

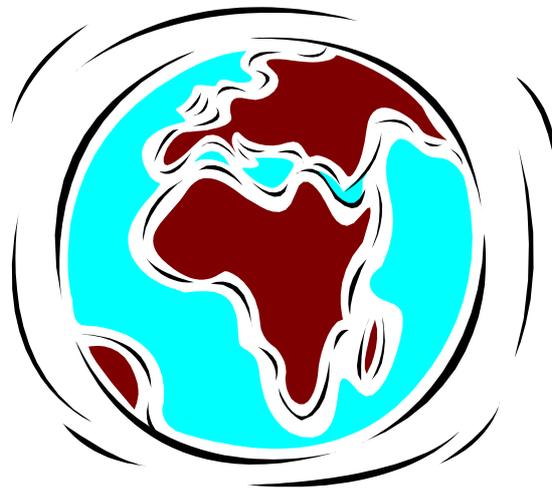
**Bioenergy and the Sustainability Transition:  
*from Local Resource to Global Commodity***

*prepared for the*

*World Energy Congress (WEC)*

*Rome, November, 2007*

*(P001500)*



31 August 2007

Francis X. Johnson, *Research Fellow*

***Climate and Energy Programme***

**Stockholm Environment Institute**

## Table of contents

Abstract .....	3
1. Introduction .....	4
2. Biomass, Bioenergy, and Biofuels .....	4
Traditional uses of Biomass .....	4
Biomass and Livelihoods .....	5
Global bioenergy potential .....	6
Food vs. Fuel .....	7
Liquid biofuels .....	7
Land use patterns .....	8
Income and Population .....	9
3. Bioenergy Conversion options .....	9
Biological Conversion .....	10
Combustion and Co-firing .....	10
Gasification and Pyrolysis .....	11
Chemical conversion from oil-bearing crops .....	11
4. Elements of the Bioenergy Transition .....	12
Turning waste products into renewable resources .....	12
From traditional biomass to modern bioenergy .....	13
From small-scale to multiple scales .....	13
From single to multiple product(s) .....	13
From Chemical to Biological Processes .....	14
From carbon sink to carbon management .....	14
From local fuel to global commodity .....	14
5. Impacts and Sustainability .....	15
Sugar crops .....	15
Woody Biomass .....	16
Oil-bearing and other biomass crops .....	16
Socio-economic Impacts .....	16
Sustainability Criteria .....	17
6. A Conceptual Model .....	18
Bioenergy Potentials .....	18
Constraints/Demands .....	18
Alternative Institutions and Policy Options .....	19
Outcomes .....	20
7. Conclusions .....	20
8. References .....	21

## **Abstract**

The looming threat of climate change and the invaluable role of energy in development have complicated the global transition to sustainable energy while also increasing the urgency of the transition. Bioenergy has a key role in this transition due to its unique characteristics among renewable energy sources, the concentration of bioenergy potential in major developing country regions, and the close relationship between biomass resources and carbon management strategies. This paper offers a review and a conceptual model for bioenergy's role in the transition, outlining its key elements and their significance with respect to environment and development.

In spite of the globalising economy, the security of energy supply continues to be threatened by geo-political conflicts. Continued expansion of energy consumption is also constrained by its environmental impacts—locally, regionally, and globally. At the same time, two billion persons have little or no access to modern energy services. The diversity and flexibility of bioenergy systems offers opportunities to bridge some of the key divisions—technical, political, economic, and environmental—that have complicated international efforts to address climate change and promote equitable development of global resources. The challenge is to take advantage of the heterogeneity of biomass resources to facilitate the most effective use of those resources in the emerging bio-economy.

## 1. Introduction

Biomass is living matter derived from plants and animals; energy sources from biomass are often divided into two main categories: biomass wastes (or residues) and energy crops. Biomass wastes or residues refer to the remaining biomass after harvesting and/or after processing. The two categories differ significantly in the economics of their utilisation as well as in biophysical terms:

- Biomass wastes and residues include forest and agricultural residues (e.g. bagasse, cereal husks, straw); urban organic wastes; and animal wastes. They normally offer the most widely available and least-cost biomass resource options. The principal challenge is to develop or adapt reliable, cost-effective handling methods and conversion technologies (Leach and Johnson, 1999).
- Dedicated energy crops refer to plantations of trees, grasses and/or other energy crops. Bioenergy plantations are optimised for energy production, through which the harvested biomass is used directly, or serves as feedstock for further production of more specialised fuels. The principal challenges centre on lowering biomass production costs and reducing risks for biomass growers (e.g. stable prices) and energy producers (e.g. guaranteed biomass supply).

These approaches can be—and generally are—mixed, by growing biomass for profitable non-energy purposes (e.g. timber) and using the harvest residues for bioenergy. In some regions, mixed approaches will provide the most attractive long-term option, given projected global demands for wood products and the possible scarcity of suitable land in the long-term for dedicated energy crops once basic food and fibre needs are met. Future scenarios for bioenergy trade should include consideration of timber markets, as the two regional markets can be in conflict (Smeets et al, 2004).

The transition from traditional uses of biomass for energy to more efficient and higher quality bioenergy, often referred to as *modern*<sup>1</sup> bioenergy, is important for many reasons, but foremost among them the following:

- Modern bioenergy provides higher quality energy services that are more versatile and more efficient than traditional bioenergy. Traditional use of solid biomass as fuel can only deliver poorly-controllable heat, whereas modern bioenergy can deliver a variety of efficient and well-controllable energy services (Leach and Johnson, 1999).
- Assuming that environmental impacts are appropriately incorporated into overall system designs, modern bioenergy is much more likely to be sustainable in the long-term compared to traditional uses, due to savings in land, water, and other resources as a result of higher efficiency and greater precision in matching the mode of implementation to the differing needs of energy users in particular applications.

## 2. Biomass, Bioenergy, and Biofuels

Biomass accounts for about 11% of total primary energy consumed globally, more than other renewables and nuclear power together. Fossil fuels continue to account for the overwhelming share of global primary energy consumption, together accounting for nearly 80% of the total. Other renewables, including hydro, account for less 3% of all primary energy consumption. (Figure 1a). Biomass is also by far the most significant among renewable energy sources, accounting for about 80% of renewables used (Figure 1b). Modern bioenergy could potentially surpass large hydro in the coming years, given the significant rate of growth in liquid and solid biomass use and the increasing reluctance in many regions of the world to accept the environmental impacts of large-scale hydro.

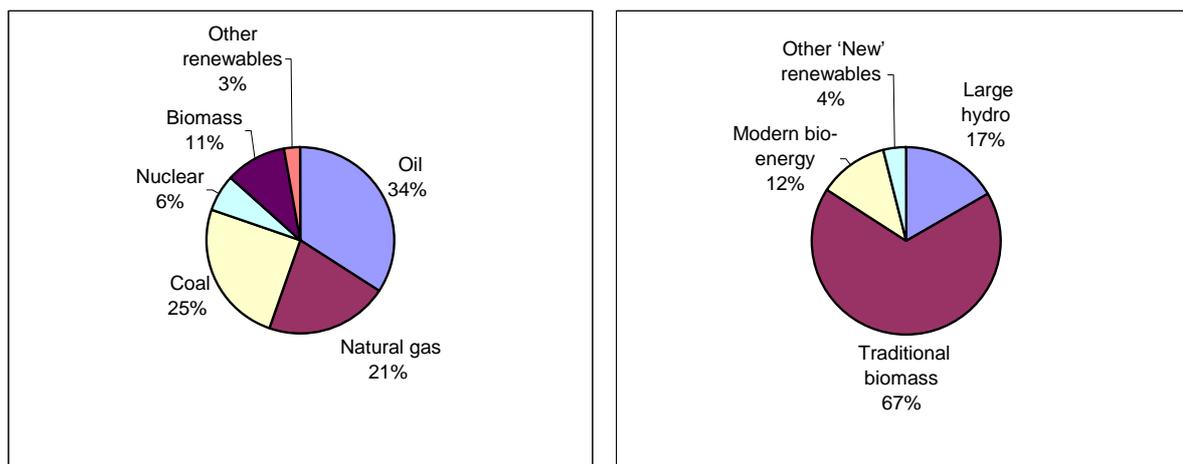
### *Traditional uses of Biomass*

The overwhelming majority of biomass energy—over 80%—is consumed as solid fuels in traditional uses at low efficiencies for cooking, heating, and lighting; the consumers are the more than

---

<sup>1</sup> The term “modern bioenergy” is loosely defined as conversion and use of biomass at higher efficiencies into more versatile energy carriers—electricity, liquid, gaseous fuels and process heat (ESMAP 2005).

two billion people that rely on traditional biomass fuels and/or have no access to modern energy services (UNDP, 2004). The dependence on traditional biomass in sub-Saharan Africa is far greater than any other world region, accounting for over 70% if South Africa is excluded. The impacts of a lack of access to modern energy are felt in many ways—the sometimes deadly effects of indoor air pollution, the tremendous amount of time devoted to gathering firewood, the lack of health and education services that require reliable energy supplies, and many other problems. Greater access to electricity and modern fuels would open up new economic opportunities and provide basic amenities that are taken for granted in the OECD countries. Cleaner and safer renewable fuels, such as gel fuel made from bio-ethanol, have been proposed as a solution to health and safety issues that can—at the same time—take advantage of the region’s under-utilised agricultural capacity (Utria, 2004).



**Figure 1a: Shares in 2004 of global primary energy consumption.**

**Figure 1b: Shares in 2004 of total renewable energy consumption.**

Source: IEA (2007)

The deforestation in developing countries that was observed in the 1970s was at first attributed to household consumption for woodfuel and charcoal, but subsequent research later showed that the deforestation was in fact attributable mainly to companies and industries that were clearing land for agricultural uses and timber (WEC, 1999). Furthermore, the notion that communities would quickly descend into a “Tragedy of the Commons” in their use of forest resources turned out to be a gross simplification that ignored the role of informal institutions. Local communities that had control over their own resources often showed a marked ability to implement informal customs and institutions to preserve some land and forest for future uses, (Leach and Mearns, 1988).

Consumption of biomass for traditional uses can be sustainable under certain conditions, especially in areas with low population density (Chidumayo, 2002). It is difficult in the longer-term to sustain traditional uses of biomass due not only due to their low efficiency but because of the difficulty of controlling the level and quality of energy services provided. A transition from traditional to modern bioenergy in the developing world is thus an important element in the global transition to sustainable energy.

### ***Biomass and Livelihoods***

It is important to assess bioenergy within the overall biomass resource base and the socioeconomic context of affected communities, i.e. biomass is much too important and complex to be viewed only as a source of bioenergy. The trade-offs among the many different uses of biomass are often summarised in terms of the 4Fs: Food, Feed, Fibre, and Fuel. Even this division into four categories is much too simplified; biomass serves or impacts many inter-connected and critical functions/services, including housing, materials, maintenance of biodiversity, ecosystem integrity, nutrient cycles, water quality, erosion control, and recreation. The proper management and utilisation of biomass and bioenergy also helps to shape the role of citizens and communities as caretakers for resources they will pass on to future generations.

The bioenergy development strategies for particular regions should be based on socio-economic priorities in combination with the overall resource base that is available and the subset of that resource base that can be harvested for bioenergy use. A consideration of these broader issues must include the extent to which development of biomass resources can help create, maintain, and/or expand sustainable livelihoods for the local population as well as in other areas that are connected socially, economically, and ecologically to the local or regional community or communities involved.

Several livelihood indicators have been identified in terms of enhancing social capital, improving the quality of work, and insuring the future availability of the natural resource base (Scoones, 1998):

- Creation of working days;
- Poverty reduction;
- Well-being and capabilities;
- Livelihood adaptation, vulnerability, and resilience;
- Natural resource base sustainability

Bioenergy generates far more jobs than any other energy source—renewable or non-renewable. Furthermore, these jobs are created mainly in rural areas where poverty is worst, and thus can help to slow down or even reverse migration to urban centres. It is harder to generalise about the impacts of bioenergy development with respect to the other four indicators. Rapid degradation of forests and soils for short-term profit will obviously not lead to sustainable livelihoods, whereas careful managed growth strategies can not only maintain the resource base but in some cases enhance it.

### *Global bioenergy potential*

Biomass that is produced in tropical and sub-tropical climates has an average productivity that is over 5 times higher than that of biomass grown in the temperate regions of Europe and North America (Bassam 1998). Since developing countries are located predominantly in the warmer climates and lower latitudes, they have a tremendous comparative advantage. However, most research and development funding as well as a considerable amount of direct subsidies are provided for the production of biomass in the EU and in North America, where technology and strong infrastructure can compensate somewhat for the natural disadvantage.

A recent study found that the bioenergy potential of sub-Saharan Africa—after accounting for food production and resource constraints—was the greatest of any of the major world regions (Smeets et al, 2004). Using four scenarios, the potentials included various categories of biomass, among which residues and abandoned agricultural land were the most significant globally. The high potential results from the large areas of suitable cropland in the region, large areas of pasture land presently used and the low productivity of existing agricultural production systems.

Overall, the global potentials range from 30% to over 200% of current total energy consumption (recall Figure 1a). Other sources of bioenergy that are not included in the potentials above include animal wastes, organic wastes such as MSW, and bioenergy from natural growth forests. Inclusion of such sources would increase the potentials by an additional 10 to 50%, depending on the assumptions (Smeets et al, 2004). Nor is water-based bioenergy production included in the estimates, the potential for which could be quite large, such as in the case of algae-oils for bio-diesel (Briggs, 2004).

It is important to note that these are techno-economic potentials, and there will inevitably be social and cultural issues that would restrict use of some lands for energy production, as well as the economics of the markets themselves. Nevertheless, the tremendous potential for bioenergy, after accounting for food production, means that the margin for future development is significant. The concentration of the potential in sub-Saharan Africa in combination with the lack of potential in OECD countries poses interesting questions for future development and trade in bioenergy. The bioenergy and biofuels policies followed in the OECD could offer new export market opportunities for sub-Saharan Africa and other developing countries.

## **Food vs. Fuel**

Given the high level of poverty and malnutrition found in many developing countries, there is growing concern that food security may be jeopardised by expanding bioenergy production. The food vs. fuel debate is sometimes used to discourage bioenergy development, even though there is not necessarily a negative correlation between food and fuel, and in fact there are many positive economic linkages that can arise. A recent study suggested that there are synergies between food and fuel production, with the result that production increases for food and fuel will go hand-in-hand, especially as new agro-industrial biotechnology methods are deployed (Moreira, 2003). Furthermore, where equity concerns can be addressed, the income provided from bioenergy production can in some cases more than compensate for displaced food production. Where large-scale displacement occurs, it is vital that policies and institutions re-direct such income towards investment in greater agricultural productivity and/or address distributional issues related to the benefits accrued.

Another issue that will inevitably arise in the long-term in some regions of sub-Saharan Africa is the availability of water for irrigation in agriculture, which will reduce the potentials achievable in scenarios that include irrigation. The availability of water for large scale bioenergy expansion appears is globally constrained (Berndes, 2002). Some regions and/or countries, particularly South Africa, are projected to be in water deficit by 2015 or 2020. However, there is already a significant amount of irrigation in some regions, and therefore what may be more important than the total are incremental decreases or changes in the scope of irrigation in different hydrological zones. Furthermore, the scope for improvements in irrigation in agriculture as well as in biomass production is quite significant.

## **Liquid biofuels**

Biofuels have been around for over a hundred years, and bio-ethanol in particular saw significant use in the early part of the twentieth century. Before the era of cheap oil and during times of conflict such as World War II, biofuels have been recognised as a valuable domestic alternative to imported oil. The resurgence of interest in biofuels in recent years is in part for similar reasons of energy security, but now the added issues of rural development and climate mitigation make the case for biofuels even more compelling. The past several years have witnessed a growing interest in fuel ethanol as a substitute to petrol in the transportation sector on a global scale. Bio-ethanol production has nearly doubled in five years, while bio-diesel has quadrupled, although starting from a much lower base (Tables 1 and 2).

	<b>2000</b>	<b>2001</b>	<b>2002</b>	<b>2003</b>	<b>2004</b>	<b>2005</b>	<b>Global Share, 2000</b>	<b>Global Share, 2005</b>	<b>Annual Average change</b>
Brazil	10.6	11.5	12.6	14.7	14.7	16.1	55%	45%	8.6%
U.S.A.	7.6	8.1	9.6	12.1	14.3	16.2	40%	46%	16.4%
Other	0.9	1.7	1.9	1.9	2.4	3.3	5%	9%	28.5%
<b>World</b>	<b>19.2</b>	<b>21.3</b>	<b>24.1</b>	<b>28.7</b>	<b>31.4</b>	<b>35.6</b>			<b>13.2%</b>

*Source: F.O.Licht, 2006.*

The chemical process of trans-esterification for making bio-diesel has been known for well over a hundred years, although bio-diesel as it has come to be known emerged only in the past twenty years, in terms of the use of refined vegetable oils on a large-scale. Rudolf Diesel believed that the utilization of a biomass fuel represented the future for his engine. In 1911, he said “The diesel engine can be fed with vegetable oils and would help considerably in the development of agriculture of the countries which use it (Knothe, 2001).” The emergence of cheap fossil fuels, however, encouraged the diesel engine manufacturers to alter their engines to utilise the lower viscosity petroleum diesel. Throughout the 1990s, interest re-emerged based on experiments in the 1980s and plants were opened in many European countries, especially in France, Germany, and Italy.

Among the various biomass and biofuel options, bioethanol and biodiesel have the greatest significance in terms of international trade in the near-term. However, market developments to date suggest a preference for domestic consumption, due primarily to energy security concerns; the only

major exporter of biofuels is Brazil. Furthermore, with national subsidies in most producing countries and with only a few major players, the conditions for a competitive international commodity market are not yet developed. The future direction of biofuels trade is tied to agricultural reform in the case of bio-ethanol. Biodiesel is classified as an industrial product and is not subject to the high import tariffs that still exist in the EU, U.S. and elsewhere.

	2000	2001	2002	2003	2004	2005	Global Share, 2000	Global Share, 2005	Annual Average change
Germany	250	315	511	813	1176	1897	26%	45%	50.0%
France	373	364	416	406	395	559	40%	13%	8.4%
Italy	89	160	239	310	364	450	9%	11%	38.4%
other EU	112	128	130	181	330	713	12%	17%	44.8%
<b>EU Total</b>	<b>813</b>	<b>912</b>	<b>1210</b>	<b>1630</b>	<b>2265</b>	<b>3618</b>	<b>86%</b>	<b>86%</b>	<b>34.8%</b>
U.S.A.	8	19	57	76	95	284	1%	7%	106.4%
other	125	190	256	284	273	307	13%	7%	19.7%
<b>World</b>	<b>945</b>	<b>1121</b>	<b>1523</b>	<b>1989</b>	<b>2633</b>	<b>4209</b>			<b>34.8%</b>
<i>NOTES: other EU includes EU-25 starting in 2004 and 2005</i>									
<i>Sources - estimated based on: Euroobserver, 2006; National Biodiesel Board, 2006.</i>									

### Land use patterns

There are significant differences not only in the bioenergy potential of world regions, but also their population density and the existing levels of land use. Table 3 lists a number of major world regions. Within sub-Saharan Africa, the Southern African Development Community (SADC) region, encompassing fourteen countries, is a key region for bioenergy development (Johnson and Matsika, 2006). The SADC region encompasses a sizable area, larger than Brazil, China, or the U.S. and more than three times the size of India. It has a considerable amount of forested lands, nearly as much as the U.S. and China combined. The region has an even greater amount of pastures, grasslands, and other agricultural lands. The present amount of land cultivated is quite small—less than 6%—the comparable figures elsewhere in the world are generally much higher. Not only is the amount of land cultivated small, but agricultural productivity levels are quite low by world standards. A great deal of pasture land could be made available for other uses such as fuel and fibre (Smeets et al, 2004).

Country/Region	Total Land Area	Forest Area		Agricultural Areas (a)		Cultivated Area (b)	
		Million ha	share of total land area	Million ha	share of total land area	Million ha	share of total land area
southern Africa (SADC)	964.1	368.3	38%	433.2	45%	53.4	5.5%
EU-15	313.0	115.7	37%	140.4	45%	84.55	27.0%
Brazil	845.9	543.9	64%	263.6	31%	66.6	7.9%
China	932.7	163.5	18%	554.9	59%	154.9	16.6%
India	297.3	64.1	22%	180.8	61%	169.7	57.1%
United States	915.9	226.0	25%	409.3	45%	175.5	19.2%
<i>Sources: FAOSTAT 2005; World Resources Institute 2005</i>							
<i>Note: (a) Agricultural areas includes temporary and permanent pastures, permanent crops, and temporary crops</i>							
<i>Note: (b) Cultivated areas includes permanent crops and temporary crops</i>							

Such aggregate figures do not necessarily indicate how much land could ultimately be made available for expanded agricultural or biomass production, since many other characteristics have to be considered. Socio-economic, cultural, environmental, and ecological factors would all have to be taken into account. The proximity of available land to markets, distribution centres, and urban areas

would also impact development options. However, the aggregate data do suggest the considerable scale of land resources compared to current utilisation.

### *Income and Population*

The poorer countries in sub-Saharan Africa have a much higher proportion of the population working in agriculture. Population density is fairly low by global standards; among the various regions shown in Table 4, population density is lowest in southern Africa and Brazil, which are also the two world regions that appear to have the highest bioenergy potential. In Africa, unlike Brazil, the rural population continues to dominate, as the overwhelming majority of the population rely on some form of subsistence agriculture. At the same time, this rural population represents a large potential workforce to support a major expansion in bioenergy production.

<b>Table 4: GDP and Population summary for selected countries and regions in 2004</b>						
Country/Region	GDP/capita (USD)		Total Population		Rural Population	Agricultural Population (b)
	Nominal GDP	GDP - PPP (a)	1000s	Density (p/km <sup>2</sup> )	share of total	share of total
Southern Africa (SADC)	1267	3142	228346	24	63%	57%
EU-15	29291	26900	380.1	121.4	22%	4%
Brazil	3325	8049	178.5	21.1	17%	15%
China	1272	5642	1311.7	140.6	61%	65%
India	622	3080	1065.5	358.4	72%	52%
United States	39935	39496	294.0	32.1	20%	2%

*Sources: FAOSTAT 2005, World Bank 2005*

*Note: (a) PPP = Purchasing Power Parity, which reflects better differences in cost of living, whereas Nominal GDP accounts more appropriately for the value of international trade.*

*Note: (b) Agricultural Population refers to those persons who earn their livelihoods from agricultural activities along with their non-working dependents*

There are major differences in different regions in access to infrastructure, which is severely limited in many rural areas in Africa: rural industries are more isolated, and it is costly to get products to market. The creation of rural-based industries such as those associated with biomass and bioenergy are especially appealing for regions that are predominantly rural. At the same time, getting these products to international markets will tend to be more complicated in comparison to opportunities for local and regional markets.

Due to logistical constraints and market structures, liquid biofuels are of greatest interest for international trade. Sugarcane, maize, and cassava are the crops most likely to be used as feedstocks for bio-ethanol production in the near term. Oil palm, sunflower, and soybean appear to be the most likely crops in the near term for production of bio-diesel. Other crops being considered are sweet potatoes and sweet sorghum for bio-ethanol and jatropha and castor oil for bio-diesel (Utria, 2004; SADC, 2005). Sweet sorghum and jatropha are considered to be promising crops, but there is very little experience with them in Africa.

### **3. Bioenergy Conversion options**

The scales at which modern bioenergy conversion systems become economically competitive vary considerably with the local conditions and the nature of the energy demand. At one extreme, there is increasing interest in large-scale plantations up to 100,000 ha for production of liquid biofuels and/or cogeneration applications. At the other extreme are village-scale systems, such as the famous 5 kW biogas-diesel generator system in Pura in southern India, which provides electricity and clean drinking water to households. The use of nearby sources of biomass residues in combination with dedicated energy crops could increase sustainability and ease system management. This section briefly reviews bioenergy conversion options.

There are many different routes for converting biomass to bioenergy, involving various biological, chemical, and thermal processes; the major routes are depicted in Figure 2. The conversion can either result in final products, or may provide building blocks for further processing. The routes are not always mutually exclusive, as there are some combinations of processes that can be considered as well. Furthermore, there are often multiple energy and non-energy products or services from a particular conversion route, some of which may or may not have reached commercial levels.

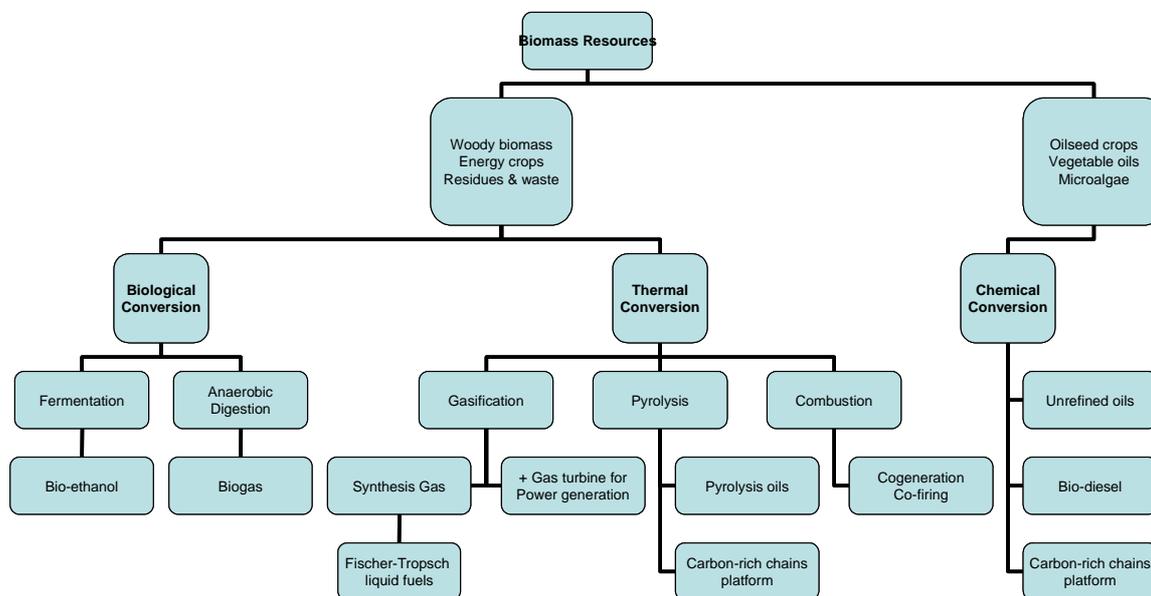


Figure 2: Various conversion routes for biomass to bioenergy

### Biological Conversion

Biological conversion is well-established, with the two main routes being fermentation and anaerobic digestion. Sugar and starch crops provide the feedstocks for the process of fermentation, in which a catalyst is used to convert the sugars into an alcohol, more commonly known as bio-ethanol. Alternatively, any lignocellulosic source can be used as feedstock, by hydrolysing it, i.e. breaking it down into its components. The reaction is catalysed by enzymes or acids; acid hydrolysis offers the more mature conversion platform, but enzymatic hydrolysis appears to offer the best long-term option in terms of technical efficiency. Lignocellulosic conversion would greatly increase the supply of raw materials available for bio-ethanol production. The lignin residues could be used as fuel for the energy required and even providing surplus energy, resulting in significantly improved energy balances and resulting potential reductions in GHG emissions.

Anaerobic digestion uses micro-organisms to produce methane in a low oxygen environment. One example is the waste stream from bio-ethanol production, known as vinasse, which can be further converted through anaerobic digestion, creating a further step in a “cascade” of energy extraction processes. Methane gas can be used directly for cooking or heating, as is common in China, or it can be used for electricity and/or heat production. For transport applications, the biogas is used in compressed form, as is natural gas. Biogas can also be upgraded, i.e. cleaned of impurities and then fed into natural gas pipelines. Both bio-ethanol and biogas are commonly used in buses and other fleet vehicles in cities such as Stockholm and in the Midwestern region of the U.S.

### Combustion and Co-firing

Combustion is simply thermal processing, or burning of biomass, which in the simplest case is a furnace that burns biomass in a combustion chamber. Combustion technologies play a key role throughout the world, producing about 90% of the energy from biomass. Combustion technologies

convert biomass fuels into several forms of useful energy e.g. hot water, steam and electricity. Commercial and industrial combustion plants can burn many types of biomass ranging from woody to MSW. The hot gases released as biomass fuel contains about 85% of the fuel's potential energy.

A biomass-fired boiler is a more adaptable technology that converts biomass to electricity, mechanical energy or heat. Biomass combustion facilities that generate electricity from steam-driven turbine generators have a conversion efficiency of 17 to 25%, but with cogeneration can increase this efficiency to almost 85%. Combustion technology still needs to be optimised, in such areas as increased fuel flexibility, lower emissions, flue gas cleaning, and particulate formation, multi-component and multi-phase systems, NO<sub>x</sub> and SO<sub>x</sub> formation. Co-firing of biomass (ranging from about 2%-25% biomass) with fossil fuels, primarily coal or lignite, is economically advantageous due to the existence of an established market for CHP, lower investment cost, flexibility, and waste disposal benefits (i.e. use of biomass-based wastes reduces the need for land-based waste disposal). The cost of CO<sub>2</sub> reduction for CHP based on co-firing biomass with coal is estimated as half the cost of exchanging old coal-fired power stations with new clean coal technology (IEA, 2005).

### *Gasification and Pyrolysis*

Gasification is another major alternative, currently one of the most important RD&D areas in biomass for power generation, as it is the main alternative to direct combustion. The importance of this technology relies in the fact that it can take advantage of advanced turbine designs and heat-recovery steam generators to achieve high energy efficiency. Gasification results in much higher efficiency, allows for phased installation, and can displace diesel generators at small-scale. The Fischer-Tropsch process converts gas-to-liquids; it is still in experimental phases for biomass (as opposed to coal); it also would allow the production of “designer” fuels. The economies-of-scale are quite large, so only large biofuels markets would make it economically attractive (Kaltschmitt et al, 1997; Walter et al, 2000).

Pyrolysis, which is essentially biomass gasification with almost no oxygen, offers a potentially wide range of products that can potentially be obtained, ranging from transportation fuel to chemical feedstock. A considerable amount of research has gone into pyrolysis in the past decade in many countries (Kaltschmitt and Bridgwater, 1997). After many ups-and-downs, the first commercial plants are coming into operation. Any form of biomass can be used (over 100 different biomass types have been tested in labs around the world), but cellulose gives the highest yields at around 85-90% wt on dry feed. Liquid oils obtained from pyrolysis have been tested for short periods on gas turbines and engines with some initial success, but long-term data is still lacking.

### *Chemical conversion from oil-bearing crops*

Oils derived from oilseeds and oil-bearing plants can be used directly in some applications, and can even be blended with petroleum diesel in limited amounts. The refined versions of oils, on the other hand, can potentially be fully interchangeable with petroleum diesel, and are therefore preferred for international trade. The raw oils can be imported and the refining done locally, as is the case with petroleum. The chemical refining process is referred to as trans-esterification, since it involves the transformation of one ester compound into another, a process that also transforms one alcohol into another. Glycerol—a viscous, colourless, odourless, and hygroscopic<sup>2</sup> liquid—is a valuable by-product of the process, and is an important raw material for various pharmaceutical, industrial, and household products.

Yet another set of options associated with these bio-chemical conversion processes relates to the creation of various carbon-rich compounds from glycerol and the fatty acids that comprise it. The carbon-rich chains form building blocks for a variety of products, which are bio-degradable and/or the result of biological processes. Such platforms might be based on the carbon chains C<sub>2</sub> and C<sub>3</sub>, which would in some respects lead to bio-refining processes that are analogous to the petroleum refining process (van Dam et al, 2005). Movement towards a bio-based economy is generally recognised as a

---

<sup>2</sup> Refers to substances that readily absorb water from their surroundings.

fundamental characteristic of the overall transition to sustainability, and the potential bio-resource platforms warrant much more investment in research, development, and demonstration.

An interesting option for the future is the production of bio-diesel from algae. The production of algae to harvest oil for bio-diesel has not yet been undertaken on a commercial scale, but feasibility studies have suggested high yields, as some algae have oil content greater than 50%. In addition to its projected high yield, algae-culture—unlike crop-based biofuels—is much less likely to conflict with food production, since it requires neither farmland nor fresh water. Some estimates suggest that the potential exists to supply total global vehicular fuel with bio-diesel, based on using the most efficient algae, which can generally be grown on algae ponds at wastewater treatment plants (Briggs, 2004). The dried remainder after bio-diesel production can be further reprocessed to make ethanol. The possibility to make both bio-diesel and bio-ethanol from the same feedstock could accelerate biofuels market expansion considerably.

#### **4. Elements of the Bioenergy Transition**

Like other renewable sources, bioenergy can make valuable contributions in climate mitigation and in the overall transition towards sustainable energy. At the same time, bioenergy also has a rather special status among renewable energy sources. Modern bioenergy will inevitably play a leading role in the global transition to clean and sustainable energy because it has two decisive advantages over other renewables:

- Biomass is stored energy. Like fossil fuels, it can be drawn on at any time. This is in sharp contrast to daily or seasonally intermittent solar, wind, wave and small hydro sources, whose contributions are all constrained by the high costs of energy storage.
- Biomass can produce all forms of energy, i.e. energy carriers, for modern economies: electricity, gas, liquid fuels, and heat. Solar, wind, wave and hydro are limited to electricity and in some cases heat. Indeed, biomass energy systems can often produce energy in several different carriers from the same facility or implementation platform, thereby enhancing economic feasibility and reducing environmental impacts.

Modern bioenergy has several other advantages over other energy resources, providing development benefits in addition to improving energy services:

- provides rural jobs and income to people who grow or harvest the bioenergy resources, as bioenergy is more labour-intensive than other energy resources;
- increases profitability in the agriculture, food-processing and forestry sectors. Biomass residues and wastes--often with substantial disposal costs--can instead be converted to energy for sale or for internal use to reduce energy bills;
- helps to restore degraded lands. Growing trees, shrubs or grasses can reverse damage to soils, with energy production and sales as a valuable bonus;

In a nutshell, modern bioenergy systems offer developing countries an opportunity to transform the inefficient traditional biomass sector into an efficient and competitive bioenergy industry. Technical advances are steadily improving the economic attractiveness of this transition, while at the same time social and environmental concerns are making them more politically attractive. To developed countries, modern bioenergy offers an opportunity to revive rural economies and to market advanced technologies to developing countries, enabling them to leapfrog over the technologies of previous decades.

#### ***Turning waste products into renewable resources***

Biomass originating from crop residues of established agro-industrial production chains is currently often considered as waste material. This biomass can be re-directed to new applications, both as a CO<sub>2</sub>-neutral energy source as well as a variety of value-added products for both local and export markets. The tools to achieve these aims are to be found in the novel design of bio-refineries.

The waste residues from agriculture, forestry, fishing, pulp and paper production, and many other “bio-oriented” industries or agro-industries are often readily available for use as an energy source. In some industries, such as pulp and paper or sugar production, these residues have long provided energy for the manufacturing processes. More recently, it has been recognised that much more energy can be extracted by two inter-related adjustments: improving the energy efficiency in production of the primary product—and—choosing more efficient conversion options and applications for the residues and other co-products. Contrary to the assumptions in standard neoclassical economic theory, transforming these waste products into renewable resources does not depend on prices alone, but also depends on the underlying institutions that raise or lower transaction costs and market barriers.

### *From traditional biomass to modern bioenergy*

Expansion and trade in bioenergy, and particularly liquid biofuels, has also taken on more strategic political importance in recent years due to a number of issues: higher oil prices and the near-term prospect of a peak in global oil production; regional energy trade disruptions related to gas and oil supplies; and the growing energy import dependence of many regions. In the case of solid biomass, the availability of high-efficiency applications at many scales—including households, small industry, and cogeneration plants—has opened up new markets for bioenergy. Prepared and compacted forms of biomass such as pellets have facilitated the growth of bioenergy in many countries and created new livelihoods in rural areas that were in economic decline. Conversion technologies have evolved with the expansion in biomass production and have been optimised for various types of biomass supply and operating conditions. Yet, such modern and efficient uses of biomass are still the exception in global terms.

The actors involved in commercialisation of biomass resources for energy production are being transformed in fundamental ways as modern bioenergy systems are deployed. Three distinct aspects of the socio-economic changes are noteworthy. The first and simplest aspect is the mechanisation of bioenergy supply, including to varying degrees the phases that occur before conversion—planting, harvesting, and preparation. The second is the variety of actors that emerged throughout the bioenergy chain, from specialists on different varieties of crops to pelletising experts to marketing of multiple fuels and feedstocks. The third is the transformation of bioenergy into a knowledge-intensive sector in the sense that localised knowledge with respect to biomass feedstocks and markets has become a crucial element in the global development of the industry.

### *From small-scale to multiple scales*

With the exception of certain industries that have major biomass output streams that can be used for energy, the scale of bioenergy use has historically tended to be small, for use in households and small businesses. Such small-scale use remains the norm in the least developed countries; elsewhere the use of bioenergy has made a natural progression towards multiple scales. The many different scales are attributable to several factors, including the importance of local supply, the quality and variety of organic and inorganic constituents, the nature of intended end-uses, and the spatial extent of the market for related products and factor inputs. Whereas nuclear, coal, and hydro are best-suited in overall efficiency terms to large-scale applications, bioenergy applications are diverse; the economics of supply vary from micro-scale (i.e. household demand level) to medium-scale plants supplying power for a small town to large-scale plants of the future based on Fischer-Tropsch conversion of gasified biomass and the creation of “designer” fuels with specific characteristics.

### *From single to multiple product(s)*

Whereas an emphasis on bioenergy may have traditionally resulted in only one commercially valuable product, a bio-based economy will require a sustainable supply of large volumes of biomass feedstock for conversion into energy and result in a new and new versatile range of products. Demand for biomass from both industry and energy plants will increase substantially in the coming years. These new demands for biomass will have serious implications on agricultural and forestry sectors globally, requiring greater attention to key environmental issues such as decline in biodiversity and degradation of ecosystems. Concerns on food security in the poorer regions of the globe, can be reversed and used as a stimulus for bio-economic development, creating a paradigm shift from more

traditional economic development (van Dam et al, 2005). The direct consequences of a bio-based economy are better utilization of forestry and agricultural residues, which might otherwise be wasted and/or release methane.

### *From Chemical to Biological Processes*

Bioconversion and biotechnology will play key roles in the transition from a fossil-based to a bio-based society and are essential for development of sensible use of renewable resources (Willke and Vorlop, 2004). The application of industrial biotechnology for processing and production of chemicals, materials and fuels, which is sometimes called “White Biotechnology” provides the key multidisciplinary knowledge system in the organization of technologies and incentives required for implementation of (bio) economic and sustainable conversion processes of bio-based materials (Carrez and Soetaert, 2005).

Fermentation processes to convert crops into food and beverages or to extract medicines and fibre have been known for thousands of years. Applied biotechnology is common practice these days in many industrial sectors ranging from pharmaceutical and chemical industries to food and non-food industries. In this context the complex technology for the conversion of biomass to materials and fuels is referred to as a “bio-refinery”. The chain of integrated processes for conversion of heterogeneous biomass to value added products is the key cluster of multidisciplinary know-how that has to be developed and optimized (Kamm et al, 2006).

Nowadays, biotechnology is frequently associated with genetic issues, making this subject politically sensitive. Modern industrial biotechnology is, however, much broader than its genetic-biotech sub-component. It also includes numerous other advanced methods of biomass conversion by either micro-organisms or enzymes and by selective extraction of valuable components. Many innovations of recent decades involving biotechnology or concerning the application of bio-based products can become commercial successes, and have simply been delayed by subsidisation or government prioritisation of petrochemical products (van Dam et al, 2005). Given recent developments of oil prices and concerns about energy security, the economics and politics are turning in favour of renewables.

### *From carbon sink to carbon management*

The emergence in the late 1990's of carbon capture and sequestration (CCS) as a potential mitigation technology led to the idea of linking CCS to bioenergy to give BECS – bioenergy with CO<sub>2</sub> storage. It illustrates a programme of carbon stock management with large-scale deployment of bio-based negative emissions systems. This would see a worldwide improvement in the way we use land. It would raise the sustainable productivity of the land through investments in tilling the soil (or minimum-tilling it) on a scale comparable with current global investments in drilling for oil. In that way, CO<sub>2</sub> is taken out of the atmosphere by increased photosynthesis. After taking carbon out of the atmosphere, it is then conserved carefully through residue handling and recycling, while consuming biofuels along with traditional products of the land. Finally, carbon-rich wastes are stocked somewhere safer than in the atmosphere (Read, 2006).

### *From local fuel to global commodity*

Creating an international market for a relatively new commodity poses a number of challenges, especially in an underdeveloped region with poor infrastructure. In the near-term, it may be preferable to concentrate on national and regional markets, where the benefits of substituting a domestic resource can be obtained without having to compete head-to-head with international companies and/or sell through large traders or distributors. The comparative advantages include the low cost of labour and the excellent growing conditions for sugarcane, sweet sorghum and other crops. Developing national and regional markets can also be seen as a logical step in the development of international export markets; indeed, several phases can be identified in bioenergy use and market development:

1. Local use of forest and agricultural residues
2. Assuring proper waste treatment, processing of residues, and energy efficiency
3. Infrastructure development;

4. National market development through supportive policies and incentives;
5. Regional biomass markets, medium-to-large scale utilization, transport logistics
6. Increasing scale, followed by decreasing costs
7. Global commodity market

Biomass markets already exist in Brazil, Canada and the Nordic countries. International bioenergy trade is growing rapidly, particularly for co-firing (wood chips, and pellets), CHP (wood chips), and liquid biofuels for transport (bioethanol and biodiesel). One major barrier to expansion of regional trade in less developed and especially landlocked regions is the high cost of road transport (UNCTAD 2005). For international shipping by tanker, costs are quite low. In the case of liquid biofuels such as bio-ethanol, the costs amount to only 1-2 cents/litre (Johnson and Matsika, 2006). For solid biomass trade, the costs would be slightly higher due to some minor additional handling costs for dry products (Hamelinck et al, 2003).

The high costs of road transport means that regional coordination strategies become quite important and facility-siting for production that is intended for export markets becomes a key issue. Some strategies would therefore aim to locate biomass conversion or processing facilities near ports, while raw materials might be shipped from inland destinations (Batidzirai et al, 2006). Cost-sharing arrangements would need to be established between inland biomass producers and operators located near the coast, and such arrangements could be facilitated by some of the various economic integration policies being pursued in different world regions.

## **5. Impacts and Sustainability**

Bioenergy is inherently land-intensive, meaning that the associated socioeconomic and environmental impacts are generally much more significant than those of other renewable energy systems. A comprehensive list is difficult to summarise briefly, but some key concerns relate to loss of ecosystem habitat, deforestation, loss of biodiversity, depletion of soil nutrients, and excessive use of water. In addition to the provision of a renewable energy source, some positive environmental impacts might include restoration of degraded land, creation of complementary land use options, and provision of non-energy resources and materials. Some specific issues that arise in the case of sugar crops, woody biomass, and oil-bearing crops, are outlined below. In general, the main impacts are on the agricultural side, and therefore where there are multiple products available, as is the case with sugar cane, it is useful to consider multiple-product--multiple-benefit scenarios (Cornland et al, 2001).

### *Sugar crops*

The environmental impacts of sugarcane have been analysed in considerable detail in the case of Brazil. When Brazil began its effort to expand sugarcane for ethanol production in the 1970s, the environmental impacts were quite significant, especially the disposal of large streams of waste effluent from ethanol distilleries. Over the past thirty years, dramatic improvements have been achieved in technical efficiency and in the efficiency of key resource inputs (e.g. water). The case of water use is particularly interesting, since cane requires significant amounts of water during a key period in the growth cycle. Cane is rain-fed in Brazil, and furthermore, the amount of water that is recycled in the cane-ethanol processes is on the order of 90% (Macedo, 2005).

In other parts of the industrial world where water is scarcer, sweet sorghum could provide a useful alternative, with its low water requirements, less than half of that of cane, and has the ability to remain dormant during periods of drought (Bassam, 1998). This creates better opportunities for small scale farmers with no access to irrigation. The use of sweet sorghum as an energy crop in southern Africa has been clearly identified and evaluated favourably (Wood, 2001). Sweet sorghum has low requirements for nitrogenous fertiliser—about 35-40% of sugar cane—with clear benefits for the farmer, as the crop will require less investment in inputs, as well as possible environmental benefits from avoiding impacts of fertiliser run-off. Sweet sorghum has high potassium uptake, however, and is therefore highly depleting of this mineral (Bassam, 1998). Sugar cane can operate on a closed-loop with respect to potassium, since it can be extracted from the filter mud residues and recycled.

## **Woody Biomass**

Woody biomass is a major source of primary energy for the majority of the world's poor. In some African countries, over 95% of households depend on wood for cooking and heating. Unsustainable extraction practices of forest and wood products industries are a major source of environmental degradation in many regions. The environmental impacts of wood fuel use by industries and households are well known, and include:

- health effects of indoor air pollution, which kills more women and children than tuberculosis and malaria (UNDP, 2004)
- contributing to deforestation, a major problem in some southern African countries
- soil degradation and erosion problems

A common impact from the use of wood fuels relates to the opportunity cost of the time spent collecting wood. The gathering of wood can require several hours per day, sometimes preventing children from attending school, and women from improving their livelihood by engaging in other, possibly profitable enterprises.

However, the consumption of woody biomass as a fuel need not be inherently unsustainable. Improvements in conversion efficiency and use are needed, especially in more densely populated regions. Improved charcoal and wood burning stoves have an important role to play in poor areas where modern energy services are unlikely to penetrate for many years. A number of studies have suggested that even traditional charcoal use can be sustained in regions that are not too densely populated; analysis in the Lusaka region in Zambia showed that charcoal use had not exceeded the sustainability threshold (Chidumayo, 2002). However, an important question will be whether policy should aim towards providing “clean cooking fuels” through more efficient energy carriers, both non-renewable such as LPG, and renewable, such as ethanol gel fuel.

Woody biomass is also available in large quantities as a residue from forest-based industries. This has been demonstrated in Sweden and other countries, where sawdust and residues from the timber industry is used extensively for energy. This has the economic and environmental benefits of using what would otherwise be a waste product. Similar efforts have been directed at small-scale sawmills in less developed countries.

## ***Oil-bearing and other biomass crops***

Jatropha trees yield oil that is highly suitable for use in raw form or for refinement into bio-diesel. This tree is reported to have strong environmental benefits when intercropped with other produce. It can be used as a hedge to prevent soil erosion, and can also have regenerative effects on the soil, being a nitrogen fixer (Openshaw, 2000).

Several oil bearing crops, currently used predominantly in food products, are strongly associated with severe environmental impacts. In particular, soy bean plantations are encroaching on rainforests in Brazil, and the palm oil industry is a major cause of deforestation in Malaysia and Indonesia. In order to preserve the credibility of bioenergy as an environmentally sustainable source of energy, particularly in the context of a possible future international trade in biofuels, such sustainability concerns will have to be addressed. Some form of social and environmental certification would seem to be desirable. The precise structure of such a scheme, whether it could be mandatory, or would have to remain voluntary, and how it could be linked to other existing social and environmental certification schemes, needs to be established.

## ***Socio-economic Impacts***

Socio-economic impacts that are of primary interest generally include income generation, job creation, provision of new services, creation of new infrastructure, establishing opportunities for entrepreneurs, and stimulating innovative technical and institutional approaches. At the same time, large scale projects have encountered controversy involving the acquiring of traditional land and competition with food crops. Key health benefits in the case of bio-ethanol include phase-out of lead in petrol, especially in Africa, where leaded fuel remains widespread (Thomas and Kwong, 2001).

The range and extent of socioeconomic impacts of bioenergy use is greatly dependent on the scale and intensity. The Brazilian model exemplifies the large scale intensive approach, using high capacity central processing points fed by intensively farmed surrounding areas. The establishment of large estates can bring significant benefits to employees, such as health care, sanitation and improved infrastructure. Indeed, the large-scale crop enterprises are more economically efficient. However, the question remains whether or not they can be designed to improve local livelihoods.

The high proportion of subsistence farming amongst livelihoods in developing country rural areas, and the complexities of land ownership under traditional land law regimes, has made such large scale acquisition of land somewhat more controversial. It has been suggested that a smaller scale approach may be more appropriate, possibly involving the contracting of small scale farmers to work as 'outgrowers', dedicating a proportion of their land to growing a crop for guaranteed purchase by a processing company. Such an approach has the advantage of providing additional seasonal income for poor rural farmers, without dismantling the structure of their existing livelihoods, which may be vital to their survival. However, the lower intensity of land use entails a larger area of agricultural production for each processing plant, resulting in feedstock transport costs becoming a serious obstacle to commercial viability.

A decentralised approach could also help to reduce feedstock transport costs by reducing the weight of the cargo—in other words—by decentralising more of the production process through the setting up of small scale distilleries. This would create another important benefit for the rural poor—access to clean, domestic fuel—with resultant benefits to health from reduction of indoor air pollution. The economic viability of such small scale distilleries has not been proved, however, and concerns have been expressed about the dangers of alcohol abuse. It is nevertheless an area worthy of some further investigation.

Seasonal employment can pose social problems in industries such as sugarcane. The sudden influx of migrant seasonal workers into regions to which they have no attachment has been reported to have negative effects on community cohesion, causing ethnic tension and disintegration of traditional structures of authority. Migrant workers sometimes establish unauthorised settlements that they are unwilling to leave at the end of the season, ultimately increasing overall unemployment levels and pressure on land for subsistence farming. Due to the sometimes promiscuous behaviour of migrant workers, it has been noted that HIV infection rates are higher around sugar cane estates (FAO, 1995).

### *Sustainability Criteria*

There has been considerable effort during the past few years aimed at the development of sustainability criteria for biomass and biofuels, both within regions and in the context of international trade. In Europe, a recent analysis shows that 15-17% of expected primary energy requirements in the EU-25 in 2030 could be met through bioenergy, even with the application of rather stringent sustainability criteria. The expansion would be facilitated by increased availability of significant quantities of waste residues, the increasing productivity of agricultural biomass sources, and the increased amount of land available for dedicated energy plantations (EEA, 2006).

It is worth reiterating that in the context of bioenergy projects, 'there are no "one size fits all" solutions' (ESMAP, 2005). Socio-economic and environmental impacts must be assessed for every new bioenergy project in the context of the pre-existing ecological, cultural, agro-industrial and land use systems that are specific to the area under consideration. However, it is possible to devise a 'check list' of sustainability criteria most likely to be relevant to a bioenergy project. The following are among key criteria are identified by Smeets et al (2005) in their case studies of Ukraine and Brazil.

- Land use patterns: deforestation, competition with food, protection of natural habitats;
- Socioeconomic: child labour, minimum wages, employment, health care, education;
- Environmental: soil erosion, fresh water use, fertilisers pollution, agricultural chemicals.

The costs of applying these criteria can be assessed in a 'loose' and 'strict' fashion, the latter set sometimes being defined as not merely minimising negative impacts, but making positive improvements, most notably in the provision of health care and education services (Smeets et al,

2005). It is worthwhile considering whether the concept of sustainability in bioenergy projects or programmes should mandate simply that conditions measured according to these criteria should not be negatively impacted; or whether in fact true sustainability should entail positive improvement of conditions. At the same time, it is important to recognise that bioenergy in some cases will replace fossil fuels; as such costs and benefits must be compared to those of the fossil fuels being replaced.

Sustainability criteria for bioenergy will inevitably have to address certain core criteria, which will differ considerably in different regions and for different crops. The core criteria would likely cover the following areas (Fritsche et al, 2006):

- land use and land ownership, including food security;
- maintenance of biodiversity;
- reduction and minimisation of greenhouse gas emission;
- soil erosion and degradation;
- water use and contamination;
- socio-economic impacts;

The criteria would also have to be applied at varying levels: local, regional, national, and international (i.e. particularly in relation to trade). Undoubtedly there will be conflicts across the scales and consequently a governance system or an environmental regime would have to be somewhat flexible but also capable of maintaining fairly high standards.

## **6. A Conceptual Model**

This section provides a simplified conceptual model for assessing the role of bioenergy in the sustainability transition; the model begins with assessments of bioenergy or biomass potential and then proceeds with the imposition of constraints, the specification of alternative scenarios, the identification of various policy options, and the mapping of possible outcomes. There are many feedbacks in this process, and it is expected that some type of adaptation system must inherently be part of the resource management regimes in order for sustainable bioenergy systems to be maintained and strengthened. A diagram of this model is provided in Figure 3 and discussed briefly in the sections below.

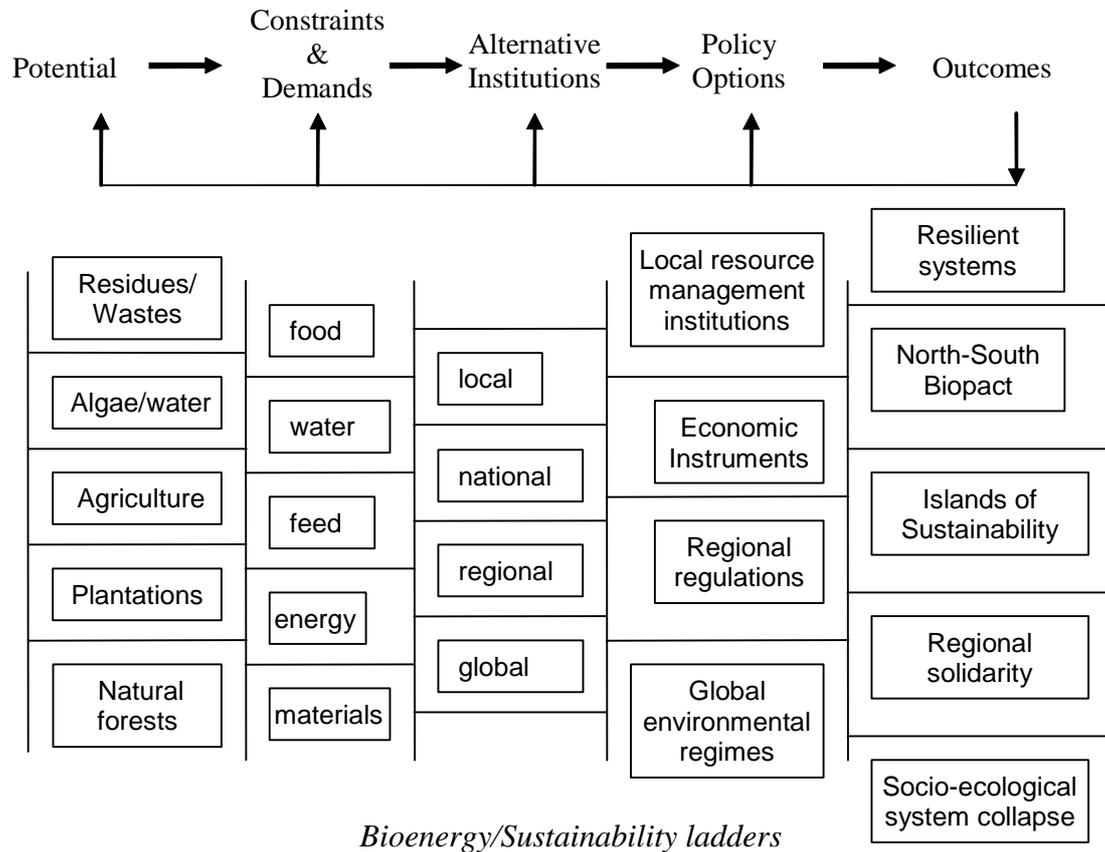
### *Bioenergy Potentials*

Assessments of bioenergy potential are done at various scales, ranging from regional to global. The global assessments of gross potential tend to indicate significant potential when efforts are included to optimise the production and use of biomass resources subject to the constraint that food needs are met first (Smeets et al, 2004). National studies can provide more detail on specific crops and specific end-use markets (Batidzirai et al, 2006). A coarse hierarchy of the different types of biomass resources that could be harnessed can be described as proceeding in order of the likelihood of decreasing long-term sustainability: residues/wastes -> algae/water -> agriculture -> plantations -> natural forests. The maximum use of residues/wastes for energy production is inherently sustainable on the basis of attempts to close the loop in resource life-cycles. At the other extreme, natural forests will need to be preserved for their many other socio-economic and ecological benefits. Such a hierarchy is of course a gross simplification; institutions can be envisioned and even observed in which natural forests and agriculture can simultaneously provide significant amounts of energy, material, and food needs in a sustainable manner. Such institutions, however, become quite complex in the face of growing populations AND increasing levels of material demands.

### *Constraints/Demands*

Although relevant to the discussion, the classic food vs. fuel constraint may not be the major constraint on a macro-basis, as distributional effects can often be observed as having greater likelihood of decreasing food security than price-quantity interactions. A more pressing issue is that bioenergy potentials do not necessarily consider the synergistic effects of overlapping resource constraints, such as water scarcity (Berndes et al, 2002). There are also cultural constraints that are not

considered, particularly the importance of pastoral traditions that require large amounts of grazing land; the maximum bioenergy scenarios assume landless agriculture, which may in fact be undesirable for both socio-cultural and ecological reasons. Another constraint to the value of bioenergy potential estimates is that the favourable growth of particular crops will often be affected by micro-climatic factors rather than gross changes in soil and climatic conditions, which will require the tailoring of new varieties and the need for high yields. The case of biomass grown in water for energy use and/or bioenergy based on unicellular and simpler organisms has the advantage of avoiding competition with land use in the context of growing populations.



**Figure 3: A Conceptual Model for Bioenergy and the Sustainability Transition**

*Alternative Institutions and Policy Options*

Until the past decade or so, the policies and institutions that had a significant impact on the expansion of bioenergy were local or national. The valuable role of local institutions in maintaining biomass resources for multiple uses has long been recognised in traditional cultures that rely almost exclusively on biomass for energy, materials, and livelihoods (Leach and Mearns, 1988). National policies and institutions have been crucial in establishing large markets for bio-ethanol in countries such as Brazil and Malawi (Johnson and Rosillo-Calle, 2007). More recently, regional and international organisations have emerged to address the growing international trade in biomass and biofuels, as well as the greater sharing of technologies and agricultural expertise. The efficiencies that can be obtained through greater regional coordination of bioenergy strategies include transport and distribution, as well as political and economic coordination (Johnson and Matsika, 2006).

The potential for significant expansion in international trade has resulted in efforts to create environmental and social certification in order to improve the sustainability of the overall energy system (Smeets et al, 2005). The energy and economic costs of long-distance transport by ship or tanker of biofuels and prepared biomass (such as wood pellets) turn out to rather small, amounting to

only a few percent of total energy balance and economic costs (Hamelinck et al, 2003). Land-based transport of biomass and biofuels is much more costly and inefficient and consequently international markets are often preferred to regional markets. The implications for international trading regimes are significant in some cases, since agricultural markets are protected by a variety of subsidies and preferential arrangements. The facilitation of greater market efficiency in bioenergy trade will require major changes in international trade agreements, while sustainability requirements will tend to act as a brake on such trade. The tensions between environment and development goals as well as the choice between export-led and import substitution strategies for growth become evident in these circumstances.

### Outcomes

Mapping the bioenergy market developments into various outcomes can be accomplished by reference to some representative scenarios; the scenarios are not intended to cover the full range of possibilities, but rather to indicate the potential general directions of the recent rapid changes in bioenergy systems and markets. The scenarios also bear some relation to the underlying philosophy of interactions between socio-economic and natural systems in the context of future sustainability (Raskin et al, 2002). In the most negative scenarios, *socio-ecological systems collapse* in the face of excessive extraction and utilisation; one such example has been identified in scenarios describing the possible clearing of peat bogs for biodiesel production from palm oil in Indonesia. The *Regional Solidarity* outcome is based on the coordination of regional bioenergy strategies in order to improve the overall development prospects and the energy security situation; it does not necessarily address sustainability concerns nor does it insure that international cooperation is facilitated.

The *Islands of Sustainability* outcome is based on the adoption of sustainability certification of biofuels and biomass trade internationally; the medium-term result is that trading partners exist in North and South, but they are relatively isolated in terms of taking advantage of the bioenergy potential as well as the efficiencies of larger markets. The *North-South Biopact* is based on a concept that is under development for a global regime that recognises the mutual dependencies of North and South in investing in a wise and efficient use of the global bioenergy resource base (Mathews, 2007); such a regime is underpinned by the inherent efficiency of biomass production in the South coupled with the importance of fossil fuels substitution and the “contraction and convergence” arguments for equitable adjustments in energy and material consumption globally. The *Resilient Systems* outcome would take the sustainability elements of the other outcomes one step further by introducing adaptive mechanisms to deal with a changing climate alongside the equitable construction of socio-ecological parameters for bioenergy use. Furthermore, resilience requires the re-incorporation of local institutions and even greater local control over resources, since the crucial embedded knowledge of land and water resources means that sustainable bioenergy is inherently local in many respects.

## 7. Conclusions

Is modern bioenergy a local resource or a global commodity? It will have to be *both* in order to achieve a successful sustainability transition. The knowledge required to harness bioenergy efficiently and sustainably is inherently *local*; the provision of modern infrastructure, conversion technologies, and the best utilisation of the resource base is inherently *global*. The concept of a bridge fuel or of energy sources that can smooth the sustainability transition is NOT only—and perhaps not even primarily—a technical issue. Socio-economic, environmental, and geo-political dimensions are increasingly important in the sustainability transition; the global economy and the bio-physical interdependencies have linked the evolution of energy systems more and more to overall social development patterns. The equitable distribution of resources between and within generations is inextricable from the way in which bioenergy is used and carbon is managed. For these reasons, bioenergy plays a unique and potentially critical role in the sustainability transition.

## 8. References

- Bassam, N. (1998) "Energy Plant Species-Their Use and Impact on Environment and Development," James and James, London.
- Batidzirai, B., Faaij, A. P.C., and Smeets, E. (2006) "Biomass and bioenergy supply from Mozambique," *Energy for Sustainable Development*; Volume X No. 1, March.
- Berndes, G. (2002) "Bioenergy and Water - the implications of large scale bioenergy production for water use and supply," *Global Environmental Change* 12, 253-271.
- Briggs, M. 2004. "Wide scale Biodiesel Production from Algae," UNH Biodiesel Group, available at: [www.unh.edu/p2/biodiesel/article\\_alge.html](http://www.unh.edu/p2/biodiesel/article_alge.html).
- Carrez, D. and Soetaert, W. (2005) "Looking ahead in Europe: White biotech by 2025," *Industrial Biotechnology* 1 (2) 95-101.
- Cornland D., Johnson F., Yamba F, Chidumayo E., Morales M., Kalumiana O, Mtonga-Chidumayo S. (2001) "Sugarcane Resources for Sustainable Development: A Case Study in Luena, Zambia," Stockholm Environment Institute, Stockholm, Sweden ISBN: 91 88714 71 3.
- Chidumayo, E.N., 2002. "Charcoal Potential of Southern Africa: Zambia Country Study," report to EC DG-Research under contract ERBIC18CT980278.
- EEA (2006) "How much bioenergy can Europe produce without harming the environment?," Copenhagen, EEA Report No 7/2006. ISBN 92-9167-849-X.
- EurObserv'ER (2006) "Observatoire des énergies renouvelables," Le baromètre des biocarburants" (Biofuels Barometer), May 2006, n° 167.
- ESMAP (2005) "Advancing Bioenergy for Sustainable Development: Roles for Policymakers and Entrepreneurs, report prepared by Stockholm Environment Institute (SEI) for the World Bank Energy Management Assistance Programme (ESMAP), Report 300/05, March.
- FO LICHT (2006). World Ethanol and Biofuels Report, London, UK.
- FAO (1995) "The effects of HIV/AIDS on farming systems in eastern Africa," FAO Farm Management and Production Economics Service [Online] Available at: <http://www.fao.org/>.
- FAOSTAT (2006) FAO statistical database, [www.fao.org](http://www.fao.org).
- Fritsche et al, 2006, "Sustainability Standards for Bioenergy," Öko-Institut (Institute for Applied Ecology), on behalf of the World Wide Fund for Nature, November; <http://www.oeko.de>.
- Hamelinck et al (2003) "International bioenergy transport costs and energy balance," NWS-E-2003-26 ISBN 90-393-3508-7. Copernicus Institute, Utrecht University, Netherlands.
- IEA, 2005, "World Energy Outlook," International Energy Agency, [www.iea.org](http://www.iea.org).
- IEA (2007) "Renewables in Global Energy Supply: an IEA fact sheet," International Energy Agency, Paris, France; January; [www.iea.org](http://www.iea.org).
- Johnson, F.X. and Matsika, E. (2006) "Bioenergy Trade and Regional Development: the case of bio-ethanol in southern Africa," *Energy for Sustainable Development*, Volume X No. 1 March 2006.
- Johnson, F.X. and Rosillo-Calle, F. (2007) "Biomass, Livelihoods, and International Trade," Climate and Energy Report 2007-01, April, Stockholm Environment Institute: Stockholm, Sweden.
- Kaltschmitt M., Bridgwater A. V., (1997) (eds). Biomass Gasification and Pyrolysis - State of the Art and Future Prospects, CPL Press, UK, 550pp.
- Kamm, B., Gruber, P. and Kamm, M. (2006) "Biorefineries—Industrial Processes and Products: Status Quo and Future Directions," Wiley-VCH, Weinheim.
- Knothe, Gerhard. "Historical Perspectives on Vegetable Oil-Based Diesel Fuels." (2001): Inform. 12, 1103-1107. <http://www.biodiesel.org/>

- Leach, G and Johnson, F. (1999) "Modern Bioenergy," *Renewable Energy for Development*, Stockholm Environment Institute, May.
- Leach, G. and Mearns, R. (1988) "Beyond the Woodfuel crisis: People, Land, and Trees in Africa," Earthscan: London.
- Macedo, I.C., 2005. "Sugar Cane's Energy – Twelve Studies on Brazilian Sugar Cane Agribusiness and its Sustainability," UNICA, Brazil.
- Mathews, J. (2007) "Biofuels: What a Biopact between North and South could achieve," *Energy Policy* 35 (2007) 3550–3570.
- Moreira, R., 2006 "Global Biomass Energy Potential," *Mitigation and Adaptation Strategies for Global Change*, Vol. 11, Number 2: 313-333, March.
- Openshaw, K. (2000) "A Review of Jatropha Curcas: an Oil Plant of Unfulfilled Promise," *Biomass and Bioenergy*. 19: 1-15.
- Raskin, P., Banuri, T., Gallopin, G., Gutman, P., Hammond, A., Kates, R., and Swart, R. (2002) "Great Transition: The Promise and Lure of the Times Ahead," A Report of the Global Scenario Group, Stockholm Environment Institute: Stockholm, Sweden and Boston, USA.
- Read, P. (2006). "Addressing the Policy Implications of Potential Abrupt Climate Change: A Leading Role For Bioenergy", Special Issue Mitigation and Adaptation Strategies for Global Change, 11/2.
- SADC, 2005, "Strategy for biofuels in SADC," Southern African Development Community briefing paper, October, [www.sadc.int](http://www.sadc.int).
- Scoones, I. (1998) "Sustainable Rural Livelihoods: A Framework for Analysis," IDS Working Paper 72, Brighton: IDS.
- Smeets, E., Faaij, A., and Lewandowski, I., 2004 "A quickscan of global bio-energy potentials to 2050: an analysis of the regional availability of biomass resources for export in relation to the underlying factors," Copernicus Institute Report NWS-E-2004-109, Utrecht, Netherlands.
- Smeets, E. Faaij, A. Lewandowski, I. (2005). "The impact of sustainability criteria on the costs and potentials of bioenergy production," Copernicus Institute: <http://www.fairbiotrade.org/>
- Thomas, V. and Kwong, A. (2001) "Ethanol as a lead replacement: phasing out leaded gasoline in Africa," *Energy Policy* 29 (13) pp. 1133-1143.
- UNCTAD (2005) "Review of Maritime Transport," United Nations Conference on Trade and Development, Geneva, October, UNCTAD/RMT/2005, ISBN 92-1-112674-6.
- UNDP (2004) "World Energy Assessment, United Nations Development Programme, New York, ISBN: 92-1-126167-8, [www.undp.org/energy](http://www.undp.org/energy).
- Utria, B., 2004. "Ethanol and gel fuel: clean renewable cooking fuels for poverty alleviation in Africa", *Energy for Sustainable Development*, Vol. VIII No. 3, September, pp. 107-114.
- van Dam, J.E.G., B. de Klerk-Engels, P.C. Struik, R. Rabbinge (2005) "Securing renewable resources for changing market demands in a biobased economy," *Industrial Crops and Products* 21 (129-144).
- Walter A, et al (2000). New Technologies for Modern Biomass Energy Carriers, in: *Industrial Uses of Biomass Energy-The Example of Brazil*, F. Rosillo-Calle, S. Bajay & H Rothman (eds). Taylor & Francis, London, pp. 200-253.
- WEC (1999) "The Challenge of Rural Energy Poverty in Developing Countries," World Energy Council, London, October.
- Willke, T. and K.-D. Vorlop (2004) "Industrial bioconversion of renewable resources as an alternative to conventional chemistry" *Appl Microbiol Biotechnol* 66 (2004) 131-142.
- Woods, J., 2001, "The potential for energy production using sweet sorghum in southern Africa," *Energy for Sustainable Development*, Vol. V No. 1, March, pp. 31-38.