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A Review of Biomass and Biomass Mixed with Coal in Heat and Power Generation

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A REVIEW OF BIOMASS AND BIOMASS MIXED WITH COAL IN HEAT AND POWER GENERATION

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ABSTRACT

This paper reviews biomass and mixed coal/biomass as fuels for energy production. The status of biomass and mixed coal/biomass as alternative energy fuels is explored based on current research and development (R&D). Consideration is given to technical, environmental and economic aspects of the R&D, outlining the strengths and weaknesses of each. The paper concludes that biomass and biomass mixed with coal will be important energy fuels of the future. Conclusions are based on such factors as: the abundance of coal, renewability of biomass, net reductions in CO_2 and SO_2 emissions, disposal benefits of waste-derived-energy and the versatility of particular technologies. Disadvantages of these energy sources are also reviewed. They include: the establishment of a strong market, required emission control for other gas emissions, increased transport and handling costs of biomass, and technical problems confronted during conversion.

(**Key words**: supply, demand, bioenergy, MCBE, renewable resources, greenhouse gases, environment, economy, and future)

INTRODUCTION

This paper is important to those who are interested in technical, environmental and economic aspects of future energy alternatives. The objectives are to outline the value of biomass and biomass mixed with coal as clean alternative sources of energy in producing heat, electricity and liquid fuels. An introductory definition of energy is given followed by a brief exploration of world energy production, consumption and resource trends. This introduction finishes with a summary of methods used to secure energy supplies needed for future survival and economic progress. In subsequent sections, bioenergy and mixed coal and biomass energy (MCBE) are the two biomass dependent energy systems discussed in detail. Each resource is considered separately to define the resource, discuss supply and demand patterns, and review the advantages and disadvantages of its use in energy production. A section on common technologies illustrates the processes presently available for converting the raw fuel into energy forms such as heat, electricity and liquid fuels.

DEFINITION OF ENERGY

The ability of matter or radiation to do work

Heat, is measurable radiation of energy indicated by temperature change over time. Units of heat are joules or the British thermal unit (Btu) and a unit of energy is a calorie (Manahan, 1993: 26). One Btu is equal to 1054.5 joules and one joule is equal to 4.18 calories. The joule is the accepted system international (S.I.) unit for measuring heat although the others are still in use. Fuels are assessed according to their energy value using one of the aforementioned units. In order to make direct comparisons between the energy potential of various fuels with various units of measurement, it is possible to convert the energy values into energy content using a tonne of oil equivalent. One tonne of oil equivalent is equal to 41.868 Gigajoules (or x 10^9 joules). The four most energetic of conventional fuels today are:

fuel oil	=	1.07 tonnes of oil equivalent
natural gas	=	1.05 tonnes of oil equivalent
coal	=	0.5 - 0.7 tonnes of oil equivalent
wood*	=	0.36 tonnes of oil equivalent

*with approximately 20% moisture content

(conversion used raw data from DTI conversion fact sheet, 1994)

Fuel oil is a product of the highly regarded light crude oil used for a wide variety of fuels and as feedstocks (Harker, 1991: 188). The energy value of wood increases as moisture content decreases (IDAE, date unknown: 11).

ENERGY PRODUCTION, CONSUMPTION AND RESOURCE TRENDS

Energy supply and demand vary geographically according to a multitude of physical and social factors which include:

- available resources
- climate conditions
- topography
- technical advancement and
- economics

Predictions of future energy demand rely heavily on expected economic changes (Harker, 1991: 186). Energy predictions are necessary for industrial progress and improvements in regional standards of living (World Resources, 1995: 165). Naturally, the primary fuels of the world have changed through time in response to changes in the above mentioned factors.

In developed countries oil was preceded by coal and biomass, in the form of wood. Wood dates back farther than any other energy source utilised by humans. In 1850, 91% of total US energy consumption was wood (United States Congress, 1981). As the developed countries of today achieved this status, coal replaced wood and oil replaced coal. Meanwhile, however, Third World countries have not achieved this developed status and have thus remained reliant on wood for energy. Over consumption of wood for fuel and global wood production for other uses has lead to widespread deforestation particularly in these Third World countries. Silvicultural methods have been encouraged but agricultural land-use has economic potential therefore it is a stronger competitor for the land, especially in poorer economic regions. A course of action has been to reduce the use of firewood in these poorer nations by stimulating wealth and implementing efficient energy technologies (Gilliland *et al.*, 1979).

East Africa has long been a centre for research and development into technologies such as the common wood cookstove. In marketing, successful implementation of new technologies requires thorough field tests. When UNICEF and CARE-Kenya developed one of the first improved stoves in the 1980s field tests were not thorough enough, thus resulting in a stove incompatible with most cooking pots (Kammen, 1995). Such hindrances make progress slow but the eventual outcomes are potentially vital to global reduction in atmospheric pollutants and increased energy efficiency. When Third World countries improve standards of living through whatever means, they will then be able to deal with such problems as deforestation. Until that time, human survival depends on using the resources they have within the technical and economic limitations.

The progress of countries now developed was characterised by several general patterns. Healthy economies allowed for research into better fuels such as coal. Coal was more efficient than wood thus making it more desirable. As profits accumulated from the efficiency of coal, other options were researched to further improve efficiency and consider environmental issues, hence the displacement of coal by oil in the 1960s. This was motivated by oil's high energy value and availability. It was also easier to recover, cheaper to transport and cleaner to use than coal and wood (Gilliland *et al.*, 1979). Oil was not expensive to produce or to purchase. Countries without significant oil industries began to import oil because they could afford it. Eventual increases in import prices lead by the Organisation of Petroleum Exporting Countries (OPEC) in 1973 significantly reduced the benefits of oil energy and brought about abrupt economic changes.

In many developed countries, natural gas has increased in popularity due to environmental advantages. It is a cleaner burning and more efficient fuel compared with other conventional fuels and its use means that it is no longer a wasted by-product of oil production (Gilliland *et al.*, 1979). Other benefits include its versatility as a fuel being suitable for most energy uses except transportation fuel. The future of natural gas relies on oil exploration and production and although it has become a valued fuel option of the 1990s in most developed countries, the middle east has not shown as much appreciation for its energy potential.

Based on this review of world energy trends, it would seem that energy systems are a significant driving force for evolution from Third World to developed nation status. These changes in energy systems are prompted by economic progress, enabling investment into research and development aimed at increasing efficiency. Profits from increased efficiency were then used to even further improve efficiency and to consider environmental concerns. Once this level was achieved environmental issues became a priority. Developed countries of the 1990s consider environmental issues the driving forces behind energy related developments (Allgeier, 1994: A2). Consequences of non-renewable fossil fuels along with global greenhouse gas and acid rain producing emissions are at the forefront of these issues.

RESEARCH AND DEVELOPMENT OF ALTERNATIVE ENERGY TECHNOLOGIES

The diversification of fuels to include renewable resources and the implementation of cleaner energy production technologies have become widely accepted as a strategy that will lead to sustainable energy supplies.

Renewable energies such as wind, solar, hydro, bioenergy and wave energy have been successfully developed and some have become commercially available. Research, in time, will improve the efficiency of these technologies and reduce the price of implementing them (Bemtgen, 1994: A1). Once this has been achieved, such renewable energies will become more attractive than oil because they will share, if not exceed, the benefits of wide distribution and availability, low production costs and established technology. Additional benefits are reduced emissions of gases largely responsible for the global greenhouse effect and acid rain (Mosbech, 1994: A6), and renewability, which will inevitably lead to political and economic influence.

Bioenergy and MCBE are central to this review for three main reasons:

- they can utilise existing conversion technologies
- biomass supplies are available to almost every region of the world in some form
- coal is the most abundant fossil fuel in the world and is well distributed geographically (Blackburn, 1987: 107).

BIOENERGY

Definition

Biomass is the shorthand term for organic material, both aboveground and belowground and both living and dead, e.g., trees, crops, grasses, tree litter, roots, etc. (OECD, 1991: 6-1). Biomass used as fuel in energy production is referred to as bioenergy.

Forms of biomass used in energy production include: energy crops, wood and wood wastes, agricultural and agroindustrial wastes, sewage sludges and, municipal solid wastes. With such diversity, biomass is available to every country on earth. (Williams and Uqaili, 1995)

Two sources pertaining to biomass energy are significant in this review. The first has been edited by Bridgwater and is a useful book of papers giving a comprehensive review of thermochemical processing from growing the raw material to production and marketing of useful final products (Bridgwater, 1984a). A.V. Bridgwater works at Aston University in Birmingham and has been involved with bioenergy for some considerable time. His research and involvement in the field of bioenergy has been very useful in writing this review. The other source is a book edited by Hall and Overend consisting of papers discussing various aspects of the bioenergy industry (Hall and Overend, 1987). They are both excellent references covering aspects of biomass resources, thermochemical conversion processes, bioenergy developments, environmental factors and future potential.

Supplies and demand

Energy crops

Energy crops are those planted as a source of energy. This type of cultivation can be divided into two categories: wood energy crops and herbaceous energy crop. Wood energy crops include short rotation forestry (SRF), one of the most promising prospects for energy from biomass (IDAE, date unknown: 5). SRF explores tree species that grow quickly, recover easily and tolerate dense plantations. Willow, poplar, robinia and eucalyptus are the most popular trees and eucalyptus has the highest bulk density of the trees. However, herbaceous energy crops such as sweet sorghum and Miscanthus have the highest bulk density of all energy crops (IDAE, date unknown: 6). Bulk density is an important factor to consider when assessing the value of a fuel. A fuel can be quite valuable at the conversion site but if the costs of transporting and processing are substantial, then the overall value of the fuel may not compare well with other fuels that are easier to handle and process. A lower bulk density generally correlates with a lower energy content (i.e. woodchips versus fuel oil). Lower bulk density also indicates that more space is needed to transport the fuel from one point to the other.

Wood and wood waste

Processing residues, forest residues and whole trees from thinnings are available in large quantities in one form or the other year round (Mitchell and Pearce, 1984: 57).

Agricultural and agroindustrial waste

Agroindustrial waste covers crop residues from processing and harvesting methods. Agriculture wastes include livestock bedding straw, waste feed, and baling leftovers.

Sewage sludge

Animal and human wastes are produced in endless quantities and as population increases so will these wastes along with their associated disposal problems.

Municipal solid wastes

MSW includes domestic wastes destined for landfills. Energy can be harnessed from MSW by incinerating it at a power station or by landfilling it and capturing the gaseous emissions for combustion. MSW is another form of biomass which is available in enormous quantities and is directly affected by population growth.

Energy content in the total reserves of biomass is equal to the that of proven oil, coal and gas reserves combined. However, 90% of biomass energy is held in trees (Hall and de Groot, 1987: 4). This makes wood a valuable form of biomass. Wood is the most valuable energy resources for Third World countries. In 1986 more than half the trees cut down in the world were used for cooking and heating in these countries (Hall and de Groot, 1986: 441). Continued population growth, especially within the Third World, will result in an increased demand for wood as fuel.

Advantages of bioenergy

Table 1 summarises advantages and disadvantages of bioenergy.

The variety of biomass sources and their renewability are aspects that will secure bioenergy as an alternative once accepted by the energy industry (Bridgwater, 1984c:35). Bioenergy advantages also include the reduction of global greenhouse and acid rain producing emissions (Bridgwater, 1995: 642) which are central environmental issues driving the energy industry towards alternative energy technologies. Even when wood biomass is directly combusted, it is carbon dioxide neutral (IDAE, date unknown: 4). 'Carbon dioxide neutral' refers to energy production having no net emissions of CO2. Given that wood crops are left to grow to their original state following each harvest, such an energy fuel is CO2 neutral in that as much is emitted as is required for regrowth. Implementation of strict management strategies in the wood as fuel industry could stimulate afforestation and effective woodland regeneration schemes in other wood dependent industries (ERC, 1991: 49).

Crop surplus is a problem shared by many countries. These surpluses can be used as energy fuel or the land can be converted to produce higher density energy crops (ETSU, date unknown: 8). In the United Kingdom, the Ministry of Agriculture, Fisheries and Food (MAFF) established a payment scheme aimed at reducing surplus crop production. This scheme is referred to as the Arable Area Payments Scheme (AAPS). It offers payments per hectare of land no longer producing such crops. Payments differ depending on the quantity of land and its original crop type. A minimum amount of land must be converted to be considered for AAPS payments (MAFF#1, 1995: 6).

AAPS covers other schemes aimed at improving European agricultural industries. These include the Farm Woodland Premium Scheme (FWPS) and the Woodland Grant Scheme (WGS). These schemes offer land owners payments for converting portions of surplus crop lands into natural woodlands. The aforementioned minimum requirement for general AAPS payments can include this converted woodland (MAFF#1, 1995: 6). Short rotation coppice (SRC) can be grown on land under any of these schemes. SRC growers may apply for an establishment grant under the WGS which offers financial assistance to growers planting the coppice on set-aside land (MAFF#1, 1995: 40). The coppice must consist of forest trees with a harvest cycle of 10 years or less and must be intended for energy purposes (MAFF#2, 1995: 43-44). This production of energy crops on set-aside land alleviates problems of crop surplus waste (ERC, 1991: 50) and stimulates new income opportunities.

AAPS A payment scheme for land owners taking a portion of surplus crop land out of production	
FWPS A payment scheme for converting surplus crop land into woodlands	**WGS** A grant scheme available to landowners requiring further financial assistance in establishing woodlands
	SRC A woodland energy crop consisting of willow and aspen considered under the WGS according to specific guidelines

Table 1: Advantages and Disadvantages of Bioenergy

Bioenergy	
Advantages	**Disadvantages**
Biomass is the only renewable energy form containing fixed carbon which benefits in storage of fuel	Possibility of further deforestation if measures for protection are not secured
Carbon dioxide neutral	Present prices for fossil fuels are too low to make bioenergy an attractive option
SRC reduces surplus crop production and increases the value of AAPS set-aside land	A market for bioenergy has not been firmly established
Reduced SOx and NOx emissions can be achieved	The low bulk density of biomass makes it difficult and expensive to transport, handle and store relative to wind or solar energy
Use of sewage sludge and landfilled material reduces waste disposal pressures	Turbine and engine requirements for fuel gas combustion are stringent and require costly clean-up and compression measures
Establishment of energy crops on unused land can reduce erosion impacts	Water scrubbing is an effective clean-up method but produces a waste water problem
Alternative energy source with secure fuel supplies	Technical problems occur if the system has not been optimised (slagging, fouling and corrosion)
Where payment schemes aren't encouraging land use conversions, crop surplus can also be used as a fuel (i.e. straw fired power plants)	The high moisture content in biomass affects conversion efficiency (more moisture = less efficient burnout)
Bioenergy systems stimulate employment (i.e. fuel supply, transport, conversion, technology, and energy distribution)	The heterogeneous nature of biomass makes it difficult to achieve a uniform quality feedstock
International efforts to exploit renewable energies encourage R&D on bioenergy	Every source of biomass requires pre-treatment processing
Bioenergy can provide: fuel for transport, heat, and power on a small or large scale	Alkali metals in biomass have low melting temperatures which are problematic in high temperature conversion systems
Biomass can be less hazardous to handle than fossil fuels	Biomass can contain high levels of chlorine resulting in dioxin emissions
Biomass has various sources thus reducing single source reliance	To optimise a system can be risky and expensive
Every source of biomass can utilise the same conversion technology	
Biomass fuels have virtually no ash or sulphur	
Implementation of stringent SRC management strategies could stimulate effective afforestation strategies in other wood-dependent industries	
Sewage sludges and other wastes in bioenergy systems can provide an income	

Efforts to establish a market for bioenergy exist in the United Kingdom under the government's Renewables Order to stimulate renewable energy technologies. The Non-Fossil Fuel Obligation (NFFO) was established under the Renewables Order to stimulate the market for new renewable energy technologies from a variety of technology bands (ETSU, 1995). These bands include: solar, wind, hydro, landfill gas and in 1994 expanded to include a technology band committed to energy crops. However, this marketing strategy only offers temporary support. Success and longevity of the technologies depends on their ability to establish public acceptance and reduce production and operation costs quickly and efficiently.

Further advantages of bioenergy stem alternative disposal routes for sewage sludges. As Powlesland and Frost stated in their 1990 report, "in 1987 the 3rd report of the House of Commons Environment Committee on the Pollution of Rivers and Estruaries (House of Commons 1987) concluded that the UK policy of dumping sewage sludge at sea was regarded as unacceptable by other nations and could not be relied upon as an open ended option for sludge disposal" (Powlesland, 1990: 1). The idea that sewage sludge may be a suitable fuel for energy production is attractive from this viewpoint. Benefits include: alleviation of waste disposal pressures, renewability and a high quality, enriched ash fertiliser by-product (Bemtgen, 1994: A1).

Studies on energy from sewage sludge have been carried out within the Energy Technology Support Unit (ETSU) of the UK Department of Trade and Industry (DTI). Evaluations were conducted by van de Kamp and Smart (1993) and emphasised waste problems associated with slurries and sludges along with the feasibility of developed energy conversion technologies. Conclusions indicated that combined heat and power systems optimise the conversion processes and after burning combustion processes reduces NOx, CO, CO_2, N_2O and NH_3 emissions. They did not, however, consider MCBE as a wise route for development due to the fact that MCBE will have to concur with renewable energy emissions legislation which is far more challenging. Research into MCBE has indicated that emissions associated with MCBE of coal with sewage sludge or any biomass form, are well below emission legislation requirements (Gulyurtlu et al, 1995: 142). (Refer to the MCBE section for further discussion)

Before leaving the topic of sewage sludge advantages the use of sludge as fertiliser on SRF should be mentioned. Recent legislation with regard to sludge recycling on farmland does not apply to forested areas. Some tree species can utilise and benefit from the moisture, trace and nutrient elements and compounds in sewage sludge. Willow and aspen poplar short rotation coppice (SRC) are such examples. The legislation maintains that sewage sludge fertilisation is acceptable as long as the crop produced is not eaten raw or the livestock milk is not sold unpasteurized (Yorkshire Water, 1989). Project ARBRE, in the Yorkshire region of England, is a bioenergy project producing coppice crops for the purpose of energy. Treated domestic sewage sludge from Yorkshire Water's waste water treatment works is being used as an environmentally feasible fertiliser on its coppice plantations (Yorkshire Environmental, 1995).

Final advantages include the use of bioenergy for transport fuel, heat and electricity using existing coal conversion technologies (Bridgwater and Evans, 1993: 51). Biomass energy has added benefits of low ash and sulphur composition which reduce, but do not eliminate, associated problems (Manahan, 1993: 814).

Disadvantages of bioenergy

Wood is renewable but consumption rates must not exceed regrowth rates. If the use of wood for energy is not carefully implemented, present deforestation rates could increase. Sustainable forest planting, harvesting and management are vital to the success of wood as a fuel. Successful sustainable forestry relies heavily on management systems and well structured codes of practice along with well defined Annual Allowable Cut which considers forest characteristics for specific regions. The other forms of biomass, municipal solid waste, sewage sludge, and processing residues do not face this risk.

The price of fossil fuels will also influence the establishment of a market for bioenergy. At present, prices for biomass supplies, especially energy crops, cannot compete with oil, gas and coal. The near future does not predict any significant increases in the price of fossil fuels but the long-term future predicts that as supplies decrease, prices will increase. In short, the present disadvantage of fossil fuel prices will eventually become an advantage.

Public acceptance and reduced production costs are not easy to accomplish without the support of other strong organisations. A market for bioenergy must be sufficiently established and stabilised before support from the NFFO-3 is removed. Failure to do so will indicate to potential investors such as banks, utilities and consumers that bioenergy might not be the most practical choice of the available alternatives.

What would make bioenergy even more attractive would be the reduction of methane, dioxins, hydrocarbons and carbon monoxide emissions along with the elimination of such problems as slagging, fouling and equipment corrosion due to deposits. Deposits can be dealt with using an efficient ash removal system recognizing the low melting temperature of alkali metals in biomass. These improvements would optimise fuel gas application to turbines and engines (Bridgwater and Evans, 1993: 34).

Methods for dealing with problems associated with the low bulk density of biomass have been developed. Straw baling, sewage sludge caking, wood pelletisation, cubing, and briquetting are among the densification methods used to make agglomerates of regular shapes which improve the possibilities for handling and storage while producing a uniform quality mixture for conversion (IDAE, date unknown: 10). However, wood chipping is regarded as the most practical solution to the problem of low bulk density because the other methods are time consuming and costly (Miles, 1984: 71). The low bulk density combined with high moisture levels of biomass result in a less efficient fuel in terms of energy produced per unit of fuel. In time, progress will optimise mechanisms used in transforming raw biomass into dried and densified material that is easier to transport.

MIXED COAL AND BIOMASS ENERGY (MCBE)

Description of MCBE

MCBE refers to converting coal mixed with biomass into heat and power and includes combustion as well as gasification

All biomass forms discussed in the previous section are applicable to MCBE processes. Wood, agricultural crops, forest and agricultural residues, municipal solid waste, peat and energy crops have been studied as mixers with a base of various ranks of coal to determine the advantages and disadvantages of combined feedstocks.

Definition of coal

Coal is an inhomogeneous organic fuel formed from partially decomposed and metamorphosed plant materials. It varies greatly in composition but consists of carbon, hydrogen, oxygen, sulphur and nitrogen. It also contains an inconsistent fraction of inorganic mineral matter (ash) and moisture. (Radulovic and Smoot, 1993: 1)

The four main ranks of coal, from best to poorest, according to sulphur content:

- anthracite
- bituminous
- subbituminous and
- lignite

(Tank, 1983: 330)

For up to date papers dealing with clean coal and MCBE research the journal titled, *FUEL, the science and technology of Fuel and Energy* published by Butterworth and Heinemann has been extremely useful.

Supplies and demand

There are no immediate supply problems for coal; it is the world's most abundant fossil fuel (Radulovic and Smoot, 1993: 72). However, coal energy is the most polluting of conventional fossil fuels with regard to mining as well as combustion. These two factors, abundance and pollution, make coal research necessary if it is to become a desirable energy source for the future. MCBE and clean coal technology are two areas of research which have made coal power more environmentally attractive.

Clean coal technology refers to methods of producing power and heat from coal with emission controls for oxides of sulphur and nitrogen (SOx and NOx) built into the system design. Clean coal technology maintains that increased efficiency in: power generation, end use and transport are the best methods for reducing global carbon dioxide emissions (Topper *et al.*, 1994: 1061). However, these methods would be further optimised by MCBE.

Advantages of MCBE

Table 2 summarises advantages and disadvantages of MCBE.

The obvious advantages of MCBE are:

- reduced carbon dioxide emissions by using some portion of CO_2 neutral biomass
- the present price of coal
- the abundance of coal and
- the utilisation of some portion of renewable resources

MCBE takes advantage of the present affordability of coal with the assurance that supplies will last well into the future relative to other fossil fuels. The partial use of renewable fuel reduces the rate of coal consumption, helps to secure a feedstock supply and, reduces harmful emissions. Biomass and coal could establish a mutually beneficial relationship in MCBE. Coal can benefit from the renewable and carbon dioxide neutral aspects of biomass while biomass benefits from the coal market and energy efficiency. MCBE will produce more energy per unit compared with dedicated bioenergy. Further advantages include reduced handling, transport and purchasing costs compared with bioenergy simply because proportionately less of the low density feedstock is used.

The implementation of MCBE is not a severe change with respect to resource use compared with pure bioenergy. Further support is found in the results from the APAS Clean Coal Technology programme. They have concluded that combining biomass with coal in power generation reduces global greenhouse gas emissions and provides a cheap, abundant and environmentally friendly energy alternative (Bemtgen, 1994: A1).

Anders Nordin, of the University of Umea, also encourages the implementation of combined fuel combustion (co-combustion) systems. His previous work has found that biomass fuels contain relatively large amounts of calcium, potassium and sodium in reactive forms and coal has long been known to contain harmful levels of sulphur. He has found that natural reactions occur during combustion which retain sulphur and convert it into solid alkali sulphates. By optimising this sulphur retention when combusting biomass and coal, sulphur content can be retained rather than emitted by more than 70% (Nordin, 1995: 615).

According to Hein and Spliethoff of the University of Stuttgart, straw, wood and sewage sludge are especially practical mixers with coal in pulverised fuel and fluidised bed combustion systems. Biomass co-combustion is one of the cheapest possibilities for thermal utilisation of large amounts of biofuel (Hein and Spliethoff, 1995: 134). Gulyurtlu *et al.* state that the combustion efficiency of coal is unaffected by straw additions and that benefits such as a reduction in NOx and N_2O emissions can be achieved even without clean up measures applied (Gulyurtlu et al, 1995: 142). Mark White of ETSU, in the UK monitors activity on the MCBE side of energy production. He has found that Denmark has made significant progress in converting surplus straw into energy for district heat and electricity (White, 1995).

Table 2: Advantages and disadvantages of MCBE

MCBE	
ADVANTAGES	**DISADVANTAGES**
REDUCED CO_2 EMISSIONS	GENERAL PERCEPTION OF COAL ENERGY AS 'DIRTY'
PRESENT PRICE OF FOSSIL FUELS	REMOVAL OF SLAGS POSE PROBLEMS
UTILISES RENEWABLE RESOURCES	MCBE CANNOT BE CONSIDERED FOR GOVERNMENT SUBSIDIES UNDER THE RENEWABLE'S ORDER SCHEMES
ABUNDANT COAL SUPPLY	MCBE STRAW WITH COAL INCREASES CHLORINE CONTENT
ESTABLISHED COAL INDUSTRY AND MARKET	
REDUCED HANDLING AND TRANSPORT CONCERNS ASSOCIATED WITH DEDICATED BIOENERGY SINCE BIOMASS IS ONLY A PORTION OF THE TOTAL FEEDSTOCK	
INCREASED EFFICIENCY RELATIVE TO BIOENERGY	
TECHNICAL KNOWLEDGE AND EVEN COMMERCIALISATION	
UNAFFECTED EFFICIENCY COMPARED WITH DEDICATED COAL POWER	
COAL IN MCBE MAKES IT MORE FAMILIAR TO INDUSTRY AND CONSUMERS	
SULPHUR IN COAL REACTS WITH ALKALI METALS IN BIOMASS TO PRODUCE SOLID SULPHATES THAT CAN BE PRECIPITATED OUT OF THE CONVERSION SYSTEM THUS REDUCING SULPHUR EMISSIONS	
MCBE SEWAGE SLUDGE WITH COAL COMPLIES WITH EMISSION STANDARDS OF THE RELEVANT POLLUTION CONTROL ACTS	
NOx EMISSIONS ARE ALSO REDUCED	

Disadvantages of MCBE

The use of coal in an alternative energy for the future may not be viewed with optimism. Coal is, traditionally, an unclean source of energy in its mining and conversion. To change this perception could prove difficult. Furthermore, there is a radioactive content in the resulting ash of coal burning that reaches low grade radioactive waste levels. Accurate methods for measuring levels of mercury, lead and other toxic metals have yet to be discovered.

Problems associated with ash deposits, slagging, fouling and corrosion are common to coal, biomass and mixed fuel conversion processes (Mosbech, 1994: A6). Methods of solving these problems or reducing their effects rely on the development of effective ash removal and gas cleaning production (Nordin, 1995: 615). Minchener also points to potential problems associated with increased chlorine levels when straw is mixed with coal (Minchener, 1994: A5).

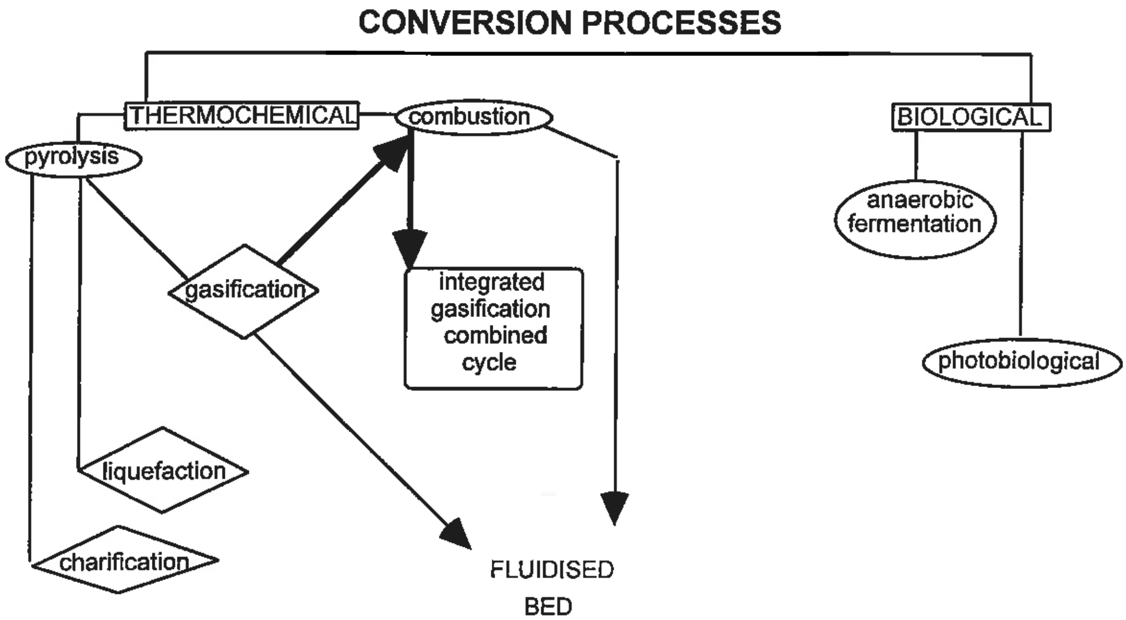
MCBE cannot be considered for support under the Renewables Order in the United Kingdom because the NFFO only considers non-fossil fuels. Coal being a fossil fuel eliminates this option for support. Therefore MCBE must create a market by other means. The strength of the coal industry would possibly be more useful in establishing a market for MCBE than the NFFO will be for bioenergy but that has yet to be determined. A complete and comprehensive understanding of emissions must also be developed (Mosbech, 1994: A6) and economic feasibility and risk minimisation proven before market establishment and stabilisation can be achieved.

MCBE does have problems associated with sulphur in coal and alkali metals in biomass which can also result in the above mentioned fouling and slagging. However, it should be emphasised that dedicated coal and biomass combustion also experience problems with sulphates, studies for dedicated energy fuels compared with Nordin's calculations indicate that co-combustion is preferable with regard to such affects as bed sintering, slagging and fouling. The sulphur in coal appears to facilitate the movement of corrosive metals like potassium out of the bed thus reducing its residence time (Nordin, 1995: 621).

COMMON TECHNOLOGIES FOR BIOENERGY AND MCBE

Figure 1 is a diagram of conversion processes. Conversion of fuels into useful energy has two processing categories- biological and thermochemical. Biological technology refers to biomass in particular and currently includes anaerobic fermentation to alcohol and methane. A more immature bioenergy technology considers photobiological processes.

FIGURE 1: Conversion processes: Thermochemical processes can be used in coal, biomass and MCBE conversion whereas biological processes are used in biomass conversion.



Thermochemical conversion processes include direct combustion and pyrolytic processes (Smith, 1987: 461) and apply to coal, biomass, and mixed fuels. In principle, almost any reasonably dry combustible can be thermochemically processed (Brandon *et al.*, 1984: 11).

Combustion

Combustion is a simple burning process in which substances combine with oxygen and produce heat. Of all conversion processes, direct combustion is best understood but it can be inefficient and significantly polluting if poorly managed (Smith, 1987: 460). Combustion technology for the conversion of coal, biomass waste and mixed fuels is fully commercial (Strub, 1984: 4) and widely used thus indicating that optimisation of the technology would still be valuable.

Co-combustion of biomass with coal has been studied for common large-scale combustion systems demonstrating the use of optimum and technically achievable process modifications. At the University of Stuttgart in Germany, pulverised fuel combustion and fluidised bed combustion have been assessed using combinations of combustion systems, fuel alterations, added biogenic fuels, varying ratios and feeding systems. (Bemtgen, 1994: A1) Process evaluations and optimisation studies have also been successfully carried out on fluidised bed combustors in Sweden (Nordin, 1995: 615).

Pyrolysis

Pyrolysis is a process by which organic material is decomposed at an increased rate due to lack of oxygen and increased temperature conditions in a reactor. Pyrolytic processes include: charification, liquefaction and gasification which produce char, oil, and gas. Oil and liquid alcohol products can be used as liquid energy fuels for transport. Advantages of pyrolysis include the handling and application of gaseous and liquid energy carriers. However, energy use of pyrolysis oils has not been sufficiently developed due to inefficient methods of purification and utilisation (Strub, 1984: 4).

Gasification is the most widely accepted and commercialised pyrolysis process. The development of gasification technology began about 150 years ago (Beenackers and van Swaaij, 1984: 91). The fundamentals are now well understood with research and development projects now focusing on technical optimisation (Strub, 1984: 4). Products of gasification are gaseous energy carriers consisting of various emissions and contaminants that require control measures (Bridgwater and Evans, 1993: 12).

Gasification also offers the most developed power generation system for bioenergy production (Bridgwater, 1995: 631). Operations are flexible in that they can be atmospheric or pressurised systems using fixed, fluid, or moving beds. Parameters can be manipulated for different feedstocks and restrictions. Each parameter combination has strengths and weaknesses and the choice depends on the limiting factors in each case. Factors may include: fuel type and operation tolerance, cost of system construction, moisture content of fuel, emission regulations and maintenance capabilities (Bridgwater, 1995: 636). Such variations in fuel characteristics may necessitate continuous optimisation of fuel feedstock. Research and development of these gasification operations inevitably rely on pilot plants and demonstrations. The role of pilot plants and demonstration units is to evaluate their potential and to study aspects of feasibility (Bridgwater, 1984b: 331). Gasification has passed pilot and demonstration stages but mitigation measures for fouling, slagging and corrosion must be improved.

Important Funding Bodies and Programme Names

Table 3: Major Action Programmes and Dedicated Areas of Support

MAJOR ACTION PROGRAMMES			
	DEDICATED AREAS OF SUPPORT		
GOVERNING BODY AND PROGRAMME NAME	**COAL**	**BIOMASS**	**MCBE**
European Commission	X	X	X
FRAMEWORK IV	X	X	X
THERMIE (DG XVII)	X	X	
JOULE II (DG XII)	X	X	
APAS (DG XII)	X		X
ALTENER (DG XVII)		X	
Department of Trade and Industry (DTI)		X	
ETSU		X	X
EUREKA		X	
Non-Fossil Fuel Obligation (NFFO)		X	
International Energy Agency (IEA)		X	

Co-gasification for large scale power generation using fluidised bed, moving bed and entrained bed gasifiers has also been studied at the University of Stuttgart. Economic studies for such power generation have been assessed. Combustion of the produced fuel gas with low environmental impact is another optimisation strategy being seriously explored (Bemtgen, 1994: A1). The technology is referred to as combined cycle conversion.

Combined cycle

Integrated gasification combined cycle (IGCC) technology is feasible for dedicated biomass, coal or mixed fuel power generation. Feedstocks are gasified then the resultant gas is combusted for power generation (Bemtgen, 1994: A1). The system becomes more efficient when waste heat is recovered for heating use. Biomass fired IGCC units have not yet been commercialised (Faaij *et al.*, 1995: 4). The greatest area of uncertainty lies in the performance and reliability of the gas cleaning systems employed before fuel gas combustion (Bridgwater, 1995: 632). The Netherlands Energy Research Foundation ECN and the University of Utrecht in the Netherlands have completed and are still conducting research and experiments on the technical, economic and environmental feasibility of the units. They have conclude that IGCC technology works well and offers many improvements when compared with traditional technologies. However, they do emphasise the need for:

- system optimisation
- increased efficiency
- reduced costs per kilowatt

and optimisation relating to:

- economies of scale
- logistics
- biomass supply and
- organisational aspects

(Faaij *et al.*, 1995: 40)

Combined fuel gasification (co-gasification) is attractive for various reasons. According to Minchener from the CRE Group in the UK, a low calorific value gas produced from renewable fuels, such as bio-fuels or municipal solid waste, when used as a reburning fuel, is very effective for NOx reduction, as long as the hydrocarbon content is kept at a reasonable level and that potential pollutants and technical problems are controlled. (Minchener, 1994)

Improvements of technologies could include laboratory / bench scale innovation and routine evaluation, modelling, as well as technical and economic system studies which in turn would optimise processes, reduce costs, improve efficiency (Bridgwater, 1984b: 331) and reduce technical risks.

With regard to all above mentioned technologies, optimisation relies heavily on the co-operation and communication of national / international research organisations. The integrated programmes operated by the European Commission and the U.S. Department of Energy with their regular contractors' meetings are important in the encouragement of ideas, developments and information (Bridgwater, 1984b: 330). Refer to table 3 listing action programmes and funding bodies committed to the success of bioenergy, clean coal technology or MCBE.

Results from studies of all conversion technologies have indicated that they are technically feasible, economically attractive and environmentally beneficial and can be applied to existing technologies with minimum input (Bemtgen, 1994: A1). Some technologies have, however, progressed at a faster rate. The fluidised bed reactor is researched and reviewed as a suitable technology for gasification, combustion and combined cycles by many researchers.

General Review of deployment potential for technologies

At present there are a range of energy technologies available or potentially available. Future changes in energy supply and demand will be influenced by technical progress. It is therefore necessary to assess how present technologies will be able to meet future energy requirements. As already discussed, environmental concerns have become increasingly important in technical appraisals of energy systems. It is no longer a case of simply more power but rather a balance between increased efficiency and reduced environmental impacts at lowest costs and risks. For every country, the energy industry's market structure is significantly influenced by fuel supply consumer demand. This has been illustrated in the recent privatisation of Britain's gas and electricity companies. Increased environmental concern, especially regarding CO2 emissions, is now evident in appraisals of new technology. The Energy Technology Support Unit (ETSU) of the UK completed an Energy Technologies report in 1994 where various technologies were assessed according to energy production, conversion, transport, and storage as well as utilisation and efficiency and reflecting the methods available for an energy balance in the UK (ETSU, 1994). Using a range of scenarios, ETSU considered various parameters for studying future economies and social backdrops. Prices and demand were essential for every scenario because, fuel prices influence the cost of conversion technologies thereby establishing competitiveness with alternative-fuel technologies or fuel-independent energy technologies that are unaffected by changes in fuel price trends (ETSU, 1994).

In ETSU's report, an energy system model was used to illustrate least cost energy production routes from primary fuels at specified prices for a number of technologies. The energy system model used by ETSU was MARKAL, a linear program optimising a selected 'objective function', in this case the total discounted system cost. The total discounted system cost considers capital costs for technologies as well as their annual running costs but annualises the 'one-off' costs. This enables energy systems that require dedicated and specialized technologies (i.e. wind farms) to be compared with systems that can utilise previously established technologies (i.e. clean coal technologies). The selected least cost path is then measured according to their ability to meet useful energy demands under various environmental constraints. This is a brief overview of how energy technologies were studied. Results indicated that combined cycle gas turbines from the fossil fuel generating technologies showed substantial energy contribution potential under all constraints and showed an increase in potential when faced with strict emission constraints and is characterised by a deployed market status.

Renewable technologies were considered separate to fossil fuel technologies and the results showed that energy crops and advanced conversion technology respond favourably to emission constraints and, for the most part, have deployed market status.

ENVIRONMENTAL CONSIDERATIONS

According to H.J. Allgeier of the European Commission, the environment is the main driving force behind European energy research, technological development and demonstration strategies. Energy resources in the future will become a pressing problem but at present are sufficient and import supplies have diversified enough to eliminate the risks of being dependent on one or few sources. The reduction of local and global pollution problems is the central environmental issue in recent action plans for energy production (Allgeier, 1994).

Combining biomass with coal as a feedstock for the new generations of "clean" coal power plants provides an innovative means of tackling Europe's greenhouse gas emission problems (Bemtgen, 1994: A1). It is necessary for Europe to ensure energy and environmental security by maximising diversity of supply and making optimum use of those supplies, while minimising the environmental impact (Allgeier, 1994). The use of biomass for power production is generally motivated by the wish to reduce CO_2-emissions (Mosbech, 1994: A6). Table 4 indicates changes in emissions compared with traditional coal combustion processes. For combustion and gasification, all mixtures have reduced CO_2 emissions.

NOx emissions initially increase in gasification but can be reduced significantly through fuel gas combustion. An Integrated Gasification Combined Cycle is a processing system offering this advantage. For combustion alone NOx emissions are reduced for all mixtures.

SOx emissions are also a problem but can be significantly reduced by adding limestone to the conversion system. In addition to flue gas control, there is the issue of sulphur retention from coal when combusted with biomass (Nordin, 1995: 615). Some of this reduction in sulphur is attributed to the decreased sulphur input due to the low sulphur content of biomass fuels (Hein, 1994).

Natural reactions during combustion of coal with biomass retain sulphur and convert it into solid alkali sulphates. By optimising this sulphur retention when combusting biomass and coal, sulphur content can be retained rather than emitted by more than 70% (Nordin, 1995: 615).

Polychlorinated biphenyls (PCBs) are destroyed in gasification and SO_2 emissions are significantly reduced in combustion. Both gasification and combustion face problems associated with halogen emissions such as chlorine and hydrochloric acid. Gasification also emits larger quantities of hydroflourine. These emission problems are reduced when an Integrated Gasification Combine Cycle is used making it a valuable technology with respect to emissions (Hein, 1994).

According to H. Mosbech of the ELKRAFT Power Company in Denmark, ash poses an environmental problem. Ash residues from central power plants are today recycled and used for cement production. Likewise, gypsum is used in plaster board production. Dedicated straw firing plants in Denmark return the produced ash to the supplier to be used as a crop fertiliser. It has not yet been confirmed whether or not mixing coal and straw produces an ash unacceptable for these uses (Mosbech, 1994: A6). Nordin also saw ash as a technical drawback when experimenting with MCBE as a means of sulphur retention. Sulphur retention may directly contribute to an increase in deposit formation due to alkali sulphate

Table 4: Gaseous emissions from MCBE according to mixture using pulverised fuel facilities and circulating fluidised beds

EMISSIONS							
CO-COMBUSTION							
MIXTURE	**GAS**						
Coal with:	**CO**	**CO_2**	**NOx**	**SO_2**	**dioxins**	**halogens (Cl) & HCl**	**N_2O**
In PF[1]		less					
Biomass		less	decrease	decrease			
straw		less	decrease	decrease	possible increase	increased	
Miscanthus		less		decrease	no change		
wood		less			no change		
Sewage sludge	decrease	less	possible significant decrease	significant decrease			
In CFB[2]							
Biomass	decrease	less	low but generally no change	significant decrease		increased	low but generally no change
straw		less				increased	
Miscanthus		less					
wood		less	decrease				decrease
Sewage sludge	decrease	less	decrease		decrease		

Data was taken from: K.R.G. Hein, 1994. Co-combustion of Coal, Biomass and Waste
1. Pulverised fuel facility
2. Circulating fluidised bed

Table 4 continued...

EMISSIONS							
CO-GASIFICATION* AND FUEL GAS COMBUSTION**							
Coal with:	HC	CO_2	NOx** (NH_3)	SOx	alkali metals	halogens (halide) & HCl/HF	Poly-chlorinated biphenyls
Biomass		less	reduced only when fuel gas was re-burned	much reduced with limestone addition	reduced	can be reduced using a sorbent	are destroyed
straw	generally no change	less	increase in gas but could be re-burned				are destroyed
wood	increase up until 50/50% mix is used then reduced	less	significant increase in gas but could be re-burned				are destroyed
Sewage sludge		less	increase in gas but could be re-burned	much reduced with limestone addition	reduced	can be reduced using a sorbent	are destroyed

Data was taken from: A.J. Minchener, 1994. Combined Gasification of Coal, Biomass and Waste

* Gasification research used fluidised bed, moving bed, and entrained flow technologies.
** Those gases with '**' are significantly reduced during flue gas combustion.

formation (Nordin, 1995). Finally, as briefly mentioned already, coal conversion is characterised by the production of low-grade radioactive waste ash and uncertain levels of toxic metals such as mercury and lead. These issues require further research.

ECONOMIC POTENTIAL

Now we turn to the economics of bioenergy and MCBE as energy alternatives. Economics is the science of production and distribution of wealth. A successful economic system is one which avoids waste and maximises profit.

With regard to financial profitability, coal energy has been successful. Coal fuelled power stations were built near coal resource locations. The closer the plant could be to the mining site, the better. This reduced costs and increased efficiency with respect to transportation. For MCBE this will be advantageous as long as the coal is still being mined from the same area. However, bioenergy using old coal energy plants will suffer the costs of time and money when biomass supplies are not close to the plant. This problem arises when energy crops are grown on set-aside land and no option for plantation location is available.

The environmental aspects of coal energy do not fair as well. Concerns associated with the atmospheric pollutants have prompted research into incentives for developing and implementing clean coal technologies. Methods have involved making coal energy more expensive to produce by introducing carbon taxes. Williams *et al.* researched CO_2 taxes and concluded that the penalty would have to be in excess of £32/tonne before clean coal generation technologies would become attractive to the producers. At this high level, the coal energy producers could choose to reduce the financial impacts by recovering and containing liquid CO_2 to sell as a material used in enhanced oil recovery (Williams *et al.*, 1994: 1072). This tactic works in Denmark but has not been accepted in many other countries.

Factors affecting the economics of bioenergy include feedstock viability due to increased yield, reduced processing expenses, and the improvement of technologies for upgrading fuel quality. Regarding yield of fuel wood, the present consumption rates in Third World countries have exceeded regrowth rates and fuel wood is becoming an increasingly depleted resource. This has resulted in areas of desertification and deforestation (Williams and Uqaili, 1995). How this affects the future of biomass energy will depend on how much value is placed on fuel wood as a bioenergy fuel. Widespread implementation of energy crop production on available agricultural land, as is the case for set-aside land in the United

Kingdom, would provide wood for energy at sustainable rates. MCBE the energy crops would further reduce rates of consumption and hence the risk of depleting resources. Price levels of other biomass fuels will also play a major role in fuel wood consumption.

Energy crops and agricultural / wood wastes cover large areas and have low bulk densities. This creates a problem of low energy value per unit area. In the case of energy crops, spatial requirements for establishment compared to obtaining coal from one spot at the pithead is significant. MCBE could reduce the effects of this density problem. However, Bill Livingston of Babcock Energy in Scotland put the problem in perspective by stating that a ratio of 5 parts willow chips : 95 parts coal (5:95) is required to eliminate these spatial requirement problems enough to make energy crops affordable (Livingston, 1995). Other inhibiting factors for the successful implementation of bioenergy relate to the uncertainty of purchasing cost of biomass and the general reluctance of users to adopt novel technology (Bridgwater, 1984b: 330).

The advantages of using CO_2 neutral biomass with large scale efficiency of coal requires that the two be mixed according to optimised ratios. The proportion of biomass used will vary according to biomass type and logistics. APAS Clean Coal Technology programme has concluded that distances and availability are more limiting at this stage of research than the combustion and gasification technology. (Allgeier, 1994) Transportation costs become prohibitive if biomass is used in large centralised power plants. Thus they have always been used in smaller, decentralised plants which inherently have lower efficiency and poorer economies but do not require different technology from coal (Allgeier, 1994).

Biomass handling, storage, drying, comminution and screening are well established in the pulp and paper industry and in combustion systems world-wide, at present there are no uncertainties in operation and performance. There is, however, a need to optimise the cost and performance of specific aspects of the conversion systems. (Bridgwater, 1995: 652)

The use of sewage sludge presents an attractive economic benefit for power generation companies. A power plant would likely be paid to accept sewage sludge (Minchener, 1994) along with other wastes that pose disposal problems. Surplus crops present disposal problems but in order to secure it's supply to power plants a purchasing price would have to be offered to make the disposal option attractive to growers. More would have to be paid for fast growing and higher density crops grown specifically for energy such as those harvested from short rotation forestry and coppice plantations.

In view of the present aims for countries to utilise diverse sources of clean and renewable energy technologies, bioenergy will probably not be a panacea to any country's energy requirements, and may only contribute partially to world energy needs (Hall and de Groot, 1987: 4). Moderate implementation combined with MCBE would be enough to support the livelihood of large areas of agricultural landowners.

CONCLUSION

Energy trends favour diversity of energy sources and technologies. It is quite clear that such diversification will reduce risks of power and resource shortages. Decentralisation of power generation by using multiple resources and by implementing various technologies will likely become more widespread and achieve more of a balance.

Bioenergy and MCBE are two options for alternative energy technologies. Using bioenergy as an energy alternative is attractive compared with coal power in that:

- biomass is renewable
- using waste derived fuels alleviates waste disposal problems
- bioenergy is compatible with existing technologies
- biomass is carbon dioxide neutral
- bioenergy reduces SOx and NOx emissions
- reduces production of, or offers a disposal route for, surplus crops and
- bioenergy is a possible incentive for improved afforestation strategies

However, bioenergy has not proven to be:

- completely absent of harmful emissions (greenhouse gases and acid rain pollutants are reduced but carbon monoxide and dioxins are still significant)
- energy efficient per unit (amenable to low bulk density and high moisture content)
- cost-effective with respect to transportation, handling and purchasing costs

MCBE has reduced some of the problems associated with bioenergy in that:

- coal and biomass mixed increases the energy value per unit area
- reduces the costs associated with transportation, handling and purchasing by simply using less of it
- makes use of a stable coal energy market
- uses the most abundant of the fossil fuels and
- the conversion technology is flexible with various systems available
- the above benefits make it suitable for virtually every region of the world able to meet the technical requirements

From this review of bioenergy and MCBE it can be concluded that there are obvious costs and energy inputs for each system as well as obvious profits and outputs. A comprehensive cost-benefit analysis allowing different regions of the world to examine the feasibility of bioenergy and/or MCBE energy systems would de a definite asset to the future of these energy systems. Consideration for spatial aspects, technology, financial investment, and time consumption involved in system set-up, operation and maintenance enable system optimisation. A valuable step for bioenergy and MCBE technologies would be to conduct a case study of a region. This regional study should utilise the best research and developments to ensure that the most advanced information is being considered. Research contributions would then be compiled to produce a cost-benefit analysis of the chosen region. The commencement of projects like this are necessary to successfully implement bioenergy and MCBE energy systems in regions best suited for them.

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