SUSTAINABLE ENERGY FROM BIOMASS

by

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Review paper
UDC: 620.91/.98
BIBLID: 0354–9836, *5* (2001), 2, 5–32

Biomass in various forms has long been the primary energy source and only in recent history of humankind other sources like fossil fuels (also derived from old biomass) have furnished the bulk of energy supply. Modern biomass energy systems are now receiving worldwide attention within the overall trend to sustainable development, security of energy supply, environmental quality and climate stabilization. In that respect, traditional biomass is supplemented by new biomass, based on advances in science and technology. Future prospects of sustainable energy from biomass, giving rise to the proportion of renewable sources in the overall energy mix, are discussed in detail.

Introduction

Security of energy supply and sustainable development are the key issues an overall energy policy. While energy consumption and demand continue to grow, there are doubts regarding the assured supply of non-renewable resources. Most recent estimates have suggested that, at present and projected rates of production, consumption and discovery, the world's oil supply will fail to meet demand by about 2020. The long gestation for large projects is likely to further exacerbate the supply situation. On the other hand, potential for renewable energy sources, including hydro, solar, wind and biomass, is tremendous. Unlike fossil fuels, which take millions of years to form, biomass is a truly renewable resource, as the plant life renews itself every year. Thus, biomass energy has a bright future as a sustainable energy resource, although presently resources like wood, biomass and biogas are classified as non-commercial fuels.

Biomass is a catchall term for any form of matter that is living or was once part of living organisms, for example leaves, wood, corncob, pea pods, algae, bacteria, kelp and manure. Biomass is thus a form of solar energy. Solar energy input to the Earth is 12000 times greater than today's commercial energy supply, while worldwide photosynthesis activity is estimated to store 17 times as much energy as the total energy consumed, and not to speak on hydrogen and fuel cells as an unlimited resource, 1 . For many advantages of solar energy, the simplest solution to energy problems is the use of biomass for energy. Although efficiency of conversion of solar energy by growing plants is only 0.1 to 2%, an increasing part of land is under cultivation for lumber, paper and food, but also for biomass to be converted to energy.

Developed countries of a century past obtained ¾ of their energy needs from burning wood, and in much of the world wood is still a primary source of heat. Yet, direct burning of wood is simply one aspect of biomass application. Many companies have begun production of ”densified biomass fuel” or what could be called ”instant clean coal”. Nature has been making coal for several hundred million years by compressing biomass of swamps and bags. So densified, coal has a high energy content, but unfortunately, often contains sulfur, which becomes a pollutant when the coal is burned. Densified biomass fuels can be made from saw dust, bark, corn cobs, pea pods, or coffee grounds by drying these materials to moisture contents of about 10% and compressing them into pellets. In this form, the biomass has an energy content higher than many coals, is free of sulphur and is easy to ship and store.

Although solid fuels are satisfactory for large boilers and heating plants, in recent decades homeowners and other small-scale consumers have become accustomed to more convenient forms of fuel such as wood gas that are automatically dispensed. Many companies are making gasifiers that convert mill waste and wood chips into a fuel suitable for use in existing oil and gas burning equipment. A more sophisticated type of gasifier that uses oxygen instead of air produces a gas that can be converted to alcohol for automotive fuel or to ammonia for fertilizer. Whereas those processes are suitable for such dry biomass as wood and straw, about 10% of biomass occurs in wet form; for example, manures and sewage. These materials can be converted by digestion to a gas very similar to natural gas or by fermentation to alcohol. From the late 1970s, thousands of automobiles are running on gasohol, a mixture of biomass ethanol and gasoline.

The large energy consumption of industrialized countries (ICs) and the growing energy needs of developing countries (DCs) are continuing to increase the use of fossil fuels considerably. The limited supplies of fossil fuels, for which the ICs are already competing and for which DCs will increasingly compete in the future, can be complemented by renewable energy sources, particularly solar and biomass. In this context the risk associated with external dependency will also be possible to reduce. Their efforts to achieve sustainable development should include renewable energy sources, especially biomass and solar energy.

The developments in the energy sector take place slowly. ICs, who long considered themselves the lucky winners in the global race for turning natural resources into economic wealth, cannot safeguard their economic future over the long term, unless the driving forces of global climate change and environmental destruction in DCs are brought to a halt. Most DCs, on the other hand, are caught in a short-term struggle for economic and physical survival. This struggle tragically pitches them against the long-term maintenance of the very environment on which their future depends. In the near term, DCs will need increasing amounts of fossil fuels, but, nevertheless, they can contribute to the climate stabilization by reducing fossil fuel consumption once efficient appliances, buildings, vehicles and industrial plants become widely available, and once dispersed cogeneration and biomass based supply technologies have reached commercial maturity and/or have been widely implemented by local organizations.

However, it may take decades until these conditions will be widely fulfilled, 5 . So long as this situation persists, DCs cannot turn their attention to issues of sustainable development and climate stabilization. Therefore, any approach to climate stabilization can be successful only if it simultaneously rekindles economic growth and social progress in the DCs. An international effort to solve the DCs development debacle has to be part and parcel of overcoming the global environmental and climate crisis.

The atmospheric environment is under threat from anthropogenic emissions to the extent that irreversible changes to the climate, the ozone layer and the quality of the air could occur. The largest single influence on the climate is expected to be caused by the steady increase in atmospheric concentrations of carbon dioxide (CO_2) and other greenhouse gases (GHGs) as a result of burning fossil fuels (coal, petroleum and natural gas), and also by deforestation, which is also related to the use of biomass. The full warming impact could be avoided if concentrations of GHGs in the atmosphere could be made to decline before the impact of previous emissions has fully materialized. This possibility is important to recognize, though the degree to which such a reversal is possible is limited both by practical and physical factors. A growing amount of research is being done on how climate changes might affect human society. However, the full threat of climate change is not visible from such data due to the facts that inertia of the climate system makes full impact of the past GHG emissions felt only with significant delay.

Emissions of CO_2 occur both anthropogenically (as a result of human activities), and naturally. Anthropogenic emissions result primarily from the combustion of hydrocarbon (fossil) fuels such as coal, natural gas and petroleum. When one of these hydrocarbon fuels is burned, essentially all of the carbon in the fuel is chemically combines with the oxygen in the air to form CO_2. Typical hydrocarbon fuels contain from 75% carbon by weight (methane) to more than 90% carbon by weight (petroleum coke). Thus, for every ton of fossil fuel burned, at least three-quarters of a ton of carbon enters the atmosphere in the form of CO_2. However, the prospect of climate change due to human activities has sparked a variety of controversies. There are many issues raised over a great likelihood that significant climate change will probably ensue in the next few decades a general warming. It is possible that some effects on a regional and global scale are already detectable and may become quite significant before the middle of this century. This time scale is similar to that required to redirect, if necessary, the operation of many aspects of the world economy, including agriculture, and the production of energy.

There is serious concern that the continuing expansion of burning fossil fuels and other human activities on the Earth is likely to increase GHG concentrations, which plays a fundamental role in determining the temperature of the Earth's atmosphere and may cause significant extended regional and even global changes of climate. It appears plausible that an increased amount of CO_2 in the atmosphere can contribute to a gradual warming of a lower atmosphere, especially at higher latitudes. Patterns of change would be likely to affect the distribution of temperature, rainfall and other meteorological parameters. This possibility adds further urgency to the need for global cooperation to take this new understanding into account in energy planning for the future sustainable development.

Proponents of renewable energy sources are developing scenarios for complete elimination of fossil and nuclear fuels by the year 2100, presuming that all energy will come from solar/wind, biomass and other renewables. According to these scenarios, the land requirements are as small as 3% of total current global cropland, permanent pastureland, and forest and woodland. In 2100 electricity would be generated from solar/wind (55%), co-generation (22%), biomass (13%) and hydro/geothermal (10%), while transport would switch from fossil fuels to biofuels (20%), electricity (40%) and hydrogen. More realistic scenarios include various energy mix components, making room for both traditional and new biomass in considerable proportions, as one shown in Fig. 1, [8].

Of course, different socio-economic structures will have very different responses to a climatic change, and will have different requirements and resources for energy, ranging from those that can invoke high technology to supply their needs to those that must make use of more easily available resources such as conventional biomass. Evidence of environmental damage from GHG emissions, coupled with recent instabilities in fossil fuel pricing and supply, illustrate the potential fragility of the society as far as energy consumption and dependency are concerned. The recent blackouts in California have shown that serious disruptions to energy supply are possible even in the world's most developed economy. These events, taken together, demonstrate that

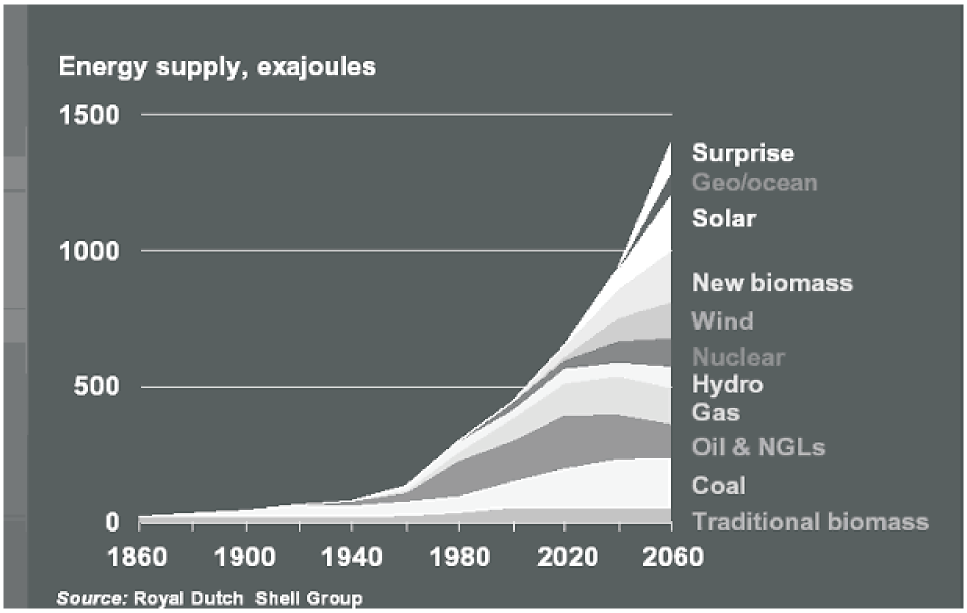

Figure 1. Past and future world energy mix

energy supply has to be planned for in a comprehensive manner. In this respect it is important to develop biomass and other renewable energies so that they can reach their full potential of economic and environmental sustainability.

In this respect, the significance of energy to the national economy and the economic impact of energy policy decisions should be examined very closely. The most important measure for reducing the risks associated with energy supply is to ensure the most diverse and balanced possible use of different types and forms of energy including biomass. In addition, efforts must be made to ensure the optimal use of every economically and ecologically feasible energy source. In this respect, the rapid growth in the use of natural gas would seem to be problematic. This trend also considerably increases both dependence on imports and greenhouse gas emissions. Although energy costs currently account only for a small percentage of gross national product, economic growth and competitiveness are highly sensitive to energy price rises. Oil price changes continue to have a direct impact on the price of natural gas and coal, and changes in primary energy prices have a far-reaching multiplier effect on the economy.

Global warming challenge for biomass

The role of biomass in global warming

Biomass in the carbon cycle on Earth

Biomass is organic matter produced by plants through photosynthesis, and, like all life on Earth, it participates in a planetary carbon cycle. Vegetation uses solar energy (photosynthesis) to absorb CO_2 from the atmosphere and convert it to biomass in the form of vegetable matter, including leaves and wood. It chiefly contains cellulose, hemicelluloses and lignin with an average composition of $C_6H_{10}O_5$, with variations depending on the nature of the biomass. Vegetation decays, releasing some carbon back into the atmosphere, while the other carbon accumulates in soils. An important area of uncertainty on the greenhouse problem is the net flux of CO_2 into the atmosphere due to changes or disturbances of natural life system. To appreciate the relative role of biomass, it is necessary to take all natural carbon cycle of the world into account (this cycle occurs between five major reservoirs: the atmosphere itself, the terrestrial biosphere consisting of land biota and soils, the upper (mixed) layer of the ocean and the deep ocean), although there still exist major gaps in our knowledge of the carbon cycle.

Though carbon makes up about 4% of the Earth's mass, most of it is contained in inorganic rock material or enclosed organic material, and only a tiny fraction (0.04%) participates in the atmospheric-biological-oceanic carbon cycle that influences the world's climate. Most (about 95%) of the carbon participating in this cycle is contained in dissolved form in the deep ocean. In principle, the deep ocean could buffer against disturbances in the other carbon cycle reservoirs, and restore the atmosphere close to its original conditions. However, the deep ocean is separated from the mixed layers of the upper ocean (0–75 m) by a thermocline and the rate of exchange across this boundary is very slow and, as so many aspects of the carbon cycle, not precisely known (but probably more important than the net terrestrial fluxes). To the extent that the deep ocean does act as a buffer, this activity is measured in thousands of years.

The world climate is thus controlled by the exchange processes in the carbon cycle reservoirs. Here, the terrestrial systems of vegetation and soils are more important than is suggested by their relative size. The land biota alone accounts for 420–660 billion tons of carbon (btC). About 90% of carbon in vegetation is contained in the woody biomass and forests and trees and only the remaining small fraction is found in crops and grasslands, [5]. But, an even larger terrestrial carbon reservoir of about 1500 btC is found in the humus materials of the surface layer (top 1m) of soils. In combination, the carbon in land biota and humus adds up to 2000–2500 btC. Soils also contain inorganic carbonates of the order of 1000 btC. Peat and other ”subfossil” organic materials contain a further 1000–3000 btC.

The atmosphere contains presently about 740 btC which is only a third as much as stored in biomass. The carbon stored in the upper (0–75 m) layer of the ocean is about the same (600–700 btC). The sum of terrestrial, atmospheric and upper ocean reservoirs represent about 3300–4000 btC. The terrestrial systems alone contain about 75% of the fast-cycle biospheric carbon that is not in the atmosphere already. These biospheric totals are of the same order of magnitude as that stored in the world's conventional fossil fuel resources, estimated at 3800–4200 btC. With the exception of some of the soil components, carbon stored in these reservoirs turns over rapidly (fast cycle-reservoirs). The typical residence times range from 1 to 30 years. As a result, the natural fluxes of carbon to and from the atmosphere are large, of the order of 60–130 btC/yr. Naturally occurring oscillations in the fluxes of terrestrial systems due to seasonal change from photosynthesis to respiration in forests outside the tropics are large enough to show up clearly in corresponding oscillations of atmospheric concentrations monitoring records.

Currently, net annual terrestrial fluxes of biospheric carbon into the atmosphere are estimated as 1.8 btC/yr., with an uncertainty ranging from 1.0 to 2.6 btC, 4 . These fluxes are only of the order of 1 to 2% of the naturally occurring fluxes caused by photosynthesis, respiration and other processes, which explains some of the difficulty in accurately measuring them. Photosynthesis is believed to absorb some 110 btC from the atmosphere every year, while natural emissions of C are of the same scale (natural respiration by plants and animals on land emits some 60 btC, while the decay of land based biomass releases another 50 btCO$_2$). This is approximately 40 times larger than carbon from emission from burning fossil fuels.

The current annual release of carbon from fossil fuels are about three times as great as biospheric ones. But this dominance of fossil fuels over biospheric releases probably began only after World War II. Fossil carbon releases did not reach 1 btC until 1920s. The point value of the current biospheric range, 1.8 btC, was not reached by fossil fuel consumption until 1952 and the high value of 2.6 btC not until 1960. Since 1860, global annual emissions of fossil fuel CO$_2$ have increased from 0.1 btC to approximately 5.9 btC per year in 1988 and over 6 btC now. Between 1860 and 1985, an estimated 90–180 btC (5–10% of the terrestrial biospheric pool) have been released into the atmosphere due to human land use activities. Another 140–180 btC were released from fossil fuels. (This is about 5% of the total fast cycle carbon in the upper ocean, the atmosphere and on land, 4).

Looking into the future to the year 2100, cumulative carbon releases from the biosphere could grow by 170% above the approximate current value of 180 btC, assuming only constant release rates of current estimates, 2.6 btC/yr. But, this increase in biospheric increases is overshadowed by the trend based cumulative fossil fuel releases, which could reach, at 2% annually compounded growth rate, about five times their current level. This would shift the balance between cumulative biospheric and fossil releases from about 50:50 between 1860 and 1980 to 30:70 between 1860 and 2100. Changes in the terrestrial life systems and soils caused by human activity could pose a large additional climate threat, compounding the impacts of fossil fuels by a significant margin.

The role of biomass in greenhouse effect

The greenhouse effect is a natural feature, in which a specific role is played by biosphere. (It is still the only basis on which the enormous differences in atmospheric temperatures and climate between planets like Mars, Venus and Earth can be explained). The Earth absorbs solar radiation mainly at the surface, where this energy is redistributed to the atmosphere and ocean and re-radiated to space at longer, thermal, wavelengths. Some thermal radiation is absorbed by the radiatively-active gases in the atmosphere, thus reducing the amount of heat re-radiated to space. It is this trapping of infrared radiation that is referred to as the greenhouse effect, and the gases in the atmosphere that let solar radiation (visible light) pass to the surface of the Earth while trapping infrared radiation (also known as heat radiation) that is re-emitted by the surface of the Earth and would have otherwise escaped to space, are called greenhouse gases (GHGs). The most important are water vapour, carbon dioxide and clouds. These contribute roughly 90% to the greenhouse effect, whereas naturally occurring ozone, methane and other account for the remainder.

The greenhouse effect is constantly in operation in maintaining the Earth's climate. Atmospheric composition is a primary determinant of global average temperature and climate which in turn establish the condition (and limits) for all life on Earth. Without the heat-trapping properties of these gases, the Earth's surface average temperature would be between –18 ^{o}C and –16 ^{o}C like the very cold surface of Mars, instead of the current average global temperature of +15 ^{o}C. Studies on planet Venus have helped make this proposition clear: the bright clouds of Venus reflect so much radiation that less solar energy reaches the surface of Venus than the surface of Earth, even though Venus is much closer to the Sun. Nonetheless, the surface temperature of Venus is about +482 ^{o}C, compared with +15 ^{o}C on Earth, and the difference in temperature is attributable to very high concentrations of GHG in the atmosphere of Venus as compared with that found on Earth, enabling a higher proportion of reflected heat to be captured within Venus' atmosphere. At a global average surface temperature of +15 °C, the long-wave outgoing radiation from the surface of Earth is 390 W/m^2, compared to 236 W/m^2 from the top layer of the atmosphere, and this reduction in the long-wave radiation is a measure of the greenhouse effect.

The individual components of the climate system, such as the atmosphere, the hydrosphere, the cryosphere, the lithosphere and the biosphere, have greatly varying response times (for example, an air molecule may remain in the troposphere for 4–8 days only, a water molecule in the deep ocean up to 1500 years and an ice sheet as long as ten thousand to a million years), which makes the climate system rather inert. Of particular importance is the sluggishness in the warming of the ocean, which is the result both of the enormous heat capacity of the ocean and the long time constant involved in ocean circulation. Inertia and feedback mechanisms mean that the full warming impacts from greenhouse gas emissions manifest only with delay. Oceanographers who have considered the way in which CO_2 is taken up by the world's oceans have concluded that, even though entire ocean volume can have very large capacity for the added CO_2, the slow rate of overturning between surface water and deep water implies that the "decay time" for the oceans to absorb most of the excess airborne CO_2 could be as large as 1500 years, [5]. Thus, what is being added to the atmosphere will probably remain there for a very long time indeed.

The atmosphere-ocean system has often been referred to as a great "heat engine" since the motions in the air (winds) and the oceans (currents) are created directly and indirectly by the differential heating between equator and poles or land and sea. (The atmosphere works to exchange tropical and polar air masses, thereby transporting the heat pole-ward). The same is generally true of the ocean circulations, which transport almost as much heat pole-ward as the atmosphere at middle latitudes. Modeling studies of various degrees of sophistication show that the world's oceans can take from a decade to as much as a century to equilibrate with the changes in radiative heating induced by changes in atmospheric GHG concentrations. Not only the heat penetration but also the CO_2 uptake and release by the ocean is a slow process, varying as a function of temperature as well as by atmospheric and ocean carbon content. This is expressed as the fraction of anthropogenic net CO_2 emissions that remains in the atmosphere. Presently, this fraction is 50–60%, while under equilibrium conditions in the ocean – atmosphere system, only about 20% of the emissions would remain airborne. If mankind can alter the heat input into this heat engine, it could run faster or slower, and the temperature distribution of the lower atmosphere in which we live may change also. That is no longer a speculative hypothetical proposition, since it is now becoming quite clear that the man is indeed influencing the heat balance of the Earth, and, if continued, this influence will probably become of increasing significance to the world's climate over the next few decades.

Since CO_2 is a chemically relatively stable gas, it remains in the atmosphere for the most part, with somewhat less than half of the added CO_2 going into solution in the oceans or being taken up by the forests of the world (although there is some controversy over the last statement in view of the possibility that the forests in the tropics may actually be shrinking slowly as a result of deforestation by mankind). Observations show that the CO_2 content of the atmosphere has already increased from its pre-Industrial revolution level, which is estimated to somewhat between 270 and 290 parts per million by volume (ppmv) to a present value of 380 ppmv. Assuming a continued increase in fossil fuel use of 3–4%/yr. of which roughly half continues to remain airborne, the level will double its pre-Industrial Revolution value by the middle of this century. To keep the Earth's climate stable, the average rate of warming should be limited to about 0.1 °C per decade, and the absolute warming relative to 1850 should not exceed 2.5 °C. However, at present, a warming commitment of 0.2–0.5 °C per decade is being added, and there is a growing consensus that the effect of increasing CO_2 will be an increase in global mean surface temperature of about 2–3 °C by the mid-century, with global distribution of these increases as presented in Fig. 2, [2].

While many human activities are emitting greenhouse gases, biomass and agricultural crops can also provide a sink for CO_2, and, consequently, alternative cropping and land use management practices could help mitigate increased emissions of these gases. That is because every green plant extracts CO_2 from the atmosphere, separates the carbon atom from oxygen atoms, returns oxygen to the atmosphere, and uses the carbon to make biomass in the form of roots, stems and leaves. Human beings plant trees, but trees also reproduce themselves. When a tree is planted, it grows and sequesters carbon for many years. Biomass in general tries to grow itself to limits of the capacity of ecosystems. It is therefore difficult to determine which activities are biogenic and which are anthropogenic.

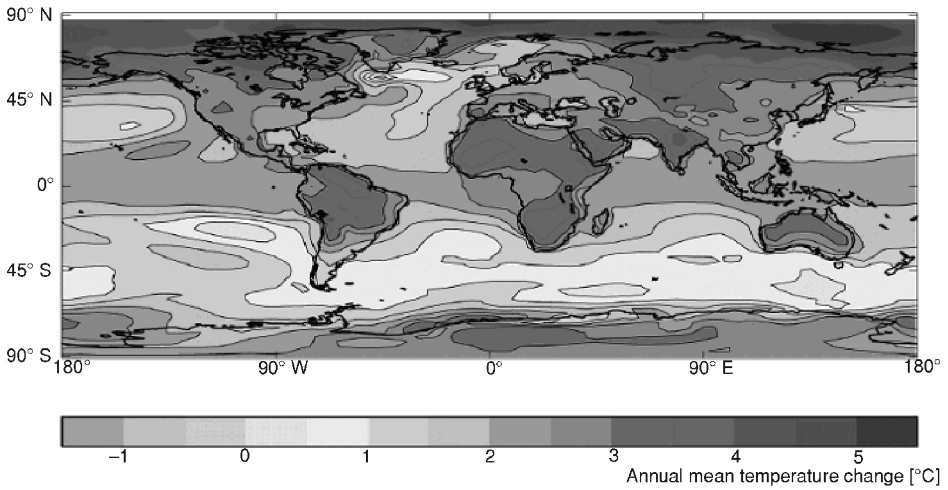

Figure 2. Global distribution of projected temperature rise by 2050

The positive temperature feedback on biospheric carbon releases would affect all vegetation and soils, especially those of the middle and higher latitudes (the forests of

Europe would be among the affected in a major way). Thus depending on the rate of warming up to several hundred btC could be released from the biospheric pool in a matter of few decades. The annual rate of such releases could outstrip releases from fossil fuels for an extended period. The potential consequences of massive forest dieback and further warming illustrate the danger of seeing greenhouse warming as mainly beneficial for northern hemisphere regions. To cope with such a serious problem of optimising global use of biomass to produce energy in a sustainable way, a more sophisticated scientific approach to the overall greenhouse effect is considered necessary, 13 .

Harvest of some of the world's most important staple food crops and biomass may fall as much as one third in some crucial regions as a result of climate change. While global population growth is making it more urgent than ever to increase the yields, experimental evidence is showing that rising temperatures linked with GHG emissions cam impair crop's ability to to flower and set seed. For every 1 °C rise in temperature in regions like the tropics, yield of staples such as rice, maize and wheat could tamble as much as 10%, [2]. As the estimated rise of the average global temperature in the tropics could climb by as much as 3 °C by 2100, the yield there may fall up to 30% as early as 2050.

Biomass use to tackle the climate change

The most important natural process that may be used to tackle the climate change is photosynthesis. The forests absorb atmospheric CO_2 through photosynthesis and convert it into biomass, primarily wood. Thus carbon sequestration from this source should be regulated by increasing forest area. Quantifying the amount of carbon that is being sequestered presents difficult methodological problems, however, because it is not clear how much (if any) of this carbon should be considered anthropogenic, and how much should be considered natural. Further reduction of greenhouse emissions is possible through the promotion of more integrated and sustainable farming practices. Cultivation practices can lead to increased emissions of greenhouse gases, but there is at least twice as much carbon locked in soils than there is stored above ground in natural vegetation. Therefore, there is a great potential to reduce GHG emissions. Less intensive and more integrated farming system would contribute to reducing GHG emissions. Additionally, tremendous potential exists in the production of non-food crops, primarily biomass for energy (energy from fossil fuels will be displaced and thus GHG emissions reduced).

Increased CO_2 concentrations and warmer climates could themselves lead to feedback effects on biospheric carbon fluxes to the atmosphere. The present understanding of such possible mechanisms is highly inadequate, particularly in view of their enormous implications for greenhouse risks, 4 . Increased carbon fixation in plants in response to higher CO_2 concentrations would be a negative feedback mechanism (the CO_2 levels used to promote plant growth in commercial greenhouses are several times those occurring naturally). On the other hand, warmer temperatures brought about by the greenhouse effect could lead to a positive feedback by accelerating the respiration of plants while producing little impact on photosynthesis. There will almost surely be shifts of the agriculturally productive areas. While the pattern of these shifts is still far from clear, there are suggestions that subtropics may become more productive as a result of more favourable rainfall, that the growing season will be longer at high and mid-latitudes, and that there may be more or less rainfall in some places.

Chemically, the main components of fossil fuels are hydrocarbons, made up of molecules containing hydrogen and carbon atoms. When these fuels are burned, atmospheric oxygen combines with the hydrogen atoms to create water vapor and with the carbon atoms to create carbon dioxide. In theory, if the amount of fuel burned and the amount of carbon in the fuel is known, the volume of CO_2 emitted into the atmosphere can be computed with a high degree of precision. In practice, however, a combination of real-world complexities can reduce the precision of estimate.

Over the last several decades, the science of atmospheric chemistry and scientific measurements have achieved great advances, but one still cannot connect, in a quantitative way, the relationship between man-made CO_2 emissions and changes in the atmospheric concentration of CO_2. Nonetheless, energy related CO_2 emissions are known with greater reliability than other GHG emissions sources, and the uncertainty in the estimate is probably only 10% or less. One real-world complexity is that it is not all of the carbon in the fuel is perfectly combusted. About 1.5% of the carbon in fossil fuels is emitted in the form of carbon monoxide, which swiftly decays into CO_2 in the atmosphere. Another 1% is emitted in the form of volatile organic compounds (including methane), which also eventually decay into CO_2.

Total emissions of nitrous oxide, N_2O, about 10 to 18 mtN/yr., are small relative to the atmospheric burden. However, due to its long residence time in the atmosphere of 120–170 years, N_2O is dominated by natural sources and therefore is the most uncertain of the five major GHGs. Unlike N_2O, the NO_x cycle is dominated by human activities. Almost all anthropogenic NO_x are produced by fossil fuel burning, with a small amount also from biomass burning. Non-methane hydrocarbons (which are sometimes called volatile organic compounds-VOCs) are produced anthropogenically by biomass and fossil fuel burning and the use of solvents.

Methane is the only GHG with a relatively short atmospheric residence time. As a result, required reductions to stabilize atmospheric concentrations are a modest 20–30% of current emission levels, and the available control options in several areas could significantly exceed this reduction target. Methane is a byproduct of the production and combustion of fossil fuels, the decomposition of human and animal wastes, digestion processes in ruminant animals, and the decomposition of organic matter in the rice paddies. Wetlands provide the single largest source at 115 mtM/yr., with an uncertainty range of this estimate from 100 to 200 mtM/yr. Approximately 70% of the emission of CH_4 released into atmosphere come from human-related activities. Approximately 20% of CH_4 emissions on a worldwide basis can be traced to energy use, and about 60% of all CH_4 emissions from energy production are byproduct of coal mine operations (70 mtM/yr.) and of the chemical and physical processes that lead to the formation of coal, from oil and gas drilling 25–50 mtM/yr., while anthropogenic emissions from biomass burning 20–80 mtM/yr., 2 .

Natural sources and sinks tend to provide larger volumes of GHGs than man made sources, including ones provided by biomass used for energy. These natural sources, however, are often grounded in particular types of natural ecosystems. When humans modify ecosystems by reclaiming swamps, cleaning land for agriculture, or logging forests, their actions have consequences for emissions and absorption of GHGs. However, estimates of emissions and absorption of GHGs resulting from changes in land use are the most difficult, complex and uncertain of all the emission inventory calculations. Likewise, potential emissions resulting from the abandonment of farmland, which is another large-scale land use, should enhance natural absorption of CO_2 and CH_4 while reducing emissions of N_2O.

The methodological problems associated with estimating the extent of these effects are also substantial as the global warming phenomena call for a more precise calculation of emissions as additional sink of CO_2 to tackle the climate change. In general, emissions estimates are computed by multiplying some activity such as coal consumption, by an emission coefficient to generate an estimate of emission. The reliability of both the activity data and the emission coefficients varies widely. However, estimates of CO_2 are more reliable than the estimates of other gases. The CH_4 emissions estimates are much more uncertain (the level of precision is on the order of 30 to 50%). The N_2O emissions estimates are even less reliable than the CH_4 emissions estimates (N_2O emissions from their largest source, nitrogenous fertilizers, may be accurate to an order of magnitude or so). All the above makes the role of biomass almost impossible to predict accurately.

Biomass to energy conversion

Biomass versus food conflict

The world population will grow from over 6 billion now to almost 9 billion in 2050 and this population must be fed. Food production will have to increase and thus pressure on arable land is expected to increase. However, arable land per person has already shrunk twice, from average 0.24 hectares in 1950 to 0.12 today, and with increasing pressure the situation in many countries is becoming critical. For example, Pakistan has only 0.08 hectares per capita today, and is expected to fall below 0.03 hectares in 2050. Therefore, scarcity of arable land and fresh water may limit biomass growth for use for food, materials and energy (bioenergy), Fig. 3, 9].

Water shortages and climate change as the two most important environmental challenges of the 21st century. A widespread land degradation, which affects now around 2 billion hectares worldwide, is also a severe problem. Moreover, water tables are falling in North America, North Africa, Arabian peninsula, and elsewhere at a high rate. The rate of falling is 0.5 meters per year in India's Punjab, and 1–1.5 meters per year in China's northern plain, where 40% of the country's grain harvest are produced. Water

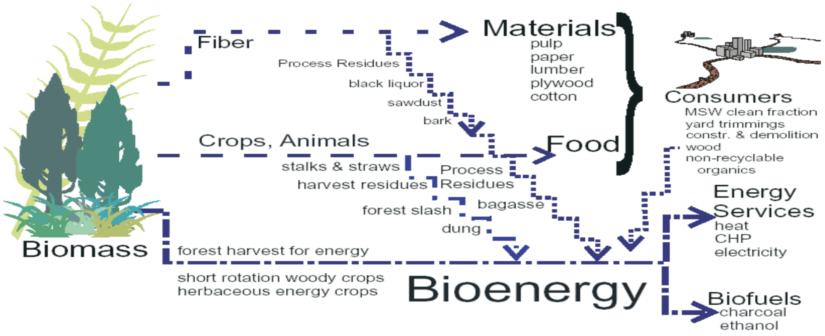

Figure 3. Biomass for materials, food, and energy use

contamination from nitrates and pesticides and salinization linked to poor agricultural practice are major problems in many countries, including even France, the Netherlands and the United States.

Enough fresh water is available world-wide to meet the need for the foreseeable future – if it were evenly distributed and appropriately used. But, water is poorly distributed across countries and across regions within countries, and across seasons. Competition for water is becoming more acute, increasing the potential for conflicts between sectors and even water wars between countries. Efficiency of water use in agriculture and industry is low. Degradation of land and water resources through water logging and salinization and ground water depletion is growing. Growing water scarcity will depress agricultural production, worsen water-related health problems, degrade land and water resources, and catalyze water conflicts between users. To address water scarcities for food and bioenergy production, new water resources are needed, and better use of the existing water supplies is required.

New sources of water are becoming more expensive, because of high construction costs for dams and reservoirs and environmental concerns and displacement of people. Therefore, a larger share of water to meet the needs must come from a more efficient use of the existing water sources in agriculture and elsewhere. Nevertheless, additional new water source as a substitute for fresh water is necessary. That is made possible to achieve by the use of salty sea water to produce fresh water by the use of energy for desalination. However, energy shortage may become a limiting factor for such a substitute. It is, therefore, necessary to avoid such multiple conflicts between food, energy and water as required by the concept of sustainable development. Of particular importance for biomass is to avoid its ”food versus fuel” conflict in that respect. Using residues as sources of ethanol and methanol could alleviate the so-called ”food versus fuel” conflict for land (farming) and fresh water (irrigation) intensive biomass and help reduce the technical and commercial risk of synthetic fuel ventures.

Biomass based energy systems

Present technology of biomass to energy conversion systems is based on the principle of conversion of the solar energy trapped by photosynthesis and stored in biomass (wood, sugar cane, algae, animal waste, *etc*.) into chemicals which can be easily utilized, particularly in the domestic sector (heating, cooking, internal combustion engines and others). Conversion technologies used in small-scale biomass projects are presented in Fig. 4, bearing in mind that the distributed generation is the major area of biomass to energy applications.

Creation of ”Energy plantations” could produce enormous amounts of biomass. Experiments show that sycamore trees, for example, can be harvested at 5 year intervals, yielding 10–16 tons of biomass per acre per year, three times the yield of traditional long rotation silviculture. Such ”Energy farms” for growing specific plants are important, uniquely because of their ability to easily provide the basic materials for biofuel production. These farms could be on land or in of-shore areas. The method applied most frequently is anaerobic digestion of organic compounds by successive action of the various types of bacteria. The mixture produced mainly consists of CH_4 (50–70%) and CO_2 (25–35%). Alcohols, principally methanol and ethanol are intermediate in the biogas production process.

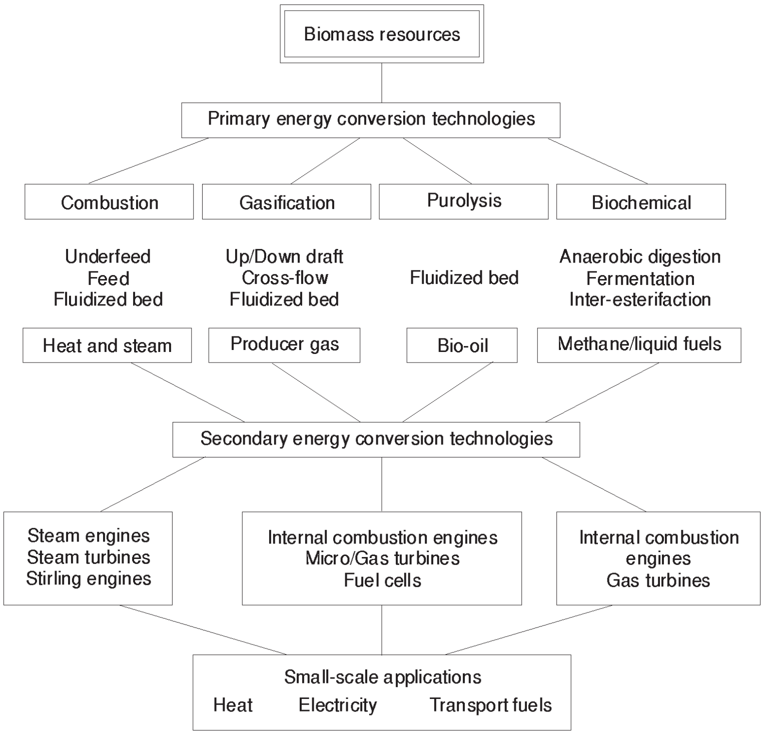

Figure 4. Conversion technologies for small-scale biomass projects

Biomass based energy systems include farm/forest component that captures solar energy via photosynthesis and makes mainly polysacharides from CO_2 and water as presented in Table 1 and conversion component that employs one or more processes (thermal, biological and extractive) to convert the biomass to liquid, gaseous and solid fuels. Using residues as sources are of special importance, as it could alleviate the aforementioned ”food versus fuel” conflict for land intensive biomass.

Table 1. Farm component of the biomass energy systems

Biomass	Primary fuel	Productivity GJ/ha/year	Remarks
Sugarcane	Ethanol	75	Only 6 months season
Mandioca (cassava)	Ethanol	50	Process energy supply
Palm oil kemels	Vegetable oils	195	Direct use in diesel engines
Forests	Firewood	180	Long growth period
	Fuelgas	175	
	Charcoal	155	
	Methanol	50	
	Ethanol	35/50	
Crop residues	Biogas	Variable	
Food processing	Firewood	Variable	Direct combustion
Water hyacinth	Biogas	1300	Large area requirements

There is a growing interest worldwide for small-scale distributed heat and power sources, which are of particular importance for biomass as a distributed energy resource. Tables 2 and 3 describe thermal and biochemical conversion processes

Table 2. Thermal conversion processes for biomass

Primary resulting fuel	Process	Thermal efficiency, % *
Charcoal, oil, gas	Pyrolysis	70–75%
Low heat content gas	Air gasification	70–75% (gas); 16–20% (electricity)
Medium heat content gas	Oxygen gasification	60–65% (SNG); 55–60% (methanol)
Medium heat content gas	Steam gasification	60–65% (SNG); 55–60% (methanol)
Heat, steam, electricity	Combustion	20–30% (electricity); 75–80% (steam)
Oil	Direct liquefaction	50–60%

*** Based on wood with 50% moisture level**

respectively. For a widespread use of biofuels in transportation, it is necessary to integrate all the subjects involved (farmers, biofuel producers, the oil industry, the automobile industry, bankers, *etc*.) and to create an international market in order to reduce risks and to make biofuels truly commercial, 2 .

Table 3. Biochemical conversion processes for biomass

Fuel	Process	Fuel yield MJ/ton	Energy use MJ/ton	Cost, $/bbl of oil equivalent
Methane (CH_4)	Anaerobic digestion	0.28–0.74	1.2	28
Alcohol (C_2H_5OH)	Hydrolysis and fermentation	0.46	1.1–1.4	68
Methyl & Ethyl esters of vegetable oils	Extraction and trans-esterification	0.30	0.2	97

There is a great potential to reduce GHGs from coal-fired plants by upgrading coal or using it with other fuels, as well as by repowering and reconstruction to combined heat and power generation. Around 100 000 MWe capacity of operating coal fired plants is more than 40 years old and almost 500 000 MWe more than 20 years old. A substantial proportion of the latter plants could be co-fired by coal and natural gas or biomass, Fig. 5 9 . This is particularly important in the countries where coal quality and generation efficiency are not satisfactory.

Schematics of biomass integrated gasification combined cycle (IGCC) and hybrid fuel cell/gas turbine systems are presented in Figs. 6 and 7 respectively, 9 . Figure 8 depicts ”trigeneration” concept with straw gasification, which is suitable for villages.

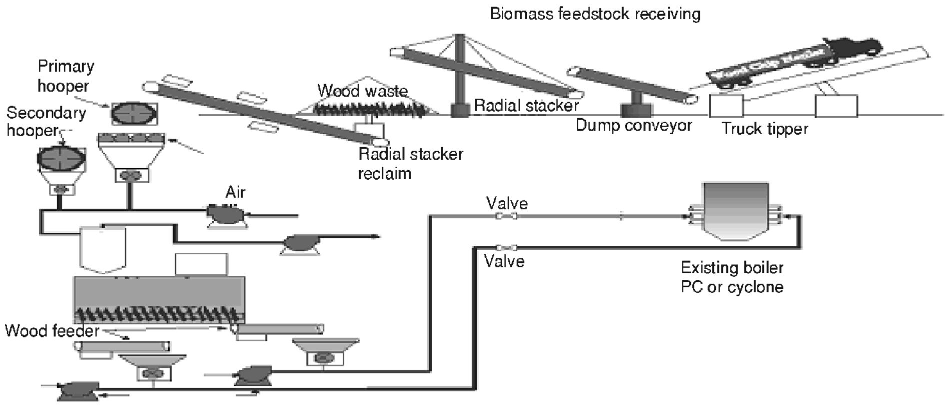

Figure 5. Biomass co-fire with coal

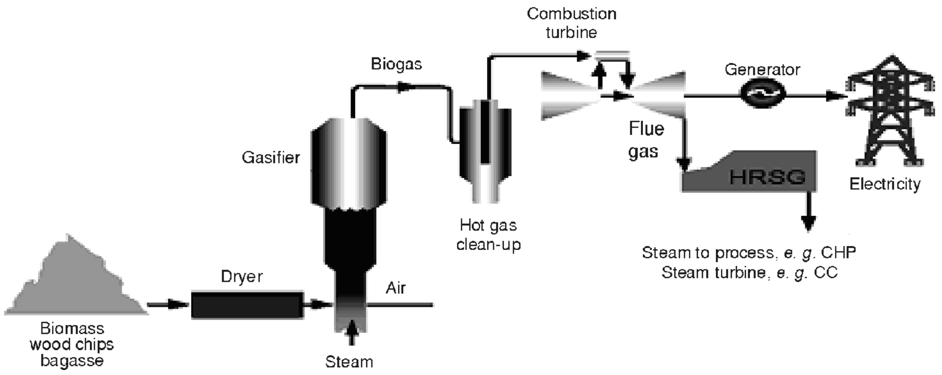

Figure 6. IGCC fuelled by biomass

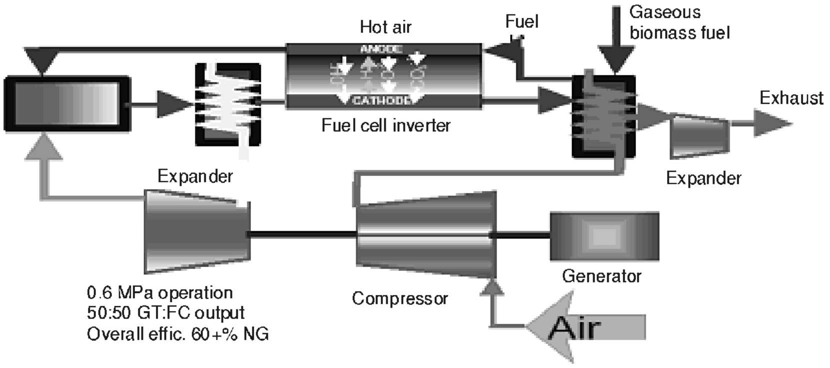

Figure 7. Hybrid direct fuel cell system using gaseous biomass fuel

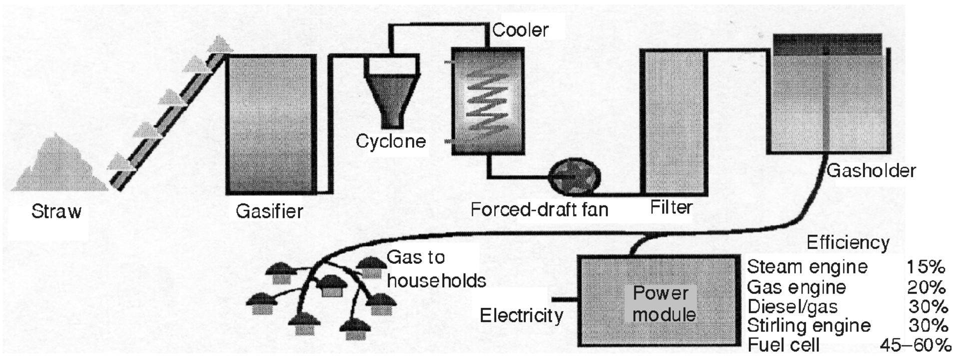

Figure 8. Small scale tri-generation concept using straw

Economic efficiency of biomass use

Economic efficiency of biomass to energy conversion is not fully recognized, but seems nearly competitive to more traditional methods. Importance of biomass to energy conversion is limited so far, but will undoubtedly play an increasing role, particularly in agriculture sector, which could become self sufficient in energy. Biomass already plays a significant role in several parts of the world, such as biogas fermentation in India, gasoline blended as an energy saving measure with methanol produced from sugarcane residuals in Brazil, *etc.* Methanol used as a fuel for automobiles, for instance, appears to be 1–1.5 times more expensive than gasoline, but this is changing, since the costs of methanol is falling as the technology develops, and gasoline is rising as a result of oil price increases.

The largest single sector for biomass use is in the bio-processing industries such as sugar cane processing, wood processing and pulp and paper industries. There residues of biomass are used for process heat and drying, as well as for electricity generation. For example, US pulp and paper sector is currently 57% self-sufficient. Increasing need for power and heat calls for an increased interest in combined cycle biomass gasification systems, raising the efficiency of generation.

Biogas is a product of anaerobic digestion, with a composition 55 to 70% of CH_4, and 30–45% of CO_2, including H_2S 200–4000 ppm. Its heating value is 20–25 MJ/Nm^3. When utilized for electricity generation via gas turbine or a gas engine and Rankin cycle, the overall installation costs are at present 2.3 $k\$/kW_e$, but expected in the future at 2.0 $k\$/kW_e$ with an efficiency improvement to 23% from 17.5%. With ICE (Internal Combustion Energy) gasifier using spark ignition technology, cost reduction is needed from 4.2 $k\$/kW_e$ to less than 2.6 $k\$/kW_e$ and an efficiency gain is to 32.4% from 23.9%. High availability and high load factors are both critical to success. With respect to environmental issue the gasifier – ICE is superior to Rankin except for CO emissions. Table 4 presents a comparison of today's (base) and future technologies.

Table 4. Technical performances of present and future technologies

Technology	Rankin power plant		Gasifier ICE		Pyrolysis diesel ICE	
	base	future	base	future	base	future
Power production, MW_e	2.0	2.0	5.0	5.0	6.2	6.2
Heat production, MW_{th}	6.8	5.8	6.0	5.7	6.5	6.5
Power efficiency, %	17.5	23.0	23.9	32.4	24.7	31.5
Overall efficiency, %	88.0	90.0	85.0	90.0	58.5	66.0
Power to heat ratio	0.30	0.35	0.83	0.88	0.95	0.95

Performance of Rankine and Gasifier ICE has been compared for use in a plant in Denmark with total load of 3.2 MW_{th}, built with an aim to optimize the fossil/biomass trade-off using a 2 MW unit using straw to cover 85–93% demand (4000 tons/yr.) and an oil fired boiler for peaking in winter, and for maintenance outage in summer. This example demonstrates sizing criteria for a 40.7 TJ/yr. demand of 400–450 households, taking into account local climate dictated degree days and monthly demand of sanitary heating 10%. Table 5 presents a comparison of the cossts of wood pyrolysis and wood combustion alternatives versus wood fuel cost.

Table 5. Economic performances wood pyrolysis concept

Variable	Assumptions		
	Low case	Base case	High case
Wood fuel $/GJ	1.3	2.3	3.3
Pyrolysis liquid $/GJ	9.6	11.1	12.5
Heat fixed cost $/MWh	4.1	7.9	11.8
Heat variable cost $/MWh	2.6	2.8	3.3

Oxygenated transport liquids

Oxygenated transport liquids are mixtures of alcohols and ethers in hydrocarbon that can be used directly as fuels. These fuels have been around since the invention of automobile (in fact, they were Henry Ford’s fuels of choice). They can be made from non-petroleum feed-stocks thus stretching hydrocarbon fuel resources, and can be beneficial to the environment. It was expected that the MTBE (methyl tertiary butyl ether) will become a universal oxygenate for octane purposes, but its widespread penetration has suffered a setback, as it was banned in California due to concerns over leakage into the water table.

The production of methane and alcohol from biomass wastes is probably the most favourable renewable energy technology from the environmental viewpoint as it provides not only a ”clean energy” supply, but also a potential tool for combating water pollution problems, managing organic wastes from municipal facilities, agriculture, wood industries *etc*., and decreasing the air pollution loads from internal combustion engines. The growth of aquatic plants and algae as raw material for the production of biofuels in polluted water bodies might help in solving eutrophication problems. Residues from fermentation process are generally regarded as excellent fertilizers. The combustion of methane produces air pollutants comparable to those resulting from burning natural gas. Automobiles fuelled with methanol, for slightly diminished performance (acceleration) and for the same distance, emit about 6–7 times less CO, NO_x and unburned hydrocarbons from those consuming gasoline and require no lead additives as an anti-knock agent.

Rising crude oil prices during the 1970s and early 1980s and fears of a critical petroleum shortage sparked interest in alcohol fuels as substitutes for gasoline and diesel. In the late 1980s and early 1990s, oil prices fell dramatically, initially shifting the focus away from alcohol fuel alternatives as public concern subsided. However, recent oil price increases (Fig. 9) and mounting evidence of the contribution of gasoline and diesel combustion to the climate change have stimulated renewed interest in long-term sustainable energy solutions. Ethanol fuels are used in many countries. In Brazil 4 milion vehicles consume neat or nitrous ethanol, while the balance of some 12 million vehicles consumes a blend of gasoline containing up to 24% ethanol by volume. In the USA, a million of flexible fuelled vehicles consume E85, a blend containing 85% ethanol by volume, and a large fleet consumes gasoline containing anhydrous ethanol.

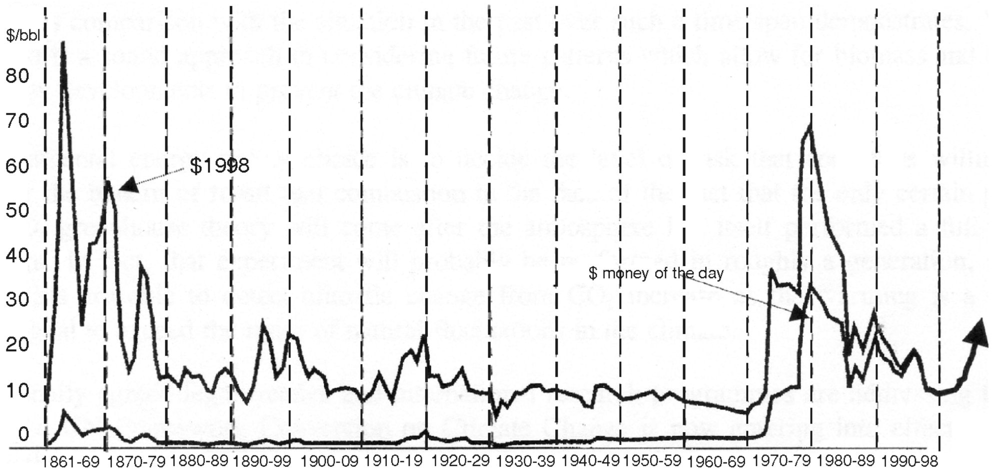

Figure 9. History of the crude oil market prices

Production and use of fuel ethanol have promoted significant technological developments in the sugarcane agro-industry and automotive industry. Substantial ethanol cost reductions have been achieved, but competitiveness with gasoline was not possible until crude oil price reached 28 $ per barrel. However, these comparisons do not take into account ethanol's value in reducing oil imports and foreign exchange drainage and superior environmental characteristics. Environmental benefits for local air quality may be measured by total removal of lead from gasoline and by a sharp decrease in emissions of CO, unburned hydrocarbons and NO_x. Increased emissions of acetaldehyde are much less preoccupying than emissions of formaldehyde from gasoline-fuelled engines. Regulatory pressure in recent years, and limited investments in the performance of the ethanol-fuelled engines, have led to a considerable reduction of emissions from gasoline-fuelled engines, to the point that they today are (with the exception of aldehydes) very similar. However, as the long-term marginal cost of oil is likely to increase, ethanol may become a rational economic option.

Recent development of fuel cells may encourage increased use of oxygenated fuels, particularly methanol and ethanol. These devices have been known for two centuries, but have been developed lately as power sources for stationary and mobile uses. Their operation can be seen as the reverse of that of battery: they bring hydrogen and oxygen into contact so as to react chemically in a controlled way, yielding electricity, heat and water.

The trends towards redefining energy policy call for a new balance between environmental protection, energy security and the prices, known as environmental least cost planning. There is a wide range of biomass based technologies, but the effort required, and absence of strong public pressure, have not yet led to incentives for reducing emissions by using biomass for energy.

Role of biomass in energy policy

Global warming and energy policy

The carbon which has been locked in the Earth for million of years in the form of fossil fuels is being taken out and burnt, thereby adding CO_2 to the atmosphere. Continually growing GHG emissions cannot be eliminated simultaneously owing to the inertia of social and economic systems. There is a natural tendency that to believe that the future will be like the recent past, but such an approach is missing major new trends, turning points and technological developments. This applies particularly for the time scale of decades to centuries appropriate for global warming, as comparison with the situation in the past over such a time span demonstrates. What is required is a sound approach to considering future patterns which allow for biomass and other new energy developments to prevent the climate change.

The fundamental energy policy choice is to decide the level of risk that society is willing to accept for the benefit of fossil fuel combustion in the face of the fact that the only certain proof of the CO_2 greenhouse theory will come after the atmosphere has itself performed a full-scale experiment. In fact, that experiment will probably be performed in roughly a generation, since the scientists are able to detect climatic change from CO_2 increase as the warming is a large enough signal to exceed the noise of natural fluctuations in the climate.

Internationally agreed legal treaties and international research programs are addressing these issues, 5 . The UN Framework Convention on Climate Change is now entering into effect, which commits the governments of developed and countries in transition to limit their GHG emissions. It is possible that some effects on a regional and global scale may be detectable and become significant before the middle of this century. This time scale is similar to that required to redirect, if necessary, the operation of many aspects of the world economy, including agriculture, and the production of energy.

Energy taxes and state aid are often employed as instruments to achieve commonly agreed objectives such as environmental protection, promoting use of renewable energy resources, *etc*. The development of some renewable energy sources calls for major efforts in terms of research and technical development, investment aid and operational aid. Co-financing of this aid includes a contribution from sectors which have received substantial initial development aid and which are now highly profitable. Through evolving forms of taxation and in certain support models (guaranteed price and compulsory purchase), business in traditional forms of energy is already helping, at least in part, to fund renewables.

To exploit the potential of renewable forms of energy, support measures are necessary. To ensure that state aid and taxes do not distort competition between countries, efforts are being made to introduce harmonization. If energy taxation is harmonized just within the EU, this would further weaken competitiveness vis-à-vis other countries, especially the OECD countries. Energy taxes, if employed properly, can guide choices towards more environment-friendly alternatives if a choice exists. The increased use of biomass for energy may be economically attractive in reducing GHG emissions. These ties in with the idea that the external costs of different energy forms should be internalized. However, it is difficult to clearly determine external costs and they tend to vary a great deal from case to case. With a view to reducing carbon dioxide emissions it might be sensible to introduce a carbon dioxide tax, but the internal market means that this is only possible if fully harmonized.

Taxing energy use will, at least in the long term, result in energy savings. However, taxing consumption also has other consequences. If they are not harmonized internationally they weaken industrial competitiveness and reduce consumption demand in the domestic economy, which affects economic growth. Plans to introduce energy taxes must take these consequences into account and compensate for them as far as possible. To ensure environmental improvements, the potential revenue from energy taxes should at least be targeted at projects designed to protect the environment.

Kyoto protocol mechanisms and biomass

Often it is possible and good from a macroeconomic point of view to reduce greenhouse gas emissions on the basis of voluntary agreements instead of relying on taxation. Emission Trading, Joint Implementation and Clean Development Mechanism are flexible mechanisms established to ease implementation of the Kyoto Protocol on climate change and to contribute to sustainable development.

Clean Development Mechanism (CDM), one of the measures under the Kyoto Protocol designed to promote "clean air" energy projects in the developing world. The mechanism would allow industrialized nations to gain special "credits" for pursuing projects that would control, limit or avoid greenhouse gas emissions in less developed countries. All technology options may be required and should remain available and countries have the sovereign right to determine their own development paths and their energy decisions should not be restricted by international policy as requirements for sustainable development can only be determined at national level, where domestic needs are best understood. In that respect, growing concerns about the effect of climate change have given ethanol an unexpected value, since the production and use of sugar and ethanol can avoid emissions of 207 kg of CO_2 per ton of sugarcane (Table 6, 2).

Table 6. CO_2 emitted in production of sugarcane, sugar and alcohol

Item	kg CO_2 per ton of sugarcane
Production, harvest and transport of sugarcane	
Carbon sequestration via photosynthesis	+694.7
CO_2 from diesel used in sugarcane agriculture	–4.7
CO_2 from burning dry leaves, tips	–198.0
CH_4 and other GHGs from burning dry leaves, tips	–1.0 to –5.0
N_2O from soil from nitrogen fertilization	–3.2
CO_2 from fossil fuels used in agricultural inputs (seedling, *etc.*)	–6.7
CO_2 from fossil fuels used in manufacturing agricultural implements	–2.4
Oxidation of sugarcane residues left in the field	–49.5
Production of sugar (45%) and alcohol (55%)	
CO_2 from fermentation	–38.1
CO_2 from fossil fuels used in manufacturing inputs (lime, *etc.*)	-0.5
CO_2 from fossil fuels used in manufacturing equipment, *etc*.	–2.8
CO_2 from burning all the bagasse, replacing fuel oil	–231.6
Avoided carbon emissions in sugar making by the use of bagasse	+104.0
Utilization of final products: sugar and alcohol	
Metabolic sugar carbon return to atmosphere	–97.0
CO_2 from alcohol burned in automotive engines	–79.1
Avoided carbon emissions by the use of alcohol	+126.7
Total avoided emissions (net)	+206.8

For example, the use of ethanol and sugarcane bagasse as fuels in Brazil avoids emissions of 12.7 million tons of CO_2 annually, reducing country's overall CO_2 emissions by 20%. Today sugarcane ethanol is the only commercial transportation fuel that claim a carbon avoidance benefit, a valuable feature if the flexible mechanisms of the Kyoto Protocol because practical financial instruments in the future.

Promoting biomass and other renewable fuels

Internalisation of external energy generation costs

Electric technologies are part of the solution to climate change in support of action to provide long-term solutions on climate change and sustainable development. The challenges of sustainable development and the enormous potential for energy savings offered by electric technologies are the bridge between energy and sustainable development. On the production side, the significant improvements in carbon dioxide emissions achieved by power generation companies over several decades, reducing from an average 1.7 kg of CO_2 per kWh of electricity produced during the 1950s and 1960s to just over 0.5 kg today.

Electricity generation from biomass is projected to increase considerably, owing to its environmental benefits. In that respect, the EU member countries, with an overall annual energy potential of biomass estimated to about 200 million of tons of oil equivalent, could achieve goal to reduce its CO_2 emissions in 2010 to 9% of those in 1990. Otherwise, these emissions could even increase from 3079 million tons of carbon in 1990 to 3298 million tons in 2010, and 3508 million tons in 2020. Table 7 illustrates the external costs of electricity generation from burning coal, natural gas and biomass depending on the circumstances in a particular country. This was the case with rather low prices paid for natural gas, but these prices are expected to rise as the oil prices rise, and moreover, may be very sensitive to the market conditions.

Table 7. External generation costs, (1998) ECU/MWh

Country	Coal	Natural gas	Biomass
Belgium	37–63	11–22	–
Denmark	–	15–30	12–14
Germany	30–55	12–23	28–29
Finland	20–44	–	8–11
France	69–99	19–31	6–7
The Netherlands	28–43	5–19	4–7
Norway	–	8–19	2
Sweden	18–42	–	3

To exploit the potential of renewable forms of energy, support measures are necessary. Traditional forms of energy already contribute to this funding even though there are no objective reasons or precedents for this. Although promoting renewable fuels for reducing pollution is important, one should not overlook cogeneration.

Cogeneration, or combined heat and power, is one of the most efficient means of generating electricity. Typically, a cogeneration plant has an overall savings of 35% in primary energy usage. Not only does this translate into more efficient energy usage, but it means a corresponding reduction in CO_2 emission. This does not advocate that renewables and cogeneration be advanced at the expense of other technologies that are needed during the 21st century. Energy taxation must have a clear impact on management of the environment; however efforts should be made to avoid any negative consequences in terms of competitiveness and social considerations. Energy taxation should therefore have an impact on the environment, but should not have a detrimental effect on competitiveness or in social terms.

Policy of the European Union

The European Union (EU) is currently dependent on external suppliers for 50% of its energy needs. This is forecast to rise to about 70% over the next twenty years. Energy is a fundamental prerequisite for civilized life as we know it today, and therefore the concern about energy dependency is fully justified. It reflects a growing awareness throughout the world that energy may not always be as readily and as cheaply available as it is today. There is also increasing awareness of the environmental damage resulting from energy use that must somehow be factored into energy policy. All this must be considered in the face of increasing expectations regarding our quality of life. These expectations impact on energy consumption, but we are also required to meet our growing needs within a framework of developments that are sustainable over time.

Under present economic conditions in the EU, any energy policy can only be successful if it emphasizes the fundamental roles of energy efficiency, energy conservation and the use of biomass and other renewable energy sources. Today, renewable energy provides 63 million tons of oil-equivalent each year (Mtoe/yr.) which is nearly 5.4% of the EU's primary energy needs. The European Commission believes that by 2010, biomass and other waste fuels could supply up to 70 Mtoe/yr. Because of concerns about CO_2 emissions, renewable fuels should be part of any country's energy balance. A reduction of 180 million tons of CO_2 might be achieved by 2005 by increasing the use of renewable energy sources to 8% of the current primary energy consumption.

The EU has been responsible for establishing the necessary common framework by applying in particular the articles on competition, the internal market and research cooperation. There are plenty of opportunities to develop and adopt new technology while improving the efficiency of energy production and use, based on the principle to produce as much as possible from as little as possible. However, the most important measures are increasing the use of renewable energy sources, such as the ALTENER programmes. The Directive of the European Parliament and of the Council on the promotion of electricity from renewable energy sources in the internal electricity market is aiming to achieve strategic goal of the EU to increase share of renewable energy from 6% at present to 12% in 2010. The Directive is calling member countries to increase their electricity generation from renewables including hydro and biomass to 22.1% in 2010, in comparison with 13.9% in 1997, Table 8.

Table 8. Percentage of renewables in electricity generation

Country	In 1997, %	In 2010, %
Austria	64	78
Belgium	2	6
Denmark	9	28
Finland	26	35
France	14	21
Germany	6	13
Greece	9	20
Ireland	4	13
Italy	16	24
Luxemburg	3	7
The Netherlands	5	13
Portugal	38	46
Spain	20	30
Sweden	50	60
Great Britain	2	10
European Union	14	22

An ambitious program to promote biofuels and other substitute fuels, including hydrogen, geared to 20% of total fuel consumption by 2020, continue to be implemented via national initiatives, or are coordinated decisions required on taxation, distribution and prospects for agricultural production. A common EU program may help to promote the development and use of biofuels for transport as a means of harmonizing support and other measures and incorporating this question into the common agricultural policy in an appropriate manner. The most important measure for reducing the risks associated with energy supply and other risks is to ensure the most diverse and balanced possible use of different types and forms of energy. The measures making energy use more efficient and increasing the use of renewable energy resources are assumed to reverse the trend of growing external dependence and increasing greenhouse gas emissions.

Conclusion

Various fuels (wood, alcohol, hydrocarbons, *etc*.) have co-existed throughout history. It is likely that they will continue to coexist in the transition to sustainable transport systems. Countries that are naturally endowed to grow food, feed and fiber to satisfy their domestic needs and the export market, and that can still either grow crops or use cellulose raw materials and wastes for biofuels like ethanol, are good candidates for early entry into production and trade of biofuels. Of course, market penetration of biofuels is likely to be limited by many constraints and competition with other energy sources. However, they could now be supported by actual driving forces that have evolved over time from concerns over security of supply, to local environment and public health, to climate change concerns, and back to security of supply.

The major drivers are currently local and global environmental concerns, especially in regard to climate change. Liberalizing energy markets had brought greater efficiencies, but taxation should be harmonized, ”externalities” should be internalized in the market price of energy products, and efficiency standards mandated by Directive. Such legislative measures should be linked, and politicians must work together with industry, who should work constructively with the legislators to make sure they have the relevant information.

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Paper submited: May 15, 2002
Paper revised: June 20, 2002
Paper accepted: July 23, 2002