The future

Opportunities and problems of Bioenergy

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Traditionally, biomass such as wood has been used for cooking and heating purposes. The oil crises of the 1970s, however, prompted interest in biomass to produce liquid biofuels and replace fossil-based transport fuels. Subsequent falls in oil prices evaporated much of the incentive and stalled the momentum to expand biofuel production in most countries, but recent years have seen a resurgence of interest, this time prompted by energy supply security, oil price volatility and the new driver: climate change mitigation. As a result, biofuel programmes have proliferated around the world, driven by mandates, targets and subsidies, whilst investment in the development of advanced biofuel technologies has racked up. And, as before, biofuels as an alternative to fossil-based transport fuel, gaseous or liquid, has been emphasized. The 2003 EU Biofuels Directive, for example, targets a 5.75% share of biofuels in transport energy by 2010 and 10% by 2020. However, biofuels can also be used to efficiently produce both heat and power in decentralized production systems based on combined heat and power (CHP) engines. Indeed, whereas transport accounted for nearly one-third of final energy consumption in the EU-27 countries in 2008, heat and electricity account for two-thirds of final consumption (Figure 1).

Key words: *biofuels, combined heat and power engine (CHP engine), EU Biofuels Directive, fermentation, transesterification*

The biofuel portfolio for transport and for CHP systems currently includes bioethanol, and biodiesel, as well as more recent introductions such as biomethane, biobutanol, hydrotreated vegetable oils (HVOs) and glycerol.

Biofuel production and technologies

On the basis of the feedstock used for production and the technologies used to convert that feedstock into fuel, biofuels are classified into either first- or second-generation biofuels. First-generation biofuels have been developed on the back of long-established farming practices aimed at providing food. Second-generation technologies that exploit industrial and agricultural by-products and food wastes, are paving a way forward to ensure food production is not compromised and renewable resources are not wasted.

First-generation biofuels are derived from various food commodities including vegetable oils, sugar, cereals and other starchy crops: oils are converted into biodiesel [fatty-acid methyl ester (FAME)] via transesterification, whereas sugars, either directly from sugar cane and sugar beet or enzymatically derived from starches, are converted into bioethanol via fermentation.

Second-generation bioethanol using the cellulose from all kinds of plant cells (e.g. straw, wood) are under development, as are synthetic fuels from any type of biomass via gasification and the Fischer–Tropsch (FT) process. HVOs are mixtures of paraffinic hydrocarbons produced by direct catalytic hydrogenation of plant oil and are similar to biodiesel produced by FT synthesis, but address some of the known problems such as cold start associated with FAME.

Second-generation biomethane from heterogeneous food waste and plant by-product streams uses anaerobic digestion, a technique which has been in existence for treating waste waters for more than a century, but is now being adopted at scale, boosted by further incentives to divert organic wastes from landfill.

Biofuels can also be produced from second-generation feedstocks that include *Jatropha*, an oilseed bush that grows successfully on marginal and semi-arid land, and on algae and aquatic biomass. These latter have been seen by the scientific community, industry representatives and decision makers globally to represent one of the most promising renewable resources for a wide range of new-generation low-carbon applications in the field of renewable energies, biofuels, nutrients, pharmaceuticals, animal feed and bio-based products. Microalgae naturally produce and store lipids, and hold the potential to produce 100-fold more oil per acre than any terrestrial plant, making them ideally suited to

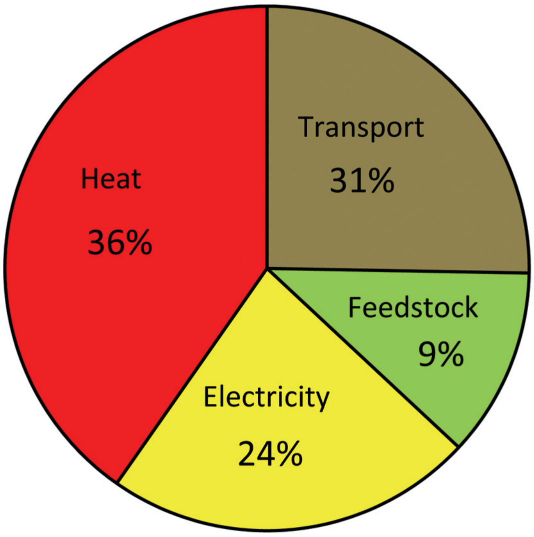

Figure 1. EU energy demand (1135 Mtoe) in 2008 (IEA)

deliver a new biopetroleum platform. Some also produce up to 80% of their mass as glycerol, another second-generation biofuel, in highly saline environments. However, industrial-scale production of biodiesel from algae costs at least 10–30 times more than making traditional biofuels at present, for which fundamental research to find economical ways to make biofuels from algae are required. There are also large gaps in our understanding of how to control and optimize lipid biosynthesis and cellular deposition in microalgae and of the reasons one algal strain is more proficient at rapid growth and efficient lipid production than another.

In Europe, Member States have argued that more attention should be paid to developing second-generation biofuels, and in 2008, the European Commission proposed that at least 40% of biofuel targets should be met by non-food and –feed competing second-generation biofuels or by cars running on green electricity and hydrogen.

CHP and bioenergy

CHP describes technologies that generate electricity simultaneously with useable heat in one single highly efficient process at or close to the point of energy use. When the captured heat is then cooled by linking it to absorption chillers, the technologies provide cooling as well as heat and power and are then referred to as tri-generation CHP (CCHP). These technologies deliver 'bioenergy' when the fuel they burn is biofuel.

Conventional ways of generating electricity in coal- and gas-fired power stations generate vast amounts of heat which is wasted (up to two-thirds of the overall energy generated), with a further 7–9% of electricity lost in the process of transmission and distribution to end-users through centralized grid and local distribution networks. In contrast, the relative sophistication of CHP systems means that CHP plants can reach in excess of 90% overall efficiency at the point of use.

Centralized production systems are dominant in most parts of the world, driven largely by economies of scale and production efficiency benefits. However, in large-scale bioenergy production, they demand huge amounts of feedstock and have justifiably been criticized when they result in monocultures with related environmental impacts. Decentralized small-scale bioenergy production units may provide a pathway to a more sustainable future: when supplied with locally sourced biofuels (e.g. plant oil, glycerol from biodiesel manufacture, wood and wood wastes, combustible agricultural wastes or biogas created in anaerobic digesters from the breakdown of waste organic matter), decentralized CHP systems cut down on transportation and marketing distances and can provide energy with a low/zero carbon footprint. They can also create local employment and generate income in marginal areas[1].

G8 leaders meeting in 2007 issued a direct charge that nations must increase their use of CHP to deliver a "clean, clever and competitive energy future". Analyses conducted by the International Energy Agency (IEA) indicate that CHP currently generates only 10% of global electricity, but argue that this could rise to 24% with thoughtful well-implemented policy intervention.

Bioenergy policies

Support for bioenergy in general, and biofuels in particular, is provided in almost all producing countries. The objectives and their relative priorities are heterogeneous, and include the reduction of fossil energy use in times of high crude oil prices and finite reserves, the reduction of greenhouse gas (GHG) emissions in the light of the evidence on climate change, the generation of new outlets for agricultural produce given relatively low farm prices, the development of rural areas (both in developed and developing countries) and others.

There are numerous policies in several countries largely covering two main areas. On one hand, tax incentives, guaranteed prices and direct support for investment and production are given to bridge the gaps between production costs and market prices. On the other, the use of biofuels is directly increased by the need to meet minimum fossil fuel/biofuel blending requirements and by mandates for public fleets.

There are several links to policies in other sectors. Direct links to agricultural policies exist through energy crop payments and the permission of non-food crop production on set-aside land, while larger use of commodities for the production of bioenergy can lead to higher agricultural prices, an objective that is common to agricultural policies. Air quality objectives are behind both bioenergy and environmental policies, whereas a more intensive production in agriculture can have negative environmental implications. Similarly, although the objective of increased energy security is joint to energy policies, higher fuel prices due to blending obligations could conflict with the objective of low energy prices. It is clear, however, that more research will be necessary to provide the evidence base for these policies.

Economics of bioenergy markets

Strong growth in bioenergy markets can be stimulated from attempts to reduce climate change resulting from the continuation of increasing CO_2 emissions, or lack of support for policies for increased oil prices in real terms. Strong growth in bioenergy production will result from high crude oil prices and strong public support. This will result in high profitability. However, this will inevitably result in higher and more volatile prices in agricultural markets, but whether the effect of more volatile prices is inevitable has been questioned and depends on the responsiveness of the bioenergy industry's demand for agricultural products. It ranges from the current percentage of total arable land used for each of the country groupings in biofuel production, to the three scenarios for 2030 set by the IEA/Organisation for Economic Co-operation and Development (OECD) to accommodate increased biofuel for transport in the World Energy Outlook 2006.

In most countries, costs of biofuel production exceed the energetic value of the resulting product, making biofuel supply dependent on public intervention. At the same time, strongly growing energy consumption around the world, and in particular the growth in transport fuel consumption, raise concerns about the future availability of fossil fuel sources as well as the developments in GHG emissions. Cross-border investments have been relatively rare to date, but are likely to become more important, and individual activities of foreign direct investments tend to be of significant magnitude.

Although much of the current fluctuation in agricultural commodity prices is caused by factors such as weather-related low harvests in Australia and other major producing countries, and reduced public stocks, the growth in biofuel production and in the associated demand for feedstock commodities clearly further supports prices for cereals, oilseeds and sugar crops. At the same time, and to the degree that profit margins remain important for biofuel producers, the low responsiveness with respect to feedstock prices together with the globally low stock levels may render international

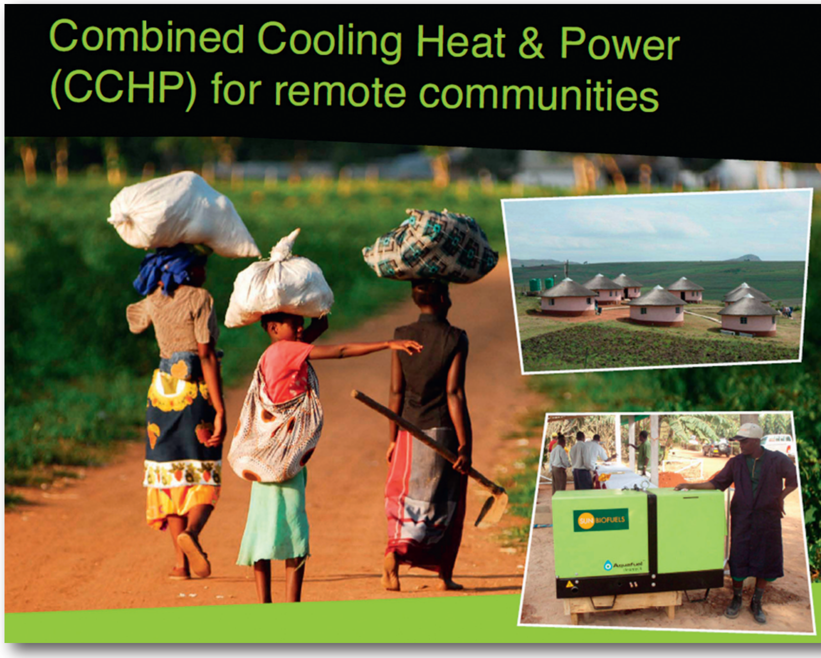

Figure 2. CCHP in Africa

Figure 3. *Jatropha* and its uses

commodity markets more volatile than in the past, resulting in an increased risk of extreme situations. However, such volatility is still open to debate.

Environmental Issues

The environmental and energy performance of bioenergy production systems varies significantly across forms of bioenergy, feedstocks, conversion processes and

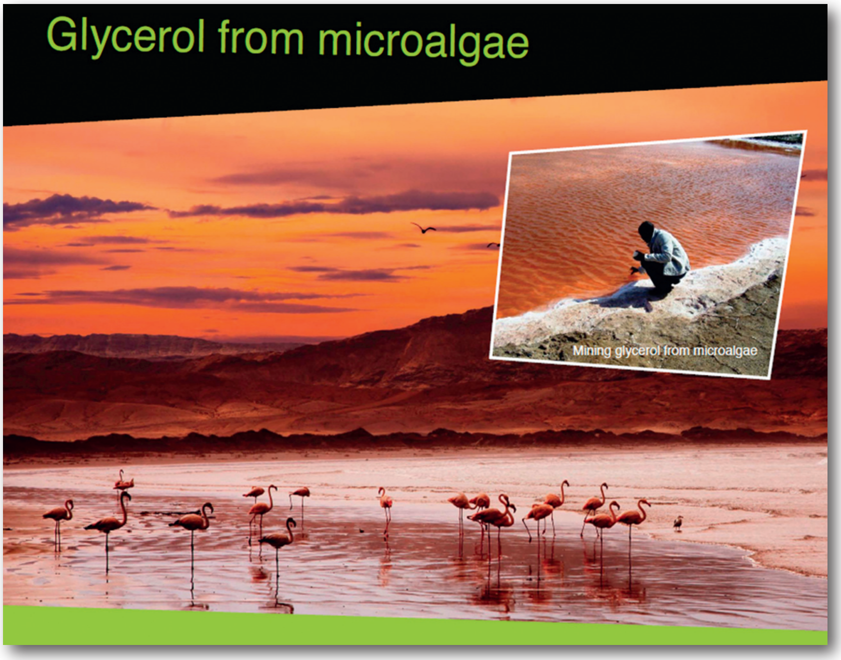

Figure 4. Glycerol from microalgae

production regions. But, in addition to these factors, life-cycle assessments of bioenergy production systems vary considerably due to differences in data used and methods applied. Most studies indicate that the use of biomass for heat and power generation, preferably combined, tends to be more efficient in terms of fossil energy savings and GHG emission reductions than most forms of first-generation biofuels, at least when produced from food commodities within the northern hemisphere. Second-generation biofuels offer higher potentials on both fronts. The implications for the local environment are ambivalent: on one hand, higher intensification of agricultural production systems can reduce biodiversity and increase soil erosion and water and soil pollution. On the other, there are potential co-benefits between energy use and Nature protection. The use of innovative bioenergy cropping systems can result in a high energy yield, but also reduce environmental pressures compared with some food cropping. These reductions in environmental pressure can be made from less nutrient input, enhanced crop diversity and less use of heavy machines. The use of forest residues can support fire-prevention measures in otherwise unmanaged forests in Southern Europe. The use of cuttings from grassland can maintain biodiversity-rich grassland and landscape diversity and provide a limited amount of bioenergy.

More research is needed to fully understand the complicated links between bioenergy production and use and the consequent net changes in fossil energy use, carbon and other GHG emissions, land use, soil carbon stocks, soil conservation, water quality and quantity and biodiversity and landscape impacts. In particular, this can be approached effectively using the techniques of lifecycle assessment.

Bioenergy and Africa

There are very few operational commercial biofuel systems in Africa, and relatively little effort has gone into promoting biofuels, despite the estimated large resource base and biofuel potential [2]. Access to secure, sustainable and affordable energy is an essential component of achieving the Millennium Development Goals, and a prerequisite for sustainable development in developing countries, yet many African countries are still unable to provide reliable energy services. Biofuels offer these countries some prospect of self-reliant energy supplies at national and local levels with potential economic, ecological, social and security benefits.

In this regard, decentralized CHP installations running on biofuels (Figure 2) could be of tremendous value because they can deliver electricity to small rural communities for which connection via the grid is too costly. A large part of the energy market in Africa comprises rural communities that could be serviced with CHP units operating in the range 20–100 kW, and operated on locally sourced biofuel. Biofuel–CHP systems would help to target poverty eradication at the small-scale farmer level, increase living standards, create employment, lower fossil fuel use and improve the ecological footprint of energy production. A key feature of decentralization is localization of ownership, management, production and marketing of bioenergy and related products, and decentralized bioenergy systems are being implemented in many parts of the world, both developed and developing, to drive local development through local ownership, creation of employment and supply of energy services[1].

The Africa–Europe Energy Partnership

In Europe, achievement of the ambitious biofuel adoption targets set by the 2003 EU Biofuels Directive is problematic, because Europe lacks the physical space needed for adequate biomass production using current technologies. To overcome this will require innovative second-generation technologies to come onstream, and a thoughtful approach in dealing with developing nations that can produce biomass. R&D investments on advanced biofuel technologies are substantial in several countries, and the first commercial lignocellulosic ethanol plant may be operational in the US in 2012. Gasification/FT schemes are being tested in Europe, and biodiesel from this technology is expected to reach markets in the next decade, although commercial-scale plants are unlikely in the EU before 2018. With regard to biomass-producing nations such as in sub-Saharan Africa, for example, the EU commitment to biofuels could provide these biomass-producing economies with a lucrative cash crop, employment opportunities and rural incomes as well as GDP. But it could also reinforce the dependency of these nations on the lowest value part of the supply chain, namely biomass production[3]. It could also unwittingly promote unsustainable agricultural practice. The Renewable Energy Directive/Fuel Quality Directive 2009 goes some way to safeguard against unsustainable practice in sourcing biomass for biofuel, whereas the Africa–Europe Energy Partnership (AEEP) of 2008 looks ahead to structured political dialogue and co-operation on energy issues of strategic importance to Africa and Europe, in particular energy security and energy access. High-level conferences will be held every 2 years; technology transfer will be promoted with a focus on locally adapted and affordable technologies; African efforts to create the necessary regulatory, fiscal and legal environment needed to attract private investments, as well as operations and risk capital will be supported, and African partners will be encouraged and assisted to increase the flow of energy sector revenues into economic and social development. The African partners will also be supported in mobilizing funds from new sources, including from energy users, oil solidarity funds and African and international private investors.

In conclusion, biofuels are likely to continue to be important in the global portfolio of renewable energy, for reasons of energy security, and to meet carbon emissions targets, but safeguards to ensure they are not purchased from biomass-producing nations without ascertaining the cultivation methods are essential. On the other hand, biofuels should also be viewed as a precious commodity that could provide a pathway to a more sustainable future in developing nations, particularly when produced and processed by local communities to meet their needs. Decentralized small-scale bioenergy production units targeted for rural community development are a good example. In this regard, partners and associates from the UK, Italy, South Africa, Namibia and Ghana are working together in a flagship programme supported by the EU–Africa Caribbean Pacific (ACP) Science and Technology to build capacity and attract investment into a number of pilot small-scale decentralized bioenergy production units running on sustainable second-generation non-food biofuels such as those based on glycerol, biogas and plant oil in Africa (Figures 3 and 4). ■

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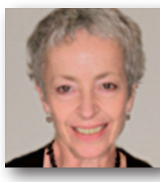

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