internalize environmental and sustainable resource-use externalities. It is therefore important to convey these issues to the investment community in a way that gives them a better understanding.

Biochar is emerging as a product, a service and a concept at precisely the time when issues such as the population of the planet (approaching 9 to 10 billion people), climate change, soil degradation, resource depletion and C-constrained economies are achieving overwhelming worldwide attention. This is a favourable contextual backdrop for the investment community if the benefits of biochar can be cogently and credibly presented. There are two essential messages to focus on that are presented in the following two sections.

Biochar as a sustainable soil productivity enhancer and restorative

First, the investment community needs to understand the future for biomass in a sustainable economy and the role of biomass to provide materials, energy and sequestration products. All the while, the vital differences in philosophy and outcomes between a sustainable economy and business as usual need to be identified, particularly where they present economic opportunities for the (business and) investment community. Within this context, the tangible benefits of biochar as a sustainable way of enhancing and restoring soil productivity (see Chapters 5 and 12) need to be confirmed and described within the integrated opportunity.

Biochar: The long-term and measurable carbon sequestration product

The biochar sequestration story needs to be presented within the framework that being:

- C-positive is part of the problem;
- C-neutral means that the particular activity is no longer part of the problem;
- C-negative is a crucial part of the solution to rising atmospheric carbon dioxide (CO_2) levels.

Therefore, where appropriately sourced biomass can be processed to contribute both essential C-based materials or energy, and with biochar available as a value-adding net sequestration by-product (Lehmann et al, 2006; Laird, 2008), the gross benefits could realize sustainable value well in excess of the more commonly understood 'business as usual' products or outcomes.

The first of the messages – biochar as a sustainable way of enhancing and restoring soil productivity – places biochar in an essential growth sector. Investors will like to be part of the next new sector as long as the claims are substantiated. The second, biochar as a long-term and readily measurable sequestration product, will provide additional revenue in any market or jurisdiction where C is traded or C sequestration outcomes are valued. Within this context, the production of biochar as a vital sequestration product will only occur where the production process also produces C-neutral or even C-negative syngas or bioliquid – but these products are collateral benefits in this biochar context.

The sustainability context for biomass generally

One of the strongest marketing angles for biochar is its integral role in the bio-based economy that is seen to emerge (Bevan and Franssen, 2006). To ensure that the investment community really understands the profound importance and implications of a bio-based economy, the most important issues need to be comprehensively presented in order to clearly outline the extraordinary commercial potential, while emphasizing that bio-business is 'sustainability' business and not business as usual. It also needs to be made clear that, as with the first-generation biofuels, the product is defined as sustainable by the raw material sourcing and subsequent production pathway.

The investment community is comfortable with indexed investments, global trends and relative positioning. They prefer to have appropriate investments in areas that are likely to be the next growth sectors. For positioning biochar in the market, the following arguments could be articulated:

- The planet decarbonized itself all those millennia ago when biomass (phytoplankton, oil and gas/forest, and coal and gas) was transformed into what are now fossil fuels.
- Today's fossil fuels are yesterday's biomass (and sunshine), and these fossil fuels represent a high-energy density that will be difficult and costly to replicate from alternative sources.
- Today's fossil fuel dependence is effectively re-carbonizing the atmosphere to levels never experienced by current civilization (IPCC, 2007).

- The current global attention on climate change will progressively move to introduce measures that provide disincentives to release CO_2 into the atmosphere – incentives to reduce existing atmospheric CO_2 levels or trading mechanisms that will internalize C-cycle impacts within all human activity.
- Against this background, biomass can be seen as the crude, unprocessed and unconcentrated raw material that can provide all the same gas, liquid and solid products that we have produced from fossil resources (Ragauskas et al, 2006). Bio-products are a substantial new industry that will not automatically produce a sustainable outcome. There will be a whole new set of disciplines, economic realities and drivers that will dictate sustainable outcomes (Giampietro and Ulgiati, 2005). Biochar is an integral part of this message. Before focusing on the specific benefits and properties of biochar, the differences between the fossil fuel sector and the replacement biomass sector must be highlighted (Mathews, 2008a). The experience of the first-generation ethanol and biodiesel sectors over the last five to ten years demonstrates that perceived benefits can be offset by total life-cycle costs. What has been observed in the current biofuels sector need not occur in the emerging biochar sector.
- Currently, unrecognized or under-valued biomass resources exist in the agricultural, forest products, animal husbandry and urban waste sectors (e.g. Kaygusuz and Türker, 2002; Hoogwijk et al, 2003). These unrealized assets require only revised value and supply chain management to access markets before any special purpose crops or initiatives are stimulated.

Biomass processing using pyrolysis for the production of potential C-neutral gas, liquid and solid (biochar) products is a new (Lehmann, 2007) but closely integrated sector. It is a sector that must engage in many facets of the existing economy. The ability of the biochar industries to generate sustainable products and outcomes will derive from fully understanding the issues and complexities. The challenge seems to be that the prevailing economic systems have yet to fully appreciate that biomass is a complex and highly differentiated resource (Ragauskas et al, 2006). If we are to avoid 'food for fuel' problems or 'forest to biochar' business models, a working understanding of biomass is essential.

Inherent characteristics of the biomass resource

Biomass is much more than firewood or just another fuel source. Electrical or stationary energy can be provided by hydro, solar, thermal, geothermal, wind, tidal or wave, and even nuclear power in a post-fossil fuels and C-constrained economy. Perhaps fossil fuels with C capture and storage (CCS) (IPCC, 2005) will eventually prove effective. However, only biomass can produce the basic gas, liquids, solids or the C-based chemicals that we currently obtain from fossil supplies.

It is worth noting that during its growth phase, biomass contributes significantly to providing ecosystem services, to the biodiversity of other organisms and even to recreational values. Once harvested, the provision of food, fibre and industrial inputs all provide essential outcomes. The provision of simple heat energy is predominantly a by-product in commercial frameworks where the highest values of biomass are fully recognized.

The basic gas, liquids and solids from biomass may be products in their own right. In most cases, the essential pyrolysis products will be presented as precursors for further refinement into more tightly specified products or reductants (Kamm and Kamm, 2004). The gases may be used to drive the pyrolysis process (Bridgwater and Peacocke, 2000), with surpluses available for synthesizing new products or generating electricity. Liquids and tars will be available for refining into liquid fuels and petrochemical precursors, and the solids, or chars, presented as activated carbon products and metallurgical reductants (coal replacements), with biochar as a soil amendment (Kamm and Kamm, 2004).

The nature of the available biomass, the process technology, local circumstances and prevailing market conditions will all affect the mix of primary and secondary products from biomass processes on a case-by-case basis (see Chapter 9). Biomass resources exist with different ratios of basic chemical constituents, such as lignin, cellulose or carbohydrates (see Chapter 8). For food production, often the reproductive structures are harvested, discarding large amounts of crop residues made up of mainly lignocellulosic materials that may be used as feedstock for energy (O'Connell et al, 2005; Crucible Carbon, 2008).

Within a framework or hierarchy where quite different biochemical fractions of plants are recognized for their specific characteristics, biochar will inevitably be a by-product of a mainstream biomass-processing sector. Biochar is a product that is manufactured to impart certain soil enhancement and soil restorative properties (see Chapters 5 and 12) and to provide net C sequestration and emission reduction (see Chapter 18).

Biomass processing must evolve to more accurately match the properties of the available resources to the required properties of the derived products (Bryant and Downie, 2007). For example, low-ash and homogeneous biomass resources (perhaps single species) might be sustainably applied to filtration products, highly specified manufacturing inputs or metallurgical reductants (Byrne and Nagle, 1997; Langberg et al, 2006). Higher-ash and less homogeneous biomass sources, such as those derived from agricultural residues or urban wastes, could be ideally applied to biochar production where the ash content can provide additional fertilizer effects (Chan et al, 2007; Downie et al, 2007; see Chapter 5).

During low-temperature (<500°C) slow pyrolysis, phosphorus (P), potassium (K) and sulphur (S) typically accumulate on the biochar product in bioavailable form (Hossain et al, 2007). Where pulp and paper sludges are pyrolysed, the ash content contains considerable quantities of calcium carbonate ($CaCO_3$) and bentonite, originally used in the paper-making process. These materials provide valuable liming properties when applied to acid soils, but would be undesirable contaminants if the same biochar was applied as a metal reductant (Van Zwieten et al, 2007). Such differences have to be recognized when designing a commercial biochar product.

Lessons from the first-generation liquid biofuels sector

Liquid biofuels may become particularly important products for the transport sector (Ragauskas et al, 2006). However, the way in which the mainstream investment community worldwide has supported the biofuels sector may create some undesirable outcomes (e.g. Searchinger et al, 2008; Tollefson, 2008). Over the past three to five years, the investment community moved quickly into the liquid biofuels market to support biodiesel and ethanol (Kennedy, 2007; Tollefson, 2008). However, this development has brought rather traditional commercial thinking to a nascent sector that derives much of its current potential by addressing unsustainable outcomes that arose when that same traditional commercial thinking failed to properly account for environmental externalities that have now resulted in the current climate change agendas. This thinking did not understand that biofuels represented an opportunity generated by the emerging sustainability industry, a sector that specifically seeks to address and redress hitherto un-costed and unaccounted for environmental externalities that have driven the climate change debate, in general, and the sustainable resource use and application debate, in particular.

It is informative to acknowledge that our traditional economic approach, which has given us such unprecedented growth over the last 250 years, has also triggered unsustainable climate change, in the most part because the prices have not reflected full ecological or social cost (Stern, 2007). The emergence of C taxes and C trading schemes (see Chapters 18 and 22) are early attempts to place commercial instruments in the market to partially address the internalization of these currently un-costed environmental or social impacts.

A similar argument can be made regarding the competing production of food versus fuel (Hill et al, 2006), whether or not it had an actual effect on food prices and supplies (Tenenbaum, 2008). The first-generation ethanol sector failed to secure the biofuel supply at a price that could be afforded by the transport fuels sector. Rapid technological development in the sector meant that many early plants were, in effect, investing in process technologies that would prove to be suboptimal or outdated well within the projected commercial life of the plants. Early adopters in this nascent sector became high-cost producers as the process technologies developed. The impacts of sharing established fossil-fuel marketing and distribution channels with the new biofuels sector on fossil fuel producers were not adequately considered.

The difference between biofuels projects that are currently not commercially viable or sustainable and the potential to produce biofuels sustainably is in the planning and application. With attention to detail, such projects can demonstrate all of the anticipated benefits, especially where integrated biochar production can provide a C-negative outcome (Mathews, 2008a).

In summary, how liquid biofuels are made is the determining factor in assessing their long-term value as alternatives to fossil fuels. If they are sourced from intensively farmed food-grade feedstocks, their overall benefit to sustainability and reducing the levels of atmospheric CO_2 is likely to be limited. The nascent biochar sector should analyse lessons learned from commercializing biofuels in the past. The customers for biochar will, to a significant extent, be attracted by its prospects for sustainability, so it is vital that biochar is delivered with its sustainability credentials intact.

Biochar commercialization framework

In constructing a sustainable business model for biochar, there are four essential building blocks to the proposition for investment that need specific attention and verifiable assumptions:

1 justification of demand;
2 demonstrable markets and growth opportunities;
3 technological reliability and at least first-order efficiency and cost effectiveness;
4 reliable and sustainable biomass supply or yield.

These factors will define the risk–reward profile for the emerging biomass processing sector, and are discussed in detail below.

Justification of demand

In a sustainable future economy, un-costed externalities will need to be brought into account. However, if an activity has no valid justification of demand and is therefore not undertaken, then all the effort identifying and accounting for collateral externalities will not be necessary. Biochar production should have no difficulty with this initial justification of demand. Nevertheless, biochar production must be sustainable from all aspects to maintain its credentials. Multiple challenges to, for example, health impacts have been voiced (Baveye, 2007) that must be taken seriously and are being addressed by the emerging technology (see Chapter 12).

Ultimately, a sustainable business model will need a community licence to operate. This licence is formally granted through the prevailing approvals and licensing process in any particular jurisdiction – and will therefore be more or less rigorous in various parts of the world (see Chapter 12). Rather than rely on selecting underdeveloped regulatory jurisdictions as business entry points, participation in the sustainability business means always being conscious of the need for the activity, the immediate and collateral impacts of that activity, and mitigating or planning for all and any unintended consequences (externalities) in the final benefit. The ultimate commercial success of the biochar sector will benefit from the systematic observance of these sustainability issues.

The biochar sector may experience commercial competition from products that might look to the less informed assessor to be biochar, but with none or few of the physical and biochemical properties of effective biochar. In these circumstances, the biochar market positioning will benefit from developing reliable industry standards that are controlled by credible organizations. Characterization and classification of biochars is a step in the right direction (see Chapter 7). Attention to this level of detail will help the investment community to engage with and support the nascent biochar sector. In summary, biochar is capable of being positioned as a value-added product with demonstrable benefits that also internalizes externalities.

Markets and growth opportunities

To take biochar to the market, individual project business plans will need to be funded. Central to the investment community is verification of the primary revenue stream generated from the sale and use of biochar.

The primary properties of biochar are as a soil-quality improver (see Chapters 2, 5 and 6). It is both an immediate productivity improver for most soils (Lehmann et al, 2003; Chan et al, 2007) and a restorative of quality following previous overuse or degradation of soil (Kimetu et al, 2008). Under certain soil and management conditions, it may supplement commercial inorganic fertilizer application, so less fertilizer is required to achieve similar crop yields (see Chapters 12 and 18). These properties can be used as a platform for facilitating market-informed discussions about the commercialization of biochar amongst the investment community.

As already stated, the properties of biochar need to be scientifically verified as the foundation value proposition for the market. They also need to be verified in order to establish the appropriate price point for biochar sales and services. In this regard, the nascent biochar sector is at a crossroads, and thoughtful management of the price point issue should be a major focus of any future biochar industry development. On the one hand, the biochar sector could follow the experience of compost products and become a commodity product. On the other hand, all of the demonstrated qualities of biochar could be commercially benchmarked against currently available alternative methods of achieving similar outcomes. A price point could then be established alongside these alternatives, with perhaps a premium for offering multiple sustainable outcomes.

For example, where nutrient retention results (see Chapter 15) or improvements in nutrient-use efficiency are found (see Chapter 5), the commercial value of replacing these nutrients can be readily measured. This would apply to gaseous losses of greenhouse gas from soil as well (see Chapter 13). Where liming values can be achieved by biochar (see Chapter 5), the benefits to acid soils can be benchmarked against commercially applied lime.

The issue of achieving full and fair value in the market for biochar products will be best managed collaboratively by the initial biochar manufacturers. This is an area where a roadmap for developing the biochar industry will be instrumental since the industry may not be able to act collectively from the outset.

The full range of benefits for the customer or land manager need to be detailed, highlighted and justified so that biochar products can be sold for their fair value, and their continued manufacture is stimulated and encouraged. The emerging biochar sector has a few differentiating features from, for example, the industries marketing compost or zeolite; but there are recurring lessons to learn. First, the major difference to the compost sector is that the biochar business will not be a low entry-cost business for those who are doing it properly. As discussed below, the unit cost of pyrolysis will need to be reduced significantly from today's costs, and carefully controlled pyrolysis processes for commercially relevant flows of biomass (see Chapter 19) at the scale appropriate for a certain system (see Chapter 9) will need to emerge. In some systems, proprietary biochar production will require a significant capital cost, with very specialist technical abilities needed to produce biochar to a volume and quality that supports the commercial promise. However, these barriers to entry to the top table of biochar producers may encourage some operators to put inferior biochar products into the market in order to take advantage of the relatively high market prices achieved by those making genuine biochar products.

Certainly, the biochar sector needs to be structured around the concept of 'market pull' (Luyten, 2003).[1] To do this, all of the immediately valuable properties need to be evaluated and benchmarked for price point against commercially available alternative methods and products that can achieve similar outcomes. The price point also needs to be compared with the net present value of no intervention and the results collated as an important element of the biochar business model that is presented to investors, which could be a focus for the proposed Biochar Industry Commercialization Roadmap.

A vital action item for the sector is to continue to research the precise science of how biochar achieves the range of results that have been demonstrated to date. Only when the science is available will biochar be able to fully optimize its production processes and fully substantiate the offer to market. For example, long-term stability of biochar (see Chapter 11) and the resultant emission reductions (see Chapter 18) needs full scientific verification. Only processes and activities that can remove CO_2 from the atmosphere and sequester it for significant periods of time will be genuinely part of the solution to climate change.

From an investment point of view, any current evaluation of the verifiable market potential for biochar is facing the following challenge: the potential customers may not commit to taking all of a potential plant output without production samples; however, production samples may not be available without a plant, and funding for a pyrolysis plant will depend upon demonstrating a market arrangement. These issues can be overcome with conditional agreements between buyers and sellers and the support of an understanding and knowledgeable investment party who specializes in these start-up projects. However, if the risks and uncertainties can be minimized, the cost of capital will be reduced.

At this point, the issue of optimum investment for the start-up of the biochar sector reverts to the research community since the more that is known of the science of biochar and its manufacture, the smaller the risk will be for the early-stage investors.

The process technology

Technology or process risk is a major concern for the investment community. Many potentially viable business propositions have not been successful when the technology was unreliable, too costly or thermally inefficient to operate.

Another inevitable issue with new technology is that even if it works as planned and produces an acceptable and anticipated product quality, the next generation of technology is certain to be better. This makes it much more difficult to attract the initial project investment (Scotchmer, 1996) since an anticipated reality is that even a completely successful first-generation project will, in effect, create the market opportunity for the second generation of new and improved plants and technologies. These will then compete in the same nascent markets with lower cost, and more efficient and more reliable technology, putting the first-generation projects in commercial jeopardy, even if at the same time increasing overall innovation (Bessen and Maskin, 2000).

The generic pyrolysis process is well understood and widely employed in a range of industries and applications (Demirbas, 2001; Bridgwater and Peacocke, 2002). However, technology that is specifically tailored to manufacture quality-assured biochar is in its infancy (Lehmann, 2007). In terms of payback periods, the current first-generation slow pyrolysis technologies are externally heated and pyrolysis typically has to allocate at least 10 per cent of the energy gain for driving the thermal process, while the remaining energy can be used externally (Demirbas and Arin, 2002). Biomass with a moisture content of above 50 per cent is typically not used for energy production due to low energy recovery (McKendry, 2002). As shown for a specific case study from Victoria, Australia (Crucible Carbon, 2008), these technologies can have paybacks of 15 to 20 years or a capital intensity value of US$300 to $500 per dry tonne of plant capacity, which in first-generation plants must be mitigated by gate fees. Figure 21.1 suggests an optimum where a capital intensity of approximately US$150 per annual dry tonne of capacity with a realistic CO_2 price of US$30 per tonne were realized, giving a two- to three-year payback period. This payback appears to be in line with the investment community's expectations for such projects (Crucible Carbon, 2008).

For an intermittent period, available technologies for the commercial-scale production of biochar are facing scale-up risks followed by optimization. Promising technologies will attract the enthusiasm of early adopters mentioned at the beginning of the chapter to provide funding for high-risk technology development. The biochar sector needs to demonstrate confidence, professionalism and certainty about its product, especially in the vital early stages. An opportunistic corporate culture established around early projects will

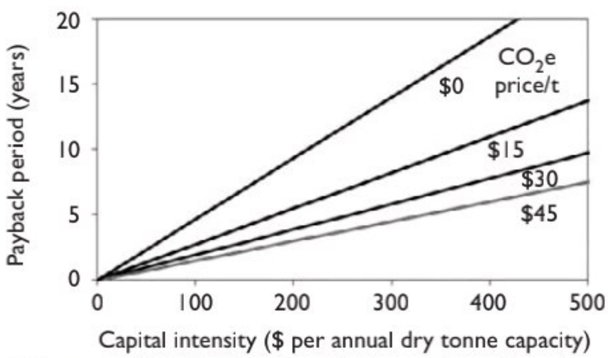

Figure 21.1 *Payback period as a function of the price of C (in CO_2 equivalents)*

Notes: Techno-economic modelling by Crucible Carbon for slow pyrolysis conditions that assume equal generation by weight of biochar, bio-oil and gas during pyrolysis, with the gas used internally to provide the process energy. In the illustrated case, the values assumed for inputs and outputs were biomass US$100 t^{-1} (on a dry weight basis), biochar US$100 t^{-1} and biocrude oil US$300 t^{-1}.

Source: Joe Herbertson (pers comm, 2007)

set the sector back in the eyes of the investment community whose support will be essential if the sector is to achieve its full potential.

Supply and the sustainable yield of feedstock

Of all the key factors that will support the fastest commercialization of the biochar industry, supply and sustainable yield issues are by far the most important, from both a broad sustainability perspective and from the financial and commercial points of view (Faaij, 2008). This will require the sources of biomass selected for biochar production to be appropriate and be able to withstand a comprehensive life-cycle analysis.

The *Sustainability Guide for Bioenergy* commissioned by the Rural Industries Research and Development Corporation (O'Connell et al, 2005) provides some useful structure to the process of determining if a particular biomass source should be sustainably applied for biochar production. The decision-making matrix provided in this scoping study (see Figure 21.2) highlights that, initially, the sustainability value revolves around a land-use issue before addressing the yield and allocation issues for the various defined fractions of a potential biomass resource (O'Connell et al, 2005, pp22–23). Certification as proof of adherence to certain standards is important in providing assurance of sustainability (Van Dam et al, 2008).

Not only must a defined source of biomass be available to support the direct commercial viability of a particular plant or project (Caputo et al, 2005), but that biomass source must be demonstrably the best and highest use of the resource and, at the same time, retain sustainability credentials that are critical for the optimum commercialization of biochar. In summary:

- Biochar derives much of its cachet by being positioned directly inside the sustainability agenda.
- This positioning, and the resultant commercial potential, requires biochar to be manufactured from sustainable yields of biomass, probably as a significant by-product of an integrated biomass processing operation, such as stalks and stems, rather than fruit or seed.
- The sustainable yield of biomass has no higher net resource value than to be converted to biochar.
- The nascent biomass conversion sector will need to vertically integrate, in the initial stages at least, to ensure that sustainability is maintained.
- The food versus fuel issues will need to be managed until emerging maturity in the sector can support greater levels of specialization and niche operations.

Since the preferred properties of biochar are still being confirmed and the processing techniques and technologies are in a rapid state of development, it is not possible to be definitive on the optimum biomass sources for biochar

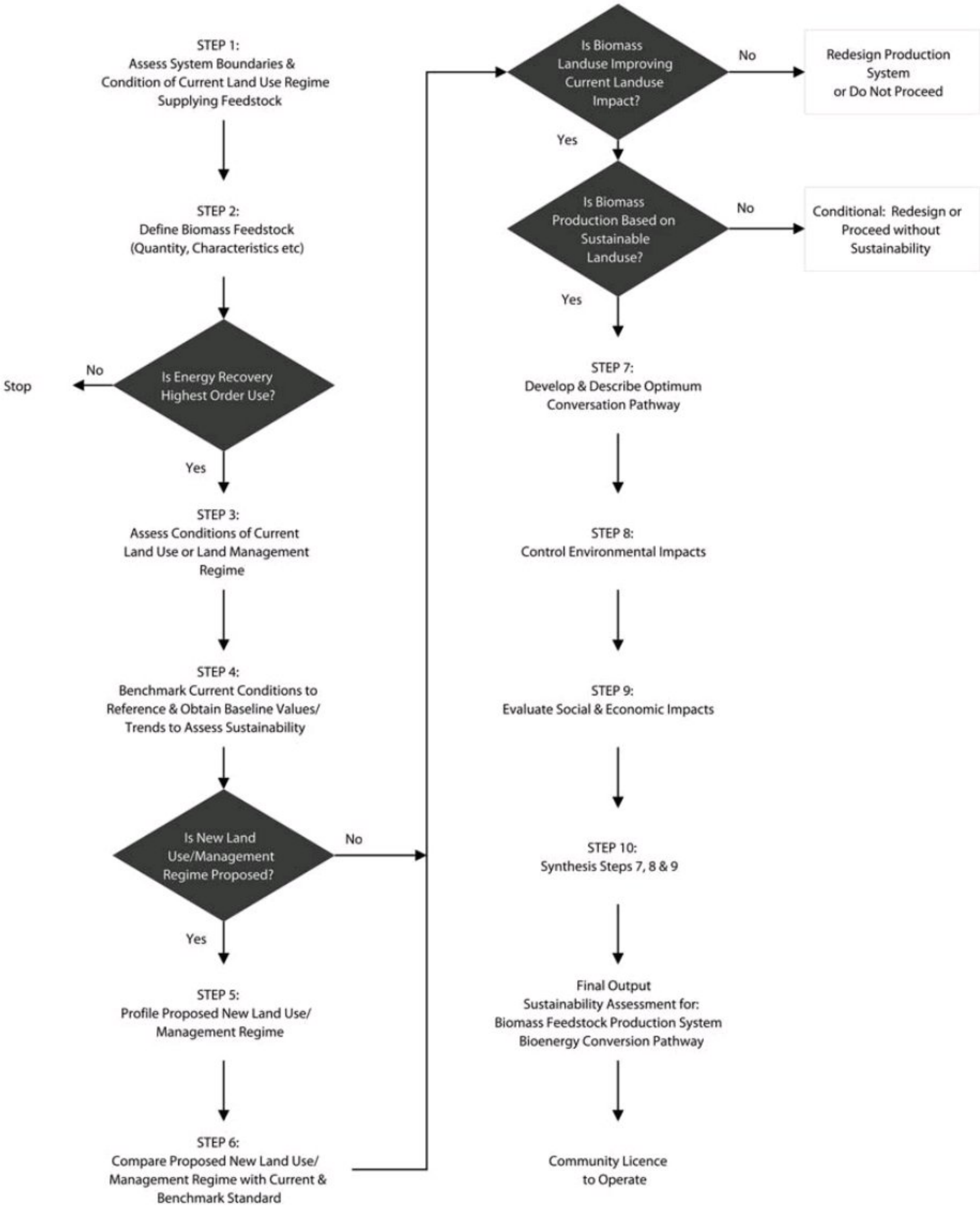

Figure 21.2 *Proposed protocol for developing sustainable land use with bioenergy recovery*

Source: adapted from O'Connell et al (2005) production. However, we do have some early clues.

Biochar as a by-product

The generic pyrolysis processes when applied to lignocellulosic residuals tend to produce approximately one third gases, one third liquids and one third tars and solids (biochar) in standard applications (see Chapter 8). These proportions can be altered by refining the process to optimize certain fractions (Strezov et al, 2008). The solid biochar product is a minority product or by-product from a gas and/or liquid production enterprise,[2] but can be maximized in production units that do not generate energy (Antal et al, 1996).

There are similarities in the better understood crude oil refining industry. Bituminous residuals are an almost inevitable by-product of the fuels, lubes and petrochemical materials manufacturing processes – but not a single refinery in the world takes in crude oil to produce only bitumen. In fact, if the crude is particularly light, no bituminous residues may be produced at all. This militates against specific biochar crops.

Biomass ash content

Biochar could be made from single-species processing or uniform quality sawdust, hardwood chips or nut shells (see Chapter 8). This type of homogeneous high-quality feedstock (especially nut shells) will tend to be optimally applied to high-quality activated carbons (Heschel and Klose, 1995). Applications where ash content or critical non-C contamination will devalue the product will limit its application in industrial processes (Schröder et al, 2007), such as metal refining, filtration or medical purposes. For example, biochar-type materials as reductants in metallurgical applications have considerable potential (Emmerich and Luengo, 1996; Yalcin and Arot, 2002); but high-ash biochars may lead to slag production or lower metal quality (FAO, 1985), though dependent upon feedstock (Mansaray and Ghaly, 1997). On the other hand, for biochars produced as a soil amendment, high ash contents may even increase the direct nutrient effects (see Chapter 5), even though the effects on surface properties (see Chapter 3) and stability (see Chapter 11) are not fully resolved. Significant liming values may be achieved with biochars that are produced from paper pulp residues (see Chapter 5), which contain high concentrations of calcium carbonate and bentonite. Similarly, high-ash biochars derived from chicken litter (Chan et al, 2007) have high concentrations of K and P that have significant fertilizer value. However, possible metal contamination in the ash would be detrimental and must be carefully quantified and monitored. This can be avoided by choosing appropriate feedstocks such as biomass.

Biomass fraction of urban solid wastes

Urban solid wastes are those surplus materials that emanate from industries and households. In Organisation for Economic Co-operation and Development (OECD) countries, these materials amount to between 700kg and 1000kg per person per year, and some 60 per cent are of biomass or lignocellulosic origin, consisting of wood, wood products, garden residues, paper that has not previously been recycled, cardboard and kitchen residues (Warnken, 2007).

Currently, most jurisdictions focus on recovering a proportion of these materials for compost manufacture (Zurbrügg et al, 2004). Two pertinent issues arise from this practice. First, quality compost cannot be made from materials of indeterminate origin that are likely to be cross-contaminated with other materials or chemicals due to the 'uncontrolled' nature of their origin. Second, most of the organic fraction is not source separated and is still present in the mixed residual waste stream, and may contain unwanted or incompatible materials (Zurbrügg et al, 2004). In addition, the organic fraction derived from urban waste streams may contain specific contaminants by load or species that mean they need to be treated specifically. However, most of this material, most of the time, would seem to be entirely suitable for biochar production because:

- During thermal processing (300°C to 600°C), a wide range of organic compounds that would be critical contaminants in compost are destroyed.
- Pyrolysis processes will have to have comprehensive off-gas management and clean-up systems (Chapter 8).
- Urban solid wastes are typically close to horticultural and agricultural markets where biochar could be of considerable value.
- Biochar is a considerably more valuable product than compost, even if it is made from select fractions of urban solid waste and is more readily transported to diverse or disparate markets due to lower weight and greater product value density (see Chapter 9).

In summary, biochar is not only valuable for all its physical, chemical and biological properties (see Chapters 2 to 6), but can also be presented to the market with impeccable sustainability credentials. Perhaps the single greatest threat to validation of those credentials will derive from the sustainability of the biomass source and yield applied to the product manufacture. Therefore, the route to market for biochar would be much enhanced by strict industry guidelines and sustainability protocols (O'Connell et al, 2005).

Commercial factors and business modelling

The previous chapters have highlighted a wide range of valuable properties of biochar. To prove and demonstrate these properties, commercial volumes of known quality biochar need to be produced to support both the needs of early adopter customers and to provide the solid case study evidence for the broader potential market. This, in turn, will establish a proven price structure and market volume.

In order to produce these volumes of biochar requires the first generation of full-scale commercial plants to be established. To attract the appropriately priced capital for these projects, a reliable business case must be put. The main elements of this must address three key factors:

1 reliable supply issues;
2 process and technical issues, leading to verifiable capital costs and operating costs assumptions;
3 revenue assumptions from service and product sales.

A risk–certainty assessment of these three foundation issues must present a workable business model for both initial plants and longer-term growth strategies for potential biochar companies. Revenue streams for biochar product sales must initially be considered as unreliable for the purposes of rewarding any capital applied to biochar manufacture. This will require the first-generation commercial-scale biochar plants to provide a waste management service for certain biomass resources in exchange for service or gate fees for their processing (Cartmell et al, 2006). If and when biochar sales and markets can be proven and established, a dependence upon gate fees will be reduced. It is advisable for initial contract conditions to be drafted to reflect this reality.

Initial projects will need to have supply certainty and assured revenue from providing waste management services. However, the limited opportunities to attract gate fees for waste management services will be quickly exhausted in the first round of commercialization, as seen for incineration (Olofsson, 2005). In the second round, a detailed marketing strategy for biochar will need to be systematically implemented and realized around the provision of actual production samples to support trials and successful case study data (see Chapter 9) for the first one to three years of plant operation.

Going forward, the biochar sector will need to both optimize revenue and returns from biochar sales and lower the capital intensity of the process plants so that the projects can afford to pay third parties to produce or collect, store and transport suitable biomass resources for the plant. Typically, costs for shipping the biomass are greater than for shipping the energy products (Searcy et al, 2007), which influences decisions of where to place pyrolysis units.

In certain jurisdictions, C is valued and traded or taxed (see Chapter 18). Therefore, the demonstrable C footprint of biochar production and sequestration needs to be confirmed and valued so that individual project business models can benefit from the additional income stream that will result. In jurisdictions where C is not yet valued or traded, government support in the form of capital grants or market development support could well provide the incremental level of confidence to attract the initial investment at reasonable rates.

This project profile would suggest that investors in first-generation projects would only invest because they share the long-term vision for the biomass conversion sector, generally, and the biochar sector, in particular. Accordingly, business models for first-generation plants will need to come with a well-substantiated and clearly articulated plan, a well-articulated strategy to achieve the full potential for biochar over time, and a highly skilled management team to deliver the strategy.

Notes

1 A market-pull strategy targets the end consumer, using advertising, sales promotions and direct response marketing to pull the customer in.

2 The 'third/third/third' ratio is useful at the planning stage of projects. Different pyrolysis systems and operating conditions will produce different ratios of oil, biochar and gas (Strezov et al, 2008; see Chapter 8). Detailed analysis for project-specific conditions will always be required.

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