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# Bioenergy Capacity Building Programme (BIOCAB) – Bioenergy Sourcebook

# FINAL REPORT

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# Bioenergy Capacity Building Programme (BIOCAB) – Bioenergy Sourcebook

**Colophon**

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## ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| BSI | Better Sugarcane Initiative |
| BSP | Biogas Support Program |
| BtL | Biomass-to-liquid |
| CDM | Clean Development Mechanism |
| CEN | European Committee for Standardization |
| CER | Certified Emission Reduction (representing 1 tonne $CO_2$-equivalent) |
| $CH_4$ | Methane |
| CHP | Combined heat and power production |
| CNG | Compressed Natural Gas |
| CO | Carbon monoxide |
| $CO_2$ | Carbon dioxide (a greenhouse gas) |
| COD | Chemical Oxygen Demand |
| COP | Conference of Parties |
| cS | centistokes (measure of viscosity) |
| DDGS | Distillers Dried Grains with Solubles |
| DOE | Designated Operational Entity |
| EB | Executive Board of CDM |
| EU | European Union |
| EUA | EU Allowance (permission to emit 1 tonne $CO_2$-equivalent under EU-ETS) |
| EU-ETS | EU Emission Trading Scheme |
| FACT | Fuels from Agriculture in Communal Technology (an NGO) |
| FAO | Food and Agriculture Organization of the United Nations |
| FSC | Forest Stewardship Council |
| g | gram |
| GHG | Greenhouse gas |
| GJ | GigaJoule (1000 MJ) |
| GS | Gold Standard |
| $H_2S$ | Hydrogen sulphide |
| ha | hectare |
| IETA | International Emissions Trading Association |
| IFPRI | The International Food Policy Research Institute |
| ILO | International Labour Organization |
| IUCN | International Union for Conservation of Nature |
| JI | Joint Implementation |
| kW | Kilowatt |
| kWh | KiloWatthour (3.6 MJ electricity) |
| LCA | Life Cycle Analysis |
| LCF | Lignocellulosic Feedstock biorefinery |
| LFG | Landfill gas |
| $m^3$ | cubic meter (1000 liters) |
| MFP | UNDP's Multifunctional Platform Programme |
| MJ | MegaJoule |
| mln. | Million |
| MPOB | Malaysian Palm Oil Board |
| MSW | Municipal Solid Waste |

| | |
|---|---|
| Mtoe | Million tonnes of oil equivalent (41.868 GJ) |
| MWe | MegaWatt electricity |
| MWh | MegaWatthour (1000 kWh) |
| $N_2$ | Nitrogen |
| NGO | Non Governmental Organization |
| $NO_x$ | Nitrogen oxide |
| O&M | Operation and Maintenance |
| $O_2$ | Oxygen |
| OECD | Organisation for Economic Co-operation and Development |
| OWF | Organic Wet Fraction |
| PDD | Project Design Document |
| PEFC | Programme for Endorsement of Forest Certification schemes |
| pH | potentia hydrogenii (measure of the acidity of a solution) |
| ppm | parts per million (0.0001%) |
| PPO | Pure Plant Oil |
| PROALCOOL | National Alcohol Program of Brazil |
| PSA | Pressure Swing Adsorption |
| R&D | Research and Development |
| RDF | Refuse Derived Fuel |
| REDD | Reduced Emissions from Deforestation and Degradation in developing countries |
| RS | Indian Rupee |
| RSB | Roundtable on Sustainable Biofuels |
| RSPO | Roundtable on Sustainable Palm Oil |
| RTFO | Renewable Transport Fuel Obligation |
| RTRS | Round Table on Responsible Soy |
| SNV | SNV Netherlands Development Organisation |
| TANESCO | Tanzania Electric Supply Company |
| TANWAT | Tanganyika Wattle Company |
| tonne | 1000 kg |
| UASB reactor | Upstream Anaerobic Sludge Bed reactor |
| UNDP | United Nations Development Programme |
| UNFCCC | United Nations Framework Convention on Climate Change |
| UNIDO | United Nations Industrial Development Organization |
| US$ | United States Dollar |
| VCS | Voluntary Carbon Standard |
| VER | Verified or Voluntary Emission Reduction (representing 1 tonne $CO_2$-equivalent) |
| Vol. % | Volume percentage |
| WTO | World Trade Organization |
| WWF | WWF-World Wide Fund For Nature |

# 1 INTRODUCTION

To be written by UNIDO.

# 2 JATROPHA

## 2.1 Introduction

This chapter focuses on different aspects of jatropha oil, a inedible vegetable oil that currently receives much attention as a biofuel. Recent years have seen large and growing investments in jatropha production worldwide. However, recent experiences with jatropha cultivation indicate that some of the plant's attributes seem to have been overestimated.

***Box 1: Some key facts on Jatropha curcas L. [1-4]***

*Jatropha curcas L.* (physic nut) is a tall shrub or small tree bearing oil containing seeds that grows in tropical and subtropical areas. It has a straight trunk with a greyish bark, and green leaves.

Plants from seedlings develop one tap root and four lateral roots. Plant maturity is reached in about 3-4 years, at which a height of several metres can be reached. Indications of plant life range from 20 to more than 50 years.

Jatropha bears fruits that generally contain 2-4 seeds each. The seeds have a ligneous hull that comprises about one-third of the seed mass. The seed kernel contains mainly fatty acids (55-60%) and proteins. Typical seed weight is about 750 g per 1000 seeds; typical oil content is generally in the range of 35-40%.

Jatropha is native to tropical America; it has most likely been distributed to Africa and Asia by Portugese ships. Nowadays it is grown in (sub)tropical areas all over the world.

Jatropha grows on marginal lands, and can withstand long periods of draught. However, it requires at least 600 mm of annual rainfall to produce fruits. Due to its toxicity it is not subject to animal browsing.

## 2.2 The background of jatropha attention

The strong attention for jatropha originates from the fast growing demand for biomass fuels in recent years. As a result of the internationally recognised climate change problem, the use of vegetable oils for the production of renewable energy has been increasing since the early 2000s. Examples are the use of vegetable oils (rapeseed, palm, soy, sunflower) for the production of biodiesel or for co-combustion in power plants in Europe. Particularly the introduction of the EU Biofuels Directive has led to a great interest from the European biofuels industry.

At the same time, concerns started to grow on national and international levels about the social and environmental sustainability of large-scale use of vegetable oils for energy production. It was observed that in some cases, tropical forests were being destroyed in order to make way for palm oil plantations in Southeast Asia. The growing demand for raw materials for the biofuel industry has been pointed out by many as the main culprit for the worldwide food price hikes in 2007. While the energetic use of most vegetable oils of tropical origin was heavily criticised for its effects on local communities and the environment, the use of oil crops grown in temperate climates was increasingly criticised for its limited greenhouse gas reduction potential.

Within the context of this discussion, jatropha emerged as an alternative, highly sustainable oil crop that was not subject to the "food versus fuel" dilemma. The main arguments to support this are the following:

- Jatropha oil is toxic, and is thus not used for human consumption. As such, its use for biofuel production does not compete with food.
- Jatropha is generally considered to grow on marginal land that is unfit for the cultivation of food crops.

However, closer investigation shows that these claims are not convincing. If a crop, edible or not, is grown on *land* for food production and used for energy, it competes with food production. Furthermore, commercial jatropha cultivation does not only take place on marginal land, as further elaborated on in section 2.5.

**Figure 2-1** *Jatropha Curcas L.*, plant and fruit[1]

## 2.3 Experience with growing jatropha

Originally, the main use of jatropha is as a living fence. Because of its toxicity, the plants are not subject to animal browsing. Parts of the plant and the oil have been used in traditional medicine. Jatropha oil has been used for the production of soap, but also as an energy source for lighting, and to a limited extent for small scale power production in rural areas.

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[1] Source: http://upload.wikimedia.org/wikipedia/commons/6/61/Jatropha_curcas.jpg and http://lh3.ggpht.com/_B7DxeMTrxh0/Rm6H34TNvMI/AAAAAAAABhQ/u_A-cIDkbac/D:%5CPicture07%5CSiam+cement+and+the+backyard%5C(M)+Jatropha+fruits.jpg

Today, the worldwide area under jatropha cultivation is estimated at about 0.9 to 1 million ha [5]. About 85% of this area is in Asia (particularly India), followed by Africa (13%) and Latin America (2%). It is expected that the cultivated area will grow to 5 million ha in 2010 to 13 million ha in 2015. At present, about 80% of jatropha is grown on small plots (<5 ha). Jatropha schemes on large-scale plantations (>1000 ha) represent less than 10% of the total.

Despite the fact that large areas have been cultivated in recent years, experts also indicate that substantial numbers of plots that were planted with jatropha have already been abandoned.

Typical growing systems are plantations and outgrowers. In many jatropha schemes, combinations of the two systems are applied.

***Outgrowers***

In the outgrower system, small farmers cultivate jatropha on their own land. Planting, maintenance and harvesting are done by the farmers themselves, often supported by dedicated organisations. In most cases, the farmer combines the production of the oil seeds with that of his food crops, where both crops are grown next to each other on the same cultivated land (share cropping). The farmers supply the harvested seeds to an entrepreneur, who processes the seeds into oil. An example of such a system is Diligent Energy Systems in Tanzania.

The outgrower system has several advantages and disadvantages:

- Specific advantages of the outgrower system are lower initial investment costs, absence of land ownership conflicts, and the potential for growth. Furthermore, it generates income for farmers and is a measure against soil erosion.
- A main disadvantage is the lack of income for the farmer during the initial 1-2 years of the jatropha cultivation, against the labour that is demanded for maintenance. This may result in neglect or abandonment of the crop.

Today, about one quarter of all jatropha schemes concern outgrower schemes. In most other schemes, outgrowers are involved in combination with plantations.

***Plantations***

The growing demand for vegetable oil, and the need to reduce production costs, lead to a rapidly increasing production scale, that is: growing jatropha on plantations. On plantations, thousands (sometimes tens of thousands) of hectares are planted. Typical plant density is about 2000-2500 plants per ha.

- Advantages of plantation schemes are a large production scale, allowing for the establishment of a dedicated organisation and more control over management, operation and maintenance (including irrigation and fertiliser application).
- Disadvantages are the high level of investments, in combination with the long time before the first yield. In addition, great care must be taken with respect to social issues (land ownership, social structure, displacement of people), biodiversity and environmental problems.

- A further disadvantage from an economic point of view is that presently jatropha can be harvested only manually.

Plantation schemes are seen on all continents, albeit often in combination with smallholder systems.

## 2.4 Applications

The jatropha oil is present in the jatropha seed kernel. After harvesting, the hulls of the seeds are removed in a dehulling step. The kernels are (mechanically) pressed, and the resulting oil is filtered. Typically, 75-85% of the available oil is extracted. Both the oil and the by-products (press cake and hull) can be used for energy production or further processing.

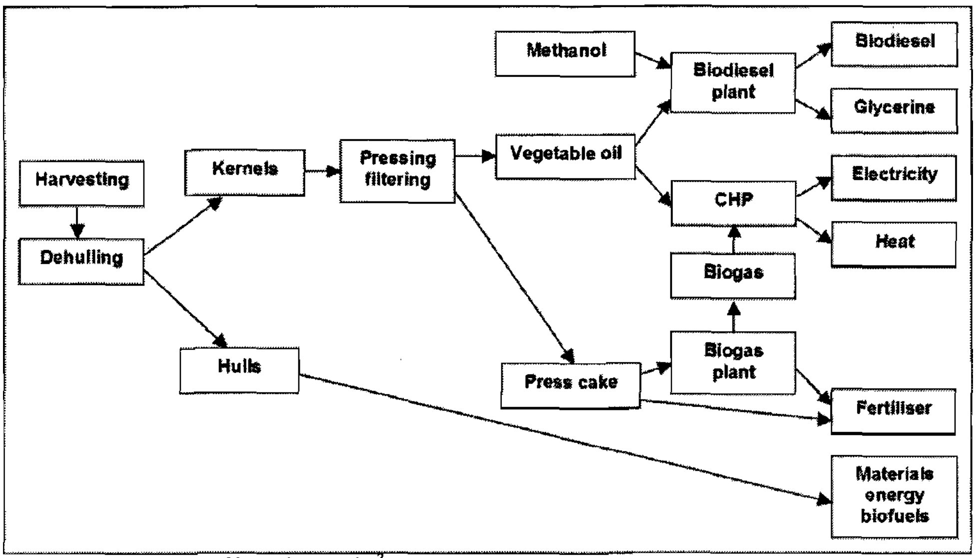

**Figure 2-2** Application of jatropha seeds.[2]

***Biodiesel production***

Although vegetable oils can be used as automotive fuels in their pure form, their use does require some serious engine modifications. Alternatively, the oil can be used for biodiesel production. Biodiesel can be used directly in most (modern) diesel engines[3], either in its pure form or blended with fossil diesel. It is produced through the process of transesterification, which is a reaction between an oil or fat (90%) with methanol (10%). The reaction products are biodiesel (90%) and glycerine (10%).

Biodiesel can be produced from a range of vegetable and animal oils and fats. However, the quality of the biodiesel largely depends on the attributes of the raw material. Fuel stability, ignition behaviour, smoothness of combustion and (in colder climates) winter

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[2] Source: made by BTG for the purpose of this publication.

[3] Some (plastic) parts in the engine fuel system can be degraded by biodiesel over time. However, in response to the upcoming biodiesel market, today most manufacturers are using resistant materials.

operability are important fuel characteristics that are dependent on the composition of the oil. There is no single oil that scores perfectly on all attributes, but jatropha comes close to an ideal raw material [6].

***Box 2: Jatropha oil attributes***

Jatropha oil is a vegetable oil that is, due to its toxicity, unfit for human or animal consumption. It is mainly composed of palmitic, stearic, oleic and linoleic fatty acids [7]. Specific physical attributes:

Viscosity (at 25 °C): 50 cS
Density: 913.6 $kg/m^3$
Saponification Number: 192
Iodine Value: 97

***Electricity production***

Like many vegetable oils, jatropha oil can be used directly for the generation of electricity in (modified) diesel engine – generator sets.

- Since the early 2000s, the use of vegetable oils for the production of combined heat and power (CHP) has increased steadily in Europe. Particularly in the last 2-3 years, many engine plants running on rapeseed and palm oil have been commissioned in for instance Germany, Italy and Belgium. Plant sizes range from below 100 kWe to several dozens of MWe. Also, the use of jatropha is anticipated: a 9 MWe CHP plant on jatropha oil is now under construction in Belgium.
- In developing countries, the interest in using vegetable oils (particularly locally produced jatropha) for the production of electricity and mechanical power is growing, for example for rural applications. A recent example is FACT Fuels, which has installed several generator sets in combination with their jatropha cultivation scheme in Mali. A further example is Winrock India, which installed several electricity generator sets running on jatropha oil for electrifying remote villages in Chhattisgarh[4].
- In a wider international context, application of vegetable oils in UNDP's Multifunctional Platform (MFP) Programme is a possibility.

***Use as a cooking fuel***

Experiments with the use of vegetable oils as cooking fuels have led to the development of several types of cook stoves. An example of a modern, efficient stove is the Protos Plant Oil Cooker of B/S/H [8]. This cooker was developed in recent years for application in developing countries. At present, it is being marketed in a number of countries in Asia.

***Use of residues***

Finding applications for the valorisation of by-products of jatropha production is seen as one of the major challenges to improve the economics of jatropha growing.

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[4] See http://www.winrockindia.org/act_proj_ene_prom_bio_1.htm.

- The jatropha press cake that is left after oil pressing has so far been seen as a fertiliser to be returned to the soil. It contains mainly proteins but due to its toxicity it cannot be used as animal feed. Experiments with detoxification, and breeding of non-toxic varieties, are ongoing.
- Recent experiments with press cake indicate that it can be used for the production of biogas, through anaerobic digestion. The biogas can be used for energy production; the digester effluent, which still contains all the nutrients in the press cake, can be applied as a fertiliser on the land. First studies by FACT show good economic results.
- Jatropha seed hulls constitute about one third of the seed weight. Experimental work in the Netherlands show that hull can be used as raw material for fibreboard production, wood-plastics composites or as a feedstock for the production of bioenergy of biofuels [9].

## 2.5 Claims

At the basis of the large interest in jatropha lie a number of claims that now appear to have been based on misinterpretation or absence of information.

***Growth on marginal land***

Up to the present, it was generally conceived that jatropha thrives on marginal soils that are unsuitable for food production. As stated above, this is one of the main arguments why jatropha cultivation does not compete with food production. However, experiences in recent years have shown that although jatropha may be grown on such grounds, yields could be very low if no fertilisation and irrigation is applied. On the other hand, jatropha has been successfully used for reclaiming marginal soils in semi-arid regions, resulting in improved soil structure, recycling of nutrients from deeper soil layers, and providing shadow to the soil.

Connected to growth on marginal land are the assumed low nutrient requirements. Like all plants, jatropha needs certain key nutrients (nitrogen, potassium, phosphor) in order to develop its system of leaves, stem, roots and fruits, and limitations in soil fertility hampers plant growth. Several experiments have shown a strong effect of nutrients on plant growth and seed yield.

***Low water requirements***

Jatropha's tolerance for longer periods of draught have led to the conception that it requires little water. However, at least 600 mm/year of precipitation is required for jatropha to bear fruit. In many regions irrigation may be needed to guarantee sufficient water for economical jatropha production.

***Oil yields***

In the absence of concrete experiences with large-scale jatropha growing, estimated per hectare oil yields of jatropha have often been far too optimistic. The main reason is "the incorrect combination of unrelated observations, often based on measurements of singular and elderly *Jatropha curcas* trees" [4]. Seed yields of up to 12 tonnes/ha have been reported, without mention of the specific circumstances. On the other hand, the data that are presently available are from immature stands, and therefore cannot be used directly for yield projections of mature trees.

A theoretical approach to seed and oil yield indicates seed yields in the range of 1.5 to 7.8 tonnes/ha, depending on crop growth conditions such as water, nutrients and the absence of plagues and diseases. Accounting for seed oil contents (35%) and oil extraction efficiency, oil yields would be in the range of 0.4 to 2 tonnes/ha.

***Resistance to pests and diseases***
Early reports on the resistance of jatropha to pests and diseases have often been projected on jatropha in general [4]. However, these reports have mostly been based on observations of singular and solitary trees, and thus do not apply generally to jatropha grown on plantations. Recent experiences with jatropha do indicate susceptibility to a range of pests and diseases.

## 2.6 Economic performance

Despite the increasing body of knowledge and experience, and the improved availability of information, the economic of jatropha cultivation and use remains unclear today. The difficulties in predicting seed and oil yields of mature jatropha stands, along with the uncertainty of input requirements, the high labour intensity of jatropha cultivation and the limited possibilities of using by-products make it difficult to predict production costs.

However, the following (fragmented) indications can be given:

- Indications of production costs of biodiesel by FACT Foundation are just over 1,000 US$ per tonne (145 US$/barrel) of jatropha based biodiesel [10]. The feasibility depends heavily on the actual market price of biodiesel. At a crude oil price level of about 100 US$/barrel, jatropha biodiesel starts to become competitive with fossil diesel.
- In Mali, the jatropha based electricity generation is more expensive than the current electricity tariff that is allowed. However, it is more competitive than using diesel [10].
- The Indian Government offers a guaranteed price for jatropha seeds of 10 RS/kg (approx 0.20 US$/kg) [11].
- In India, cultivation of jatropha on good soils was reported to be uneconomical in comparison to for example corn [11].

In the future, much will depend on the development of the oil market, and the worldwide demand for vegetable oils for the production of energy and biofuels.

# 3 BIOMETHANE

## 3.1 Introduction

The production and use of biogas is becoming more and more widespread in countries across the globe. In the EU for example, total biogas production was equal to 5.35 Mtoe in 2006 [12]. Other examples include China (750 large and 7.5 million household digesters) and India (3 million household digesters) [13]. All kinds of agricultural waste, municipal solid waste (landfill gas) and wastewater, as long as these contain organics, can be processed biologically so that a combustible gas (biogas), containing methane ($CH_4$), carbon dioxide ($CO_2$) and some impurities, is generated.

Most often the biogas produced is combusted on-site in a gas engine or boiler to generate heat and/or electricity. However, the upgrading of biogas to **biomethane** (a gas consisting of mainly methane, comparable to natural gas) combined with feed in a natural gas grid and/or use as fuel, is recently gaining ground.

## 3.2 Biomethane production and upgrading

Production of biogas can originate from a variety of sources:

- **Landfills** containing organic waste generate biogas during a number of years. This landfill gas can be extracted, collected and used as biogas.
- Municipal or industrial **wastewater** often contains organic constituents that can be converted through anaerobic digestion to form biogas. The main goal is often wastewater purification, but the utilisation of the biogas can help to reduce costs.
- **Manure**, in combination with **agricultural residues**, dedicated **energy crops** and **waste from the food and drinks industry** can be digested in purpose-built biogas plants, also called digesters, to yield biogas (see Figure 3-1 for an example).

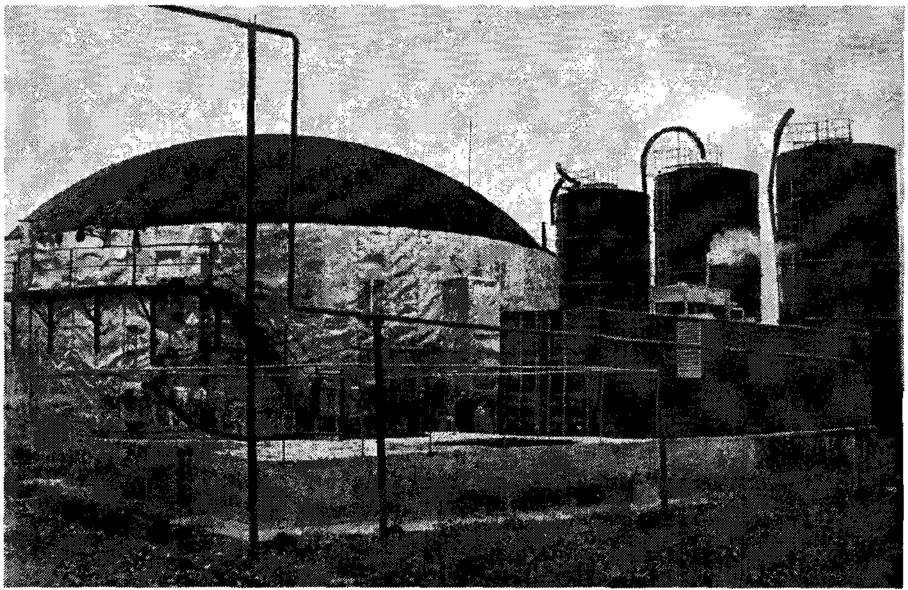

**Figure 3-1** Cow manure digester in Moldova. Source: BTG.

Production of biogas through anaerobic digestion of energy crops is an interesting application, since it allows the use of the entire crop, and not just part of it as in other technologies, such as ethanol production. This allows for a high energy yield per hectare. Energy crops are already used on a large scale for biogas production in Germany, where maize is an important feedstock for many digesters. Besides maize, also grain, sugar beet, and all kinds of other crops can be used for biogas production.

To convert the biogas to biomethane, upgrading is necessary. The composition of the biomethane is prescribed by its application, usually feed in the natural gas grid. A typical composition of biogas and natural gas (North Sea natural gas) is shown in table 3-1. The large variation in biogas composition is caused by the very diverse sources and substrates from which biogas is produced. Table 3-1 shows that removal of $CO_2$, $N_2$ (sometimes), $H_2S$ and $O_2$ is necessary to obtain biomethane that is similar to natural gas. In this framework the Wobbe index is also used. Gases with the same Wobbe index show the same behaviour when combusted.

**Table 3-1** Comparing typical biogas and natural gas compositions [14]

| Component | Biogas | Natural gas | Unit |
|---|---|---|---|
| Methane ($CH_4$) | 35 - 70 | 87 | Vol. % |
| Wobbe index | 18 - 27 | 55 | MJ/Nm$^3$ |
| Carbon dioxide ($CO_2$) | 15 - 47 | 1.2 | Vol. % |
| Nitrogen ($N_2$) | 0 - 40 | 0.3 | Vol. % |
| Hydrogen sulphide ($H_2S$) | 0 – 10,000 | 1-2 | ppm |
| Oxygen ($O_2$) | 0-5 | 0 | Vol. % |

Besides removing these components, it is also necessary to remove traces of moisture, particulates, ammonia and siloxanes. Siloxanes are organics containing silicon, oxygen and hydrogen or hydrocarbon groups that can lead to $SiO_2$, which can cause wear and erosion on downstream equipment. Oxygen and nitrogen, if present in large quantities, can be a serious problem. Oxygen and nitrogen can be present when air is mixed with the biogas, as in landfill gas extraction, when air intake cannot be avoided [15].

With the exception of $CO_2$, removal of all other components can be carried out without too high costs. Moisture and $H_2S$ for example, are also removed in the case of direct conversion of the biogas in a gas engine. Several proven and relatively low cost techniques exist for the removal of both components.

The removal of $CO_2$ is the most critical and costly part for biogas upgrading. Several technologies are available, each with their own characteristics:

- **Pressure Swing Adsorption (PSA)** involves the adsorption of $CO_2$ under pressure on an adsorbent (such as a zeolite). By reducing the pressure again, and applying a light vacuum, desorption (removal of the adsorbed $CO_2$) can take place.
- **Membrane separation** makes use of the fact that $CO_2$ (and also some of the $H_2S$) permeates through a membrane while $CH_4$ is stopped. Membrane separation can operate in a gas/gas, or a gas/liquid environment.
- For **absorption** of $CO_2$ in water or an organic solvent, biogas is fed into the bottom of a column where it meets the water or a solvent. Because $CO_2$ (and $H_2S$) is more

soluble in water than in methane, the $CO_2$ is absorbed in the liquid phase. After regeneration, the liquid can be re-used. Besides physical absorption, chemical absorption with amines is also possible. Here the $CO_2$ is separated through a chemical reaction with the amines.

- **Cryogenic separation** is an interesting, not yet mature, technology that makes use of the fact that $CO_2$ has a higher boiling point than $CH_4$ at atmospheric pressure. Through cooling of the gas, pure $CO_2$ can be removed, as well as nitrogen, which has an even lower boiling point than $CH_4$.

Cryogenic separation has not been implemented on a large scale. PSA, absorption and membrane separation are all commercially proven. Worldwide, at least 50 operational plants utilise one of these technologies in commercial applications. Although each technology has its own advantages and drawbacks, operational experience is generally good, and most plants operate a number of years already without serious problems.

The biogas upgrading costs are very much dependent on the scale of the upgrading plant. For small plants (< 100 $m^3$/hour) upgrading costs are between 3 and 4 Euroct/kWh. Upgrading plants in the range of 200 – 300 $m^3$/hour show costs of 1 – 1.6 Euroct/kWh [16, 17].

1 – 1.6 Euroct/kWh is equivalent to a price of 2.8 to 4.4 Euro/GJ. Compared to a current market price of natural gas of 5.8 Euro/GJ[5] (situation end 2008), upgrading costs are high.

## 3.3 Biomethane application

There are two main applications for biomethane:

- Feed in a natural gas grid;
- Use of biomethane in vehicles.

These applications are assessed in the next sections. Furthermore, the considerations for the choice between direct use of biogas and upgrading to biomethane are presented.

### 3.3.1 Feed in a natural gas grid

This is the application mostly used for biomethane. The reason is that a gas grid can provide a feed point nearby the biogas production site, so 100% of the demand is guaranteed. Feed in the natural gas grid currently takes place in Switzerland, Germany, and to a limited extend the Netherlands.

The obvious advantage of feed in the gas grid is that users in densely populated areas can use biomethane, albeit mixed up with regular natural gas. Natural gas is a clean burning fuel with low emissions, which can be utilised efficiently in low-costs conversion equipment (like boilers, turbines, gas engines, etc.) available at practically any scale.

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[5] http://www.endex.nl

***Box 3: Feed in a gas grid versus direct use: What is most energy efficient?***

Calculations to determine this have been made by Welink et al. [18]. Results are summarised in the next table:

| Biogas amount | Technology | Useful energy | Natural gas replaced |
|---|---|---|---|
| 1 MJ | Biomethane | 0.75 - 0.91 MJ | 0.75 - 0.91 MJ |
| 1 MJ | Combined heat and power | 0.38 MJe + 0.5 MJth | 1.24 MJ |
| 1 MJ | Heat-only in a boiler | 0.9 MJth | 1 MJ |
| 1 MJ | Electricity-only in a gas engine | 0.38 MJe | 0.69 MJ |

This table is understood as follows: suppose 1 MJ of biogas is combusted in a combined heat and power system (option 2). Electric efficiency is about 38%, thermal efficiency is 50%, hence 0.38 MJ of electrical energy and 0.50 MJ of thermal energy is generated. If that amount is to be generated through natural gas, the thermal energy would be generated in a normal boiler (90% efficiency, 0.5/0.9 MJ = 0.55 MJ of natural gas needed) and electrical energy would be generated in a natural gas fuelled power station (55% efficiency, 0.38/0.55 MJ = 0.69 MJ of natural gas needed). Therefore, in total 1.24 MJ (0.55+0.69 MJ) of natural gas would be needed to produce the same amount of heat and power that is produced by 1 MJ of biogas; hence in case of combined heat and power each MJ of biogas replaces 1.24 MJ of natural gas.

This table shows that, on the assumptions made above, feed of biomethane in the gas grid (option 1) is better than combustion in a gas engine for electricity-only production (option 4). However, it is not as energy-efficient compared to applications where the heat is also used (option 2) or when only the heat is used (option 3).

This conclusion appears not to favour feed in the gas grid. However, it should be noted that for landfill and stand-alone digestion projects, the heat is seldom used. Therefore, in most cases, feed in the gas grid is more energy efficient.

There are several barriers towards feed in natural gas grids. “Odorisation”, adding a distinct smell to the biomethane, is often required. Standards for feed-in have to be met. Also the feed-in point may be a problem. Local gas grids (especially the low pressure sections) may not have the capacity to allow for large feed loads of biomethane. It is also reported that gas grid operators are not keen on feed-in of biomethane. These operators are used to dealing with ‘single-source’, large-scale suppliers. Biomethane involves ‘multi-source’, small-scale suppliers, which require a different approach.

### 3.3.2 Use of biomethane in vehicles

This is a very interesting niche-application for biomethane. It is closely linked to the use of natural (fossil) gas in vehicles.

Use of **natural gas** in vehicles is already quite common. Natural gas is a much-used vehicle fuel in several countries, such as Pakistan (58.7% of all cars, trucks and buses), Iran (75.0%), and Argentina (22.5%). In 2008, about 9.1 million vehicles used natural gas as a fuel, an increase with respect to 4 million in 2004 [19]. Natural gas (or Compressed Natural Gas, CNG) vehicles are now available from over 40 manufacturers [20]. A few examples are the Fiat Multipla, Opel Zafira, Ford Focus CNG, and the Honda Civic. Most vehicles are bi-fuel, meaning that they can use CNG as well as gasoline. Diesel engines can be converted to operate with CNG in dual-fuel mode. However, diesel is still needed, limiting the emission reduction potential. The costs of CNG vehicles are higher than conventionally fuelled vehicles. Extra costs, when compared to standard petrol powered cars, are comparable to the extra costs for diesel engines, roughly 2,000 - 5,000 Euro [19].

Advantages of natural gas use in vehicles are lower emissions of $NO_x$, particulates and CO for example. Compared to diesel; reductions of more than 50% ($NO_x$) and even 85% (particulates and CO) have been measured [21]. This is very important for large cities, where air pollution is a serious issue. $CO_2$ emissions are also lower, because of the low carbon content of natural gas. Drawbacks are the lower attainable mileage because CNG storage requires bulky, pressurised tanks, and the filling process is somewhat slower.

**Biomethane** in vehicles is comparable to using natural gas in a vehicle. Apart from the above-mentioned low pollution, biomethane has the added advantage that it is a renewable energy form.

Especially in Sweden, biomethane in vehicles has been stimulated because of a number of specific reasons:

- There is barely any natural gas grid so that feed-in is hardly an option.
- The electricity production in Sweden is mainly carried out through large-scale hydropower, meaning low electricity prices.
- Sweden wants to become an oil-free nation in 2020, which implies for instance the phasing-out of gasoline and diesel.

About 7,000 vehicles operate on biomethane and natural gas in Sweden. About 15 plants supply biomethane for vehicle use [14]. Many Swedish cities promote the use of biomethane in vehicles with a mix of conventional and new measures such as:

- Free parking;
- Lower tax on biogas vehicles;
- Exemption from city gate tolls;
- Financial support for investment in biogas vehicles;
- Reduction of company taxes by 40% when staff chooses gas vehicles.

About 14 local fleets in Sweden operate on biomethane. Evaluation of one such project in the framework of the EU funded Trendsetter project, where 21 busses and 3 refuse collection vehicles were converted to biomethane, showed good results, but also some drawbacks:

- $CO_2$, $NO_x$ and CO emissions were reduced, but hydrocarbon emissions increased;
- Maintenance costs and fuel consumption increased.

Besides passenger cars, trucks and buses, biomethane is also used for indoor vehicles, because of the low air pollution. Examples are forklift trucks, ice-cleaning machines and even racing cars.

As mentioned earlier, biogas - and thus biomethane - can be produced from energy crops. When the energy yield of biomethane from energy crops is compared to **other renewable transport fuels** from energy crops, biomethane is a very good fuel to use in vehicles. In the next table, the average mileage of a passenger car fuelled by various biofuels, each produced by 1 hectare of energy crops, is shown:

**Table 3-2 Comparison of various biofuels yields**

| Biofuel type | Passenger car mileage on one hectare arable land (km) |
|---|---|
| Biomethane | 67,600 |
| Biomass-to-Liquids | 64,000 |
| Rapeseed oil | 23,300 |
| Biodiesel | 23,300 |
| Bio-ethanol | 22,400 |

Source: www.nachwachsende-rohstoffe.de.

This table shows that biomethane yield is comparable to Biomass-to-Liquid (BtL) fuel. BtL is a common name for technologies that use thermal techniques (e.g. gasification) to produce synthetic biofuels. These technologies are still in the demo-phase. Biomethane yields are not only far higher than the other biofuels, it can even enhance their yield, by digestion of the residues from rapeseed oil, and other crops. Main reason that yields for biomethane are so high is that the entire plant - and not just part of it - can be utilised.

Besides this yield advantage, biomethane (and BtL) has the advantage that it can be produced from waste material, or as a by-product. This way, sustainability issues are avoided.

### 3.3.3 Direct use or upgrading of biogas

When biogas is produced by a digester or through wastewater treatment, the biogas can be used directly, or can be upgraded. The choice between these options depends on a number of aspects:

*Availability of a natural gas grid.* If there is no natural gas grid close by, possibilities are severely limited. Biogas is normally produced away from industrial or residential area's, where most of the potential applications of biomethane are located. Transport of the biomethane through a natural gas grid is therefore often essential.

*Complexity and scale of the technology.* While proven, the technology required for upgrading is advanced and technical skills and training in operating a chemical facility is needed. Biomethane feed-in furthermore requires the co-operation of more parties (e.g. grid operators) than when biogas is used stand-alone. Lastly, small-scale biomethane applications are prohibitively expensive, so biogas upgrading will probably only be used in larger biogas plants. Direct use of biogas is simple and proven, requires limited infrastructure and can be used for small-scale applications.

*Economics.* As shown earlier, upgrading of biogas significantly adds to the costs of the energy. This means that the technology may only be economically advantageous if direct use is not possible (e.g. because there is no local demand), or when use of biomethane is subsidised and/or shows a high added value, as in the case of use as vehicle fuel.

## 3.4 Biomethane use and potential in developing countries

Biomethane production and use has thus far been limited (mainly) to a small number of European countries. Production of biogas in developing countries takes place on a significant scale, but upgrading of biomethane has been very limited. One exception has been the project of the Indian Institute of Technology [22]. This involves the small scale upgrading of biogas, and bottling the biomethane for use in vehicles.

The low uptake in developing countries can most likely be attributed to the high costs of biomethane, the relative large scale required, the complexity of the projects and the need of a natural gas grid infrastructure. The cost barrier towards upgrading biogas to biomethane is still significant as was shown earlier, and may constrain further implementation of the technology, also in the developed world.

This does not mean that there are no opportunities. A precondition is an existing natural gas grid such as is present in (parts of) China, India, Thailand, Argentine, Brazil and Peru. The gas infrastructure is improving in these and other countries, because of the favourable conditions for natural gas in these local markets. The economic barriers towards further use of biomethane could partly be overcome because biogas production in some cases (for example landfills) decrease methane emissions, making such projects eligible for CDM credits.

Lastly, biomethane could benefit from the general push to reduce methane emissions from other sources besides agriculture and landfills, namely the oil and gas industry and the mining industry. The international methane-to-markets partnership[6] already sees it as its task to increase methane utilisation from all these sources.

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[6] http://www.methanetomarkets.org

# 4 ENERGY FROM MUNICIPAL SOLID WASTE

## 4.1 Introduction

At present, there is much interest in energy production from Municipal Solid Waste (MSW). MSW is the waste that is produced in households. It generally comprises a mixture of organic matter (food wastes), plastics, paper, glass, metal and other inert parts. It can also include some commercial and industrial waste that is similar in nature to household waste.

MSW is primarily considered a liability. It needs to be collected and processed, which comes at a certain cost. If managed improperly, it can cause severe human health problems and harm the environment. However, MSW also represents an opportunity, for example for recycling and re-use of materials in the waste stream, and for the production of energy.

Energy from MSW is often seen as a great opportunity for developing countries to produce energy from a cheap and readily available resource. However, it also raises a few questions:

- Can MSW be classified as biomass?
- Is energy produced from MSW renewable?
- Can MSW offer a significant contribution to the energy supply of developing countries?

***Box 4: Some key facts on MSW***

- World MSW production is estimated at 2 billion tonnes per year [23].
- MSW production per capita is approximately 0.5 kg/day in developing countries, against 1.6 kg/day in industrialised countries [24].
- The energy potential of MSW depends on its composition and processing technique. MSW incineration in industrialised countries results in both 400-600 kWhe of electricity per tonne of waste [25] and at least as much heat [26]. Electricity produced from landfill gas (LFG) extracted from a well-designed and operated landfill can be up to about 200 kWh per tonne – albeit over a long period of time (15-25 years) [27].
- Compared to industrialised countries, MSW in developing countries contains more food and inert materials, and less paper and recyclables. Its moisture content is higher and its calorific value is lower [28].

## 4.2 Energy generation from MSW

In general, the processing of MSW is primarily intended to dispose of the waste and/or reduce its volume. Common techniques are landfilling and incineration. Energy recuperation can be an important part of the process, particularly in industrialised countries. There are several ways in which the energy recuperation can take place.

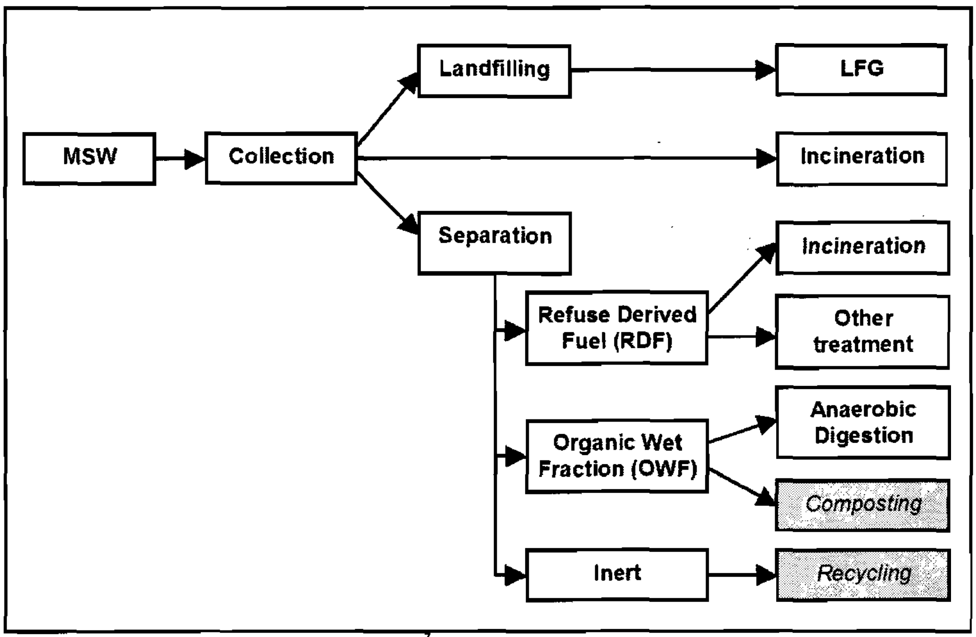

**Figure 4-1** Different MSW processing options.[7]

***Landfilling with landfill gas (LFG) recovery***

When MSW is landfilled, the organic components start decomposing in an anaerobic digestion process. This process results in the formation of landfill gas, which consists primarily of methane and $CO_2$. The landfill gas can be extracted from the landfill using a system of pipes, and can then be used for energy generation in gas engines, turbines or boilers.

The rate of decomposition in an ordinary landfill is low: it takes decades before the organic material is fully digested. Gas production will initially increase, but after having peaked (after about 10 years) it slowly decreases. After 20-30 years, gas production may drop to less than half of the peak amount, making it less economical to use for energy generation.

The main advantages of landfilling are low investment and operational costs. Initial investments in a landfill of 500 tonnes/day are in the order of 5-10 million US$, and costs for operation and maintenance of a landfill are approximately 10-20 US$ per tonne of MSW [24]. These costs are limited in comparison to the cost of collection and transfer of MSW; in developing countries these costs amount to around 30-50 US$ per tonne [28].

On the other hand, improperly designed or operated landfills may cause severe risks to human health and to the environment, for example through ground water contamination or greenhouse gas emissions from landfills. This is the case in most developing countries, where MSW is often dumped rather than landfilled.

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[7] Source: made by BTG for the purpose of this publication.

### *Incineration*

Raw MSW consists for a large part of food residues, paper and plastics. Its energy content depends on the actual composition, but in general it will be between 8-12 GJ/tonne (comparable to fresh wood). In most industrialised countries it is incinerated in Waste-to-Energy installations in which the energy is turned into electricity and also heat, which can be used for district heating, process heat for industry, or production of cooling. The total energy recuperation rate may be relatively high.

Another advantage of incineration as a processing means is that it results in a large waste volume reduction (80-95% [29]), which greatly reduces the space required for disposal. Also, if proper emission reduction measures are taken, incineration is a clean means of waste processing.

It is, however, an expensive option, both in terms of investment costs and operational costs. Investment costs of a modern 1200 tonne per day incineration plant in Europe are in the order of 300-400 million US$, while the processing costs are about 100-150 US$/tonne - half of which are capital costs [26, 30]. The main reason is the high costs of emission control, which is required for environmental considerations.

Furthermore, incineration is only applicable when a number of overall criteria is fulfilled [29]:

- Existence of a mature and well-functioning waste collection and management system for a number of years.
- A minimum and stable supply of combustible waste (at least 50,000 tons/year).
- A minimum average lower calorific value (at least 7 MJ/kg, never below 6 MJ/kg).
- The community is willing to absorb the increased treatment cost.
- Skilled staff can be recruited and maintained.
- Solid waste disposal at controlled and well-operated landfills.
- A stable planning environment of the community (planning horizon at least 15 years).

All in all, the applicability of incineration in developing countries is limited. Experiences with waste incinerators that were built in developing countries have not met great success. For example, most World Bank supported incineration projects were closed as the local wastes did not have sufficient calorific value to sustain combustion without adding additional fuels [28].

### *Separation*

MSW is increasingly separated into different fractions using a series of washing and sieving steps. Part of the waste (e.g. metals) can then be recycled, while other fractions can be used for energy generation. The latter consist particularly of Refuse Derived Fuel (RDF), a mixture of relatively high calorific components (paper, wood, plastics) which can be incinerated in Waste-to-Energy installations or upgraded to secondary fuel, and the Organic Wet Fraction (OWF) from the MSW, which can be used for biogas production [31].

Investments and processing costs are moderate. The investment costs for a modern 1200 tonne per day separation and anaerobic digestion installation are in the order of 100 million US$, and the processing costs are about 100 US$/tonne [30].

***Other processing techniques***

Other processing techniques that are in various stages of development are pyrolysis and (plasma) gasification. For MSW applications these processes have not yet been commercially proven.

## 4.3 Is MSW biomass, and is energy from MSW renewable energy?

The origin of all organic matter is carbon assimilation by plants. Plants transform $CO_2$ and water into biomass. The sun supplies the energy needed for this process. When this biomass is used for energy generation, $CO_2$ is emitted. However, this amount is exactly the same as the amount that was absorbed by the plant during its growth. Therefore, the net increase in $CO_2$ in the atmosphere related to the combustion of organic matter itself is zero. We call this the short carbon cycle, see figure 4-2. Please note that transport movements, logistics, etc. often involves the use of fossil fuels, which makes short carbon cycle processes *low* carbon rather than *zero* carbon processes.

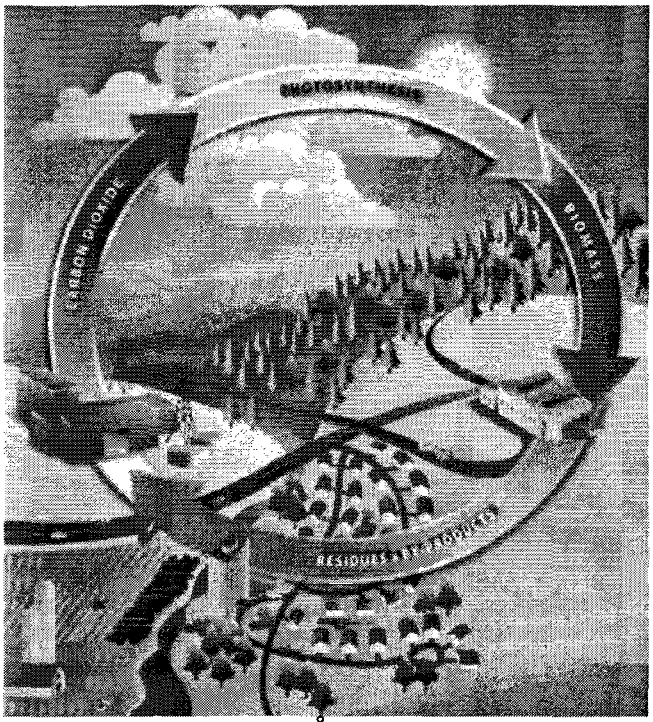

**Figure 4-2** The short carbon cycle[8]

In contrast, the long carbon cycle concerns fossilisation of organic materials over a period of millions of years, whereby coal, oil and gas are formed. When using these sources, the

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[8] Source: http://www.tegenstroom.nl/files/images/biomass%20cycle.jpg

carbon that was stored all this time is brought into the atmosphere, which does result in an increase of $CO_2$ in the atmosphere.

In order to determine to what extent the short and long carbon cycles apply to MSW, we need to look into the typical constituents of MSW:

- Part of the waste is inert (sand, metals, glas etc) and does not contribute to its energy value. Neither of the carbon cycles applies to this part.
- The parts that do contribute to the energy value are composed of a biodegradable fraction (for example food wastes, paper, wood) and a fossil fraction (plastics for example).

The short carbon cycle applies to all biodegradable organic compounds, including those in MSW (the food wastes, paper and wood for example). As such, using those compounds for energy generation does not result in increasing levels of $CO_2$ in the atmosphere and can be considered renewable. However, the fossil fraction in the MSW (plastics) is subject to the long carbon cycle. This fraction does contribute to the energy value of the waste, but this energy cannot be considered renewable.

In landfill gas capturing and use, it is precisely the biodegradable organic fraction of the waste that is transformed into gas. The energy generated is therefore fully recognised as bioenergy. In waste incineration, part of the generated energy is considered as bioenergy, for example the fraction of biodegradable organic origin (in terms of energy content).

***Box 5: MSW and Carbon Financing***

The extent to which energy recuperation from MSW can apply for CDM depends on a number of factors, for example the current practice of waste management (controlled or uncontrolled landfill), the proposed technique (LFG recuperation or incineration) and the origin of the grid electricity that is being replaced.

On December 1, 2008, a total of 102 MSW processing projects were registered with CDM, mainly LFG projects (almost 90%) and composting [32]. Less than half of these projects have an energy producing component, the others concern projects where in which methane emissions are avoided or captured and flared.

Of the registered projects, in total 26 are actually producing Certified Emission Reductions (CERs). Nearly 200 more projects more are under preparation.

### 4.4 MSW issues in developing countries

In most low- and middle-income countries, the collection, transport and processing of MSW poses large problems. Often quoted problems are the following:

- The costs of collection, transport and processing weigh heavily on municipal budgets. It is quite common that 20-40% of municipal revenues are spent on MSW management, while the majority of inhabitants remain unserved [33].

- The capacity of the MSW collection and transporting system is often inadequate. Rapid urbanization overstretches MSW collection and processing capacity. In some cases, up to 80 percent of the equipment is not operational[9].
- Weak government structures are frequently named as a major problem. Responsibilities are often shared by elected and non-elected individuals who may not be held accountable for the proper functioning of the system.

Because of the high costs, the first and foremost concern in many countries is to get the waste out of the urban areas. Further processing is of lesser importance, and in most cases the collected waste is dumped outside of the city. Often, part of the waste is burnt in uncontrolled fires. Scavenging (waste picking) is common practice, and provides a source of income for considerable groups of people.

## 4.5 The future role of MSW as biomass fuel

To what extent can MSW be considered a valuable source of renewable energy? First of all, energy from MSW can be seen as sustainable. MSW does in no way compete with food, as it does not claim land that could be used for food production. From this point of view it is an energy source that could be used to its fullest potential.

Furthermore, societies will always be producing municipal waste so its availability is reliable. However, the extent to which MSW can contribute to the energy mix is limited. The 2 billion tonnes of waste produced annually around the world could theoretically produce up to about 5% of the world's total electricity. Electricity generated from MSW constitutes less than 1% of the total electricity generated in the EU today [25, 34] although its contribution is expected to double by 2020 [26].

On the other hand, in developing countries there is very little energy recuperation from MSW so there is still large growth possible. This includes the "low hanging fruit", in other words, the projects that are relatively easy to implement, financially attractive, etc.

For developing countries, energy from MSW will concern mainly landfill gas capturing and usage, made possible by CDM funding. Recent years have shown a considerable growth in the number of landfill gas projects under CDM, although landfill gas is still mostly flared rather than used for electricity production. Besides, not all projects are successful, and gas yields are often much lower that anticipated.

It is not expected that waste incineration will play a significant role in developing countries in the foreseeable future [35]. MSW from low and middle-income societies is unfit for incineration due to its composition (little plastics and paper, high moisture content), unless the waste is separated or additional fuels are used during combustion. The higher investment and operational costs in comparison to landfilling form an additional barrier.

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[9] www.worldbank.org/solidwaste

# 5 THE BIOREFINERY CONCEPT

## 5.1 Introduction

Biorefinery is the sustainable processing of biomass into a spectrum of marketable products and energy [36]. Just as with crude oil refineries, the feedstock - biomass - is separated and refined to produce various fuels and products in a biorefinery. Biorefineries are not new. An existing example is a modern sugar factory that can fine-tune the plant to produce either more bio-ethanol or more sugar. Another example is the starch hydrolysis plant, for the production of among others glucose, which can be used for the production of many chemicals and products such as ethanol, acetic acid, etc. The biorefinery concept has been much-debated in the last few years.

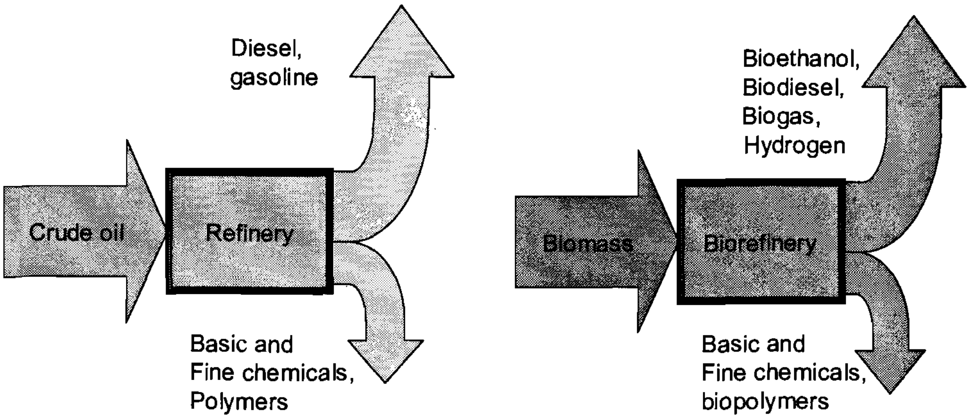


**Figure 5-1** The biorefinery concept. Instead of crude oil, biomass is upgraded and refined to produce a variety of fuels and materials. Source: Kamm et al. [36].

Fossil fuels are finite, and although supply may be guaranteed longer or shorter depending on the type of fossil fuel, their use is not sustainable. Biorefineries are expected to play an increasingly important role in the future, since they are not based on fossil fuels, but on biomass. Another reason why biorefineries receive considerable attention is that they make the best possible use of all the biomass available. For example, if only the vegetable oil part of rapeseed is used for biodiesel, nearly 95% of rapeseed plant is not used. By producing multiple products from biomass, higher yields and better economics are achieved.

In the future more and more biorefineries will dot the world's landscapes, with two key differences with crude oil refineries:

- Biorefineries will be located near the source of the biomass, because most biomass types are solids with a low volumetric density, transport and related costs are an important issue. This will also mean that biorefineries will be smaller than crude oil refineries
- There are lots of biomass types available, such as wood, sugar cane, etc. This variety in feedstock will result in lots of different biorefineries, each with their specific mix of products.

## 5.2 Typical biorefineries

Biorefineries come in all shapes and sizes and there are many classifications possible. Among others, classifications can be based on:

- Raw material input (ligno-cellulosic biomass, aquatic biomass, etc.),
- Type of technology (thermo-chemical treatment, microbial degradation, etc.),
- Status of technology (conventional vs. advanced, 1st and 2nd generation), and
- Main (intermediate) product (syngas, sugar and lignin platform).

The following general classification, presented by Kamm et al [36] is often used nowadays:

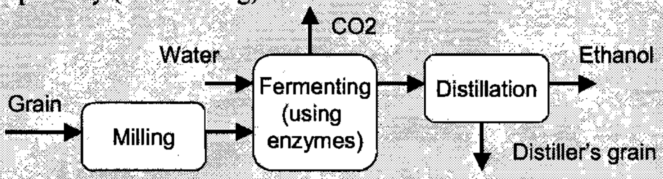
- **Conventional biorefineries** - many existing industries make use of biorefinery concepts, like for instance in the sugar, starch, vegetable oils, feed, food, pulp and paper industries and the traditional biofuel industry.
- **Green biorefineries** – where "nature wet" biomass such as green grass are converted to various products using microbial degradation.
- **The Lignocellulosic feedstock biorefinery (LCF)** - where "nature-dry" biomass, such as wood and other cellulose-containing biomass is first separated into cellulose, hemicellulose and lignin, after which further processing can take place.
- **Thermo-chemical biorefineries** - where thermo-chemical technologies are used like pyrolysis or gasification to produce an intermediary product that can be refined thermo-chemically into a portfolio of value added products. A specific type of thermo-chemical biorefineries makes use of the existing fossil oil based petrochemical infrastructure.
- **Whole crop biorefinery** - this concept uses raw materials such as cereals or maize. The straw may be utilised as in an LCF biorefinery, the seed may be converted to starch, or grinded to meal, followed by further processing.
- **Two platform biorefinery** - Here two platforms are distinguished; the sugar platform and the syngas platform. The sugar platform is based on biochemical processes, and the syngas platform is based on thermo-chemical conversion.
- **Marine biorefinery** - in which aquatic biomass (algae) are treated by cell disruption, product extraction and separation into, for instance, lipids and "algomass".

Biorefineries (for ethanol production) can also be characterised by distinguishing three types, as mentioned by van Dyne et al [37]:

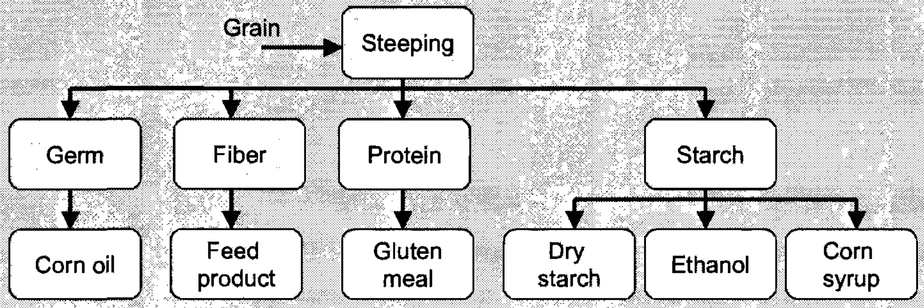
- An example of a **Type I** biorefinery is a dry-milling ethanol production plant. This plant uses grain as feedstock, which is milled and converted into ethanol and several by-products. The amount and type of by-products is fixed.
- An example of a **Type II** biorefinery is a wet-milling ethanol production plant. This plant also uses grain as feedstock. In this case, however, the production of by-products is more flexible, and can be varied depending on market conditions (see box 6).
- **Type III** advanced biorefineries use agricultural or forest biomass to produce multiple product streams, such as ethanol, chemicals and plastic. Such plants have not been built yet.

### *Box 6: Ethanol production from grain: "dry milling" versus "wet milling"*

***"Dry milling"*** ethanol production plants work by grinding the grain to flour. The flour is then fermented to produce ethanol. Ethanol is separated off, and the residue (the "sillage") is then dried to get DDGS "dried distillers grains with solubles", which is used as cattle fodder. The $CO_2$ released during fermentation is captured and sold separately (see drawing).



In the ***"Wet milling"*** process, grain is first soaked in water and sulphurous acid and 'steeped' for 1 to 2 days. It is then separated into its four basic components: starch, germ, fibre and protein. Each component can be further processed to yield products. The starch can still be converted to ethanol, but it can also be dried and sold as modified corn starch, or processed into corn syrup.



The dry milling process is now commonly used for the production of ethanol. It is cost effective, and capital expenditures are limited. Wet milling requires more investments, but the plant is more flexible, and a bigger portion of the grain is used to produce a variety of products.

## 5.3 Hot biorefinery issues

In this paragraph several issues, which have received considerable attention, will be discussed, such as production of biofuels from lignocellulosic feedstock and production of hydrogen from biomass. Besides that, criticism on the biorefinery concept will be mentioned, and the ecobalance, a tool that can play a role in determining the feasibility of (among others) biorefineries will be briefly discussed.

**Transport biofuels production from lignocellulosic feedstock,** often referred to as "second generation biofuels", are considered to have a bright future, because:

- They can be produced from non-food crops, such as wood, straw and other agricultural residues. This avoids competition with food production.

- Biomass contains typically 70% carbohydrates, which are normally not used when producing first generation biofuels. Second generation biofuels utilise the whole plant, and can thus be far more efficient, offer a better reduction of $CO_2$ emissions, and presumably better economics than first generation fuels.

These processes for the production of second generation biofuels have received considerable attention in the last few years. The production of synthetic diesel by Choren in Germany, and the production of ethanol by Iogen in Canada are prime examples.

**Choren** is now implementing an 18 million liters of diesel per year demonstration plant. In this plant, a (synthesis) gas is produced from biomass, which is subsequently chemically transformed into liquid diesel. Because this process works on heat and chemical reactions, it is considered a thermochemical route to biofuels[10]. With the production of tar-free syngas, one of the prime building blocks of a host of other chemicals is now commercialised. In the future, syngas can be used to produce methanol and ethanol, which can be used for acetic acid, acrylic acid, etc.

**Iogen** produces ethanol directly from carbohydrates using a biological route. Biomass is pre-treated to separate the cellulose from the lignin, and enzymes subsequently transform the cellulose into sugars, which can be fermented as normal to produce ethanol. Residual cellulose and lignin is to be combusted to produce electricity and heat. A demonstration plant was implemented in 2004. In 2008, Iogen supplied the first 100,000 litres of cellulose-based ethanol[11]. This plant is in fact a basic biorefinery, in which lignocellulosic biomass is separated into cellulose, hemicellulose and lignin. Further refining and upgrading takes place only for the ethanol recovery, but more products can be recovered in the future.

At the moment, first generation ethanol and biodiesel have better economics than second generation biofuels. These plants play and have played an important role in the introduction of biofuels. In nearly all cases, biofuels $CO_2$ emissions are less than fossil fuels [38]. It should however be noted that sometimes the $CO_2$ mitigation effect is very low, and that greenhouse gas balances for biofuels are still subject to research and debate. Irrespective of that, because of the competition with food and the need to increase efficiency, second generation biofuels production is set to take over the first generation biofuels.

Both the Choren and the Iogen processes are prime examples of fairly basic biorefineries, even though the processes themselves can be quite complex. If further commercialised, lots and lots of other products can be produced from either the sugars (the Iogen process) or the synthesis gas (the Choren process).

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[10] http://www.choren.com/

[11] http://www.iogen.ca/

***Hydrogen production from biomass***

Especially for transport fuels, hydrogen shows a lot of promise. During combustion in a car engine, hydrogen produces no pollutants. This will greatly decrease air pollution in cities worldwide. Hydrogen has a high energy density by weight, and application in a fuel cell could be twice as effective as an internal combustion engine. Proponents of hydrogen see a future with a very prominent role for hydrogen ("the hydrogen economy").

Practical applications of bio-based hydrogen production systems are however not market ready. Application of hydrogen in transport still poses significant technical problems. Efficiency of hydrogen transport needs to increase, hydrogen fuel tanks need to be developed, and at the moment hydrogen is produced from fossil fuels. For a truly sustainable hydrogen economy, production of hydrogen from renewable sources is necessary.

There are two routes available for the production of hydrogen from biomass: thermochemical and biological. Thermochemical routes make use of some form of pre-treatment to break the biomass down into a synthesis gas or a pyrolysis oil. These are then subjected to catalytic steam reforming to produce a hydrogen containing gas.

***Biorefinery criticism***

The development of biorefineries is also met with criticism. This criticism is mostly aimed at the production of first generation biofuels such as ethanol and biodiesel, as being too costly, unsustainable, and increasing the food prices (for example) [39]. Others point towards the destruction of high conservation value forests because of the increasing palm oil industry [40]. Second generation biofuels are seen by many as an improvement over the problems faced with the first generation biofuels.

However, also the quest for more advanced technologies is not entirely without controversy. Critics point for example to the massive amounts of cellulose material needed, which may not be harvested sustainably, the risks of erosion and degradation of soils, decreased biodiversity, food insecurity, and the displacement of marginalised people. Also the safety and predictability of genetic engineering to be used in the production of some of the refined bioproducts is questioned [41]. Furthermore, the complex processing chains for production of second generation biofuels might complicate the actual achievement of the claimed high theoretical efficiencies.

***Ecobalance***

One tool that can play a role in assessing the feasibility of biorefineries is the Ecobalance[12]. This is a type of LCA (Life Cycle Analysis) approach to assess the consumption of energy and resources and the pollution caused by the life cycle of a given product. The product is followed throughout its entire life cycle, from the extraction of the raw materials, manufacturing and use, right through to recycling and final handling of waste.

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[12] Information on this subject can be found at (among others) the website of the American Center for Life Cycle Assessment (http://www.lcacenter.org).

Some initial ecobalances have been determined for biorefineries. The German Office of Technology Assessment at the German Parliament (TAB) has published a report in which an ecobalance review was used for an initial classification of several biorefinery concepts, namely the green biorefinery, the lignocellulosic feedstock (LCF) biorefinery and the whole crop biorefinery. TAB [42] concluded that results were mostly positive, better than conventional systems, but depending on specific circumstances. For example, if lignin is converted into energy in the biorefinery concept, the ecobalance is better if the straw is directly converted into energy; if lignin is used for high-value products, the biorefinery concept has a better performance than conventional production chains [42].

## 5.4 Example – The clean catalytic Technology Centre

As explained earlier, the biorefinery concept can be applied to a lot of new and existing processes. In a wide variety of agro-industrial production processes, improvements can be achieved by upgrading and refining of biomass.

The palm oil industry, located mainly in Malaysia and Indonesia, is an important supplier of oils and fats in the world. While the production of oil and fats from palm oil in these countries constitutes 24% of all oils and fats produced in the world, it is not without controversy because of, among others, deforestation practices. Although yields per hectare are high, there are a lot of opportunities to improve the process (see Figure 5-2).

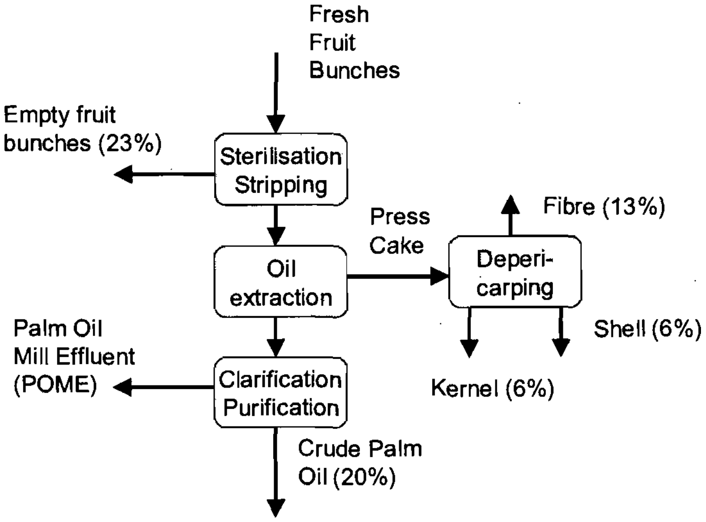

**Figure 5-2** Palm oil production. Every tonne of Fresh Fruit Bunches leads to 200 kg of crude palm oil. The other 800 kg is only partly used. Especially for the Empty Fruit Bunches, the fibre and the shell, no good applications exist at this moment.

Of course any palm oil mill is also a biorefinery. The Clean Catalytic Technology Centre for Malaysia and South East Asian Countries, established in 2004 by UNIDO and the Malaysian Palm Oil Board (MPOB), is investigating new and clean catalytic technologies for the conversion of palm oil mill generated materials into fine chemicals and energy.

Three projects are considered:

- Improvement of catalysis for the production of biodiesel from palm oil.
- Conversion of glycerol (a by-product of biodiesel production) into gasoline additives or pour point depressants for biodiesel. This process is however very energy-intensive.
- Exploration of the utilisation of palm biomass for the production of energy and fine chemicals.

## 5.5 Example – Jatropha biorefinery research in Indonesia

Jatropha is an oil-producing plant that is suitable for production of biofuels. Jatropha is not edible and can be grown on marginal lands, which can imply sustainable biofuels production. However, competition with food cannot be ruled out as also existing arable land will be used for jatropha cultivation.

In an Indonesian-Dutch co-operation project, research is carried out on a jatropha biorefinery. Indonesian participants are the Indonesian Agency for the Assessment and Application of Technology (BPPT) and the Institute of Technology in Bandung (ITB). Dutch partners are the Universities of Groningen and Wageningen.

An envisaged jatropha refinery is shown in Figure 5-3.

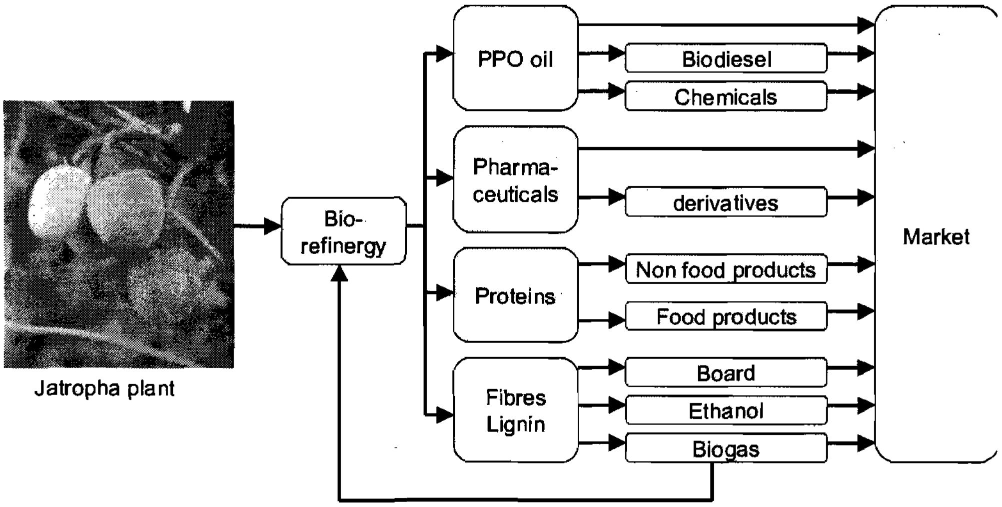

Figure 5-3 Envisaged jatropha biorefinery concept. The jatropha plant is first separated into its basic components. These can subsequently be further refined into a multitude of products. PPO stands for Pure Plant Oil. [9]

An example of a concrete project within the framework of this co-operation is the improvement of the stability of the cold flow behaviour of jatropha oil. Jatropha oil has excellent lubricating properties and is highly biodegradable. However, the low-temperature behaviour and stability are not good enough. Via various chemical reactions (hydroxylation and acetylation among others), this behaviour is improved.

Another project involves the characterisation and the application of the jatropha nutshell. Pyrolysis to produce a liquid from the nutshell is considered, as well as direct application of the nutshell material as ingredient for particleboard or wood/plastic composites.

## 5.6 The biorefinery concept and developing countries

Many of the existing (conventional) biorefineries are located in both developing and industrialised countries. These show a large variety in type of feedstock, products, and technologies. A tremendous amount of research is needed to unlock all the potentials of biorefineries. This is of interest for developing countries, since a lot of biorefineries will be located on their ground, where biomass is cheap and widely available.

Research and development, for example in tandem with industrialised countries, could unlock opportunities to create more value in the (developing) countries where the biomass is located. This would generate jobs and income, and would be good in general for the status of agro technology in developing countries.

# 6 SUSTAINABILITY AND CERTIFICATION OF BIOMASS

## 6.1 Introduction

Bioenergy can potentially provide an essential contribution to the generation of renewable electricity, heat and transport fuels. In order to achieve greenhouse gas emission reductions and to decrease dependency on fossil fuels, many countries have set ambitious targets for the use of renewable energy, including bioenergy and biofuels for transport. If the targets are too ambitious, this could lead to unsustainable biomass production. For instance, increased demand for palm oil for energy and biodiesel production stimulated the expansion of plantations, sometimes at the expense of rainforests or wetlands. The diversion of food crops like wheat, palm oil, rapeseed, soy, maize, etc. for the production of transport fuels has contributed to higher food prices; a serious development with highly undesirable impacts for especially the poor. Unsustainable biomass production seriously erodes the climate-related environmental advantages of bio-energy, and there is a strong call to stop these unsustainable practices and to accept only sustainably produced biomass. This paper investigates what 'sustainable biomass' actually is, and how it could be certified, and subsequently if and how sustainable biomass production could be promoted or even enforced and thereby avoid unsustainable practices.

## 6.2 Sustainable biomass

In 1987, the Brundtland Report introduced the following quite well known and often cited definition of sustainable development, as being "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." [43]. The concept of sustainability is commonly defined within ecological, social and economic contexts. Many NGOs as well as governments and companies have worked on the application of the concept of sustainability to biomass production, conversion and use. This resulted in various sets of principles and criteria for biomass production, like the Dutch Cramer Criteria, the British RTFO principles, German criteria of the Umwelt Bundes Amt, Principles and Criteria for Sustainable Palm Oil Production of the Roundtable on Sustainable Palm oil (RSPO), Sustainability Standards for bioenergy of the World Wide Fund For Nature (WWF), draft principles and criteria of the Round Table on Responsible Soy (RTRS) and the Better Sugarcane Initiative (BSI), etc. The development of sustainability criteria is often primarily focused on liquid biofuels, since the rapid expansion of the use of these fuels causes most public concern and require rapid action; however, many systems address solid biomass as well. Though still under development, the principles of the Roundtable for Sustainable Biofuels (RSB)[13] [44] presented in the box below can be seen as a rather complete set covering most issues of sustainable production of both liquid and solid biomass.

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[13] http://cgse.epfl.ch/page70341.html

***Box 7: Version Zero of the RSB Principles and Criteria***[14]

**General**

- *Legality:* Biofuel production shall follow all applicable laws of the country in which they occur, and shall endeavour to follow all international treaties relevant to biofuels' production to which the relevant country is a party.
- *Consultation, Planning and Monitoring:* Biofuels projects shall be designed and operated under appropriate, comprehensive, transparent, consultative, and participatory processes that involve all relevant stakeholders.

**Environmental**

- *Climate Change and Greenhouse Gas:* Biofuels shall contribute to climate change mitigation by significantly reducing GHG emissions as compared to fossil fuels.
- *Conservation and Biodiversity:* Biofuel production shall avoid negative impacts on biodiversity, ecosystems, and areas of High Conservation Value.
- *Soil:* Biofuel production shall promote practices that seek to improve soil health and minimise degradation.
- *Water:* Biofuel production shall optimise surface and groundwater resource use, including minimizing contamination or depletion of these resources, and shall not violate existing formal and customary water rights.
- *Air:* Air pollution from biofuel production and processing shall be minimised along the supply chain.

**Social**

- *Human and Labour Rights:* Biofuel production shall not violate human rights or labour rights, and shall ensure decent work and the well-being of workers.
- *Rural and Social Development:* Biofuel production shall contribute to the social and economic development of local, rural and indigenous peoples and communities.
- *Food Security:* Biofuel production shall not impair food security.
- *Land Rights:* Biofuel production shall not violate land rights.

**Economic**

- *Economic efficiency, technology, and continuous improvement:* Biofuels shall be produced in the most cost-effective way. The use of technology must improve production efficiency and social and environmental performance in all stages of the biofuel value chain.

Most general, environmental, social and economic criteria for sustainable biomass can also be found in the main forest certification schemes like FSC[15] and PEFC[16] and much

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[14] Please note that the original order of RSB principles and criteria was changed to reflect the classification into general, environmental, social and economic criteria, respectively.

[15] Forest Stewardship Council.

can be learned from experiences with these forest schemes, as is shown in box 8 below. Some issues are however not covered by the existing forestry schemes. The greenhouse gas emissions during production of the biomass should be significantly lower than the fossil fuel emissions that it is supposed to replace, because this is supposed to be one of the main benefits of using bioenergy in the first place. Life Cycle Analysis (LCA) can be used as a tool to determine and compare greenhouse gas emission reductions of different options. Secondly, the effect of biomass production on food security and prices needs to be addressed, because, unlike most forests, biomass crops are partly produced on agricultural land.

***Box 8: Forest certification***

In the last ten years, the area of certified forests has strongly increased as illustrated in figure 1. By the end of 2006, about 295 mln. ha. of forest was certified, of which 193.7 mln. ha (65%) by PEFC endorsed systems, 84.2 mln. ha (29%) by FSC systems and 17 mln. ha (6%) by other systems (the American Tree Farm System, Malaysian Timber Certification Council and the Dutch Keurhout system) [45].

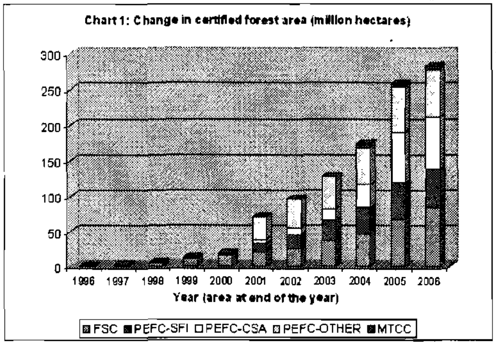

**Figure 6-1** Changes in certified forest area: [45]

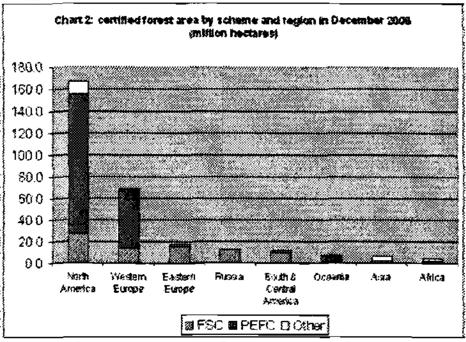

**Figure 6-2** Certified forest area by scheme and region in Dec 2006 [46]

Forest certification has taken off in North America and Europe, which form the main environmentally conscious markets. Forest certification has had limited uptake in those developing countries that supply timber mainly to less eco-sensitive markets. Depending on the local situation, various factors were identified to be responsible for this limited uptake, like non-resolution of indigenous right matters, indifference towards foreign owned companies, focus on less eco-sensitive markets, illegal logging providing a cheap alternative, poverty, political instability etc. [46].

## 6.3 Assessing the sustainability of biomass production

Given the experiences with forest certification, most biomass sustainability principles can be translated successfully into measurable criteria and indicators that enable third parties to verify whether a certain plantation or load of biomass is produced in a sustainable way. Methods for determination of greenhouse gas balances of biomass sources are also under development. Moreover, chain-of-custody certification is needed to guarantee the end

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[16] Programme for Endorsement of Forest Certification schemes.

user that his certified biomass is indeed produced in a sustainable way, which is rather difficult, but experiences with forestry certification show that it is possible.

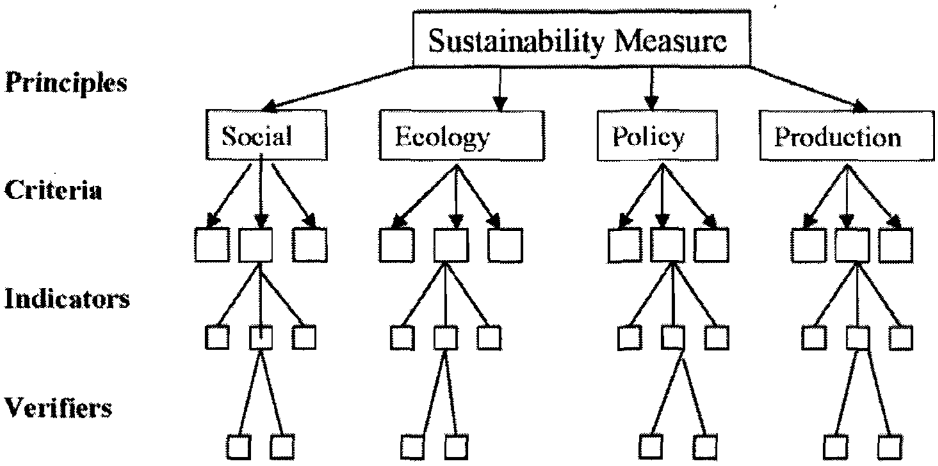

**Figure 6-3** Hierarchical structure of sustainability principles, criteria, indicators and verifiers [47].

It will be problematic to assess whether biomass is produced without impairing food security or prices. Biomass grown on degraded or marginal land as well as many biomass residues and wastes clearly do not compete with food production. However, biomass that is grown on agricultural land and agricultural crops diverted to energy production can have an impact on the global food prices. However, it is difficult to measure this impact and impracticable to attribute the effect of an individual biomass plantation to world food prices.

## 6.4 Benefits and costs of biomass certification

Biomass certification could provide biomass producers access to environmental conscious markets like Europe and North America. In case biofuel/bioenergy distributors receive premiums for using certified biomass based on governmental financial incentives, part of the benefits could be passed on to the sustainable biomass producers. However, care should be taken that these financial benefits are indeed passed on to the biomass producing countries: parallel to the developments in the forestry sector [46], in many countries certification will become common practice after a certain period and the level of price premiums will decrease or diminish.

The costs of certification can be divided into *direct* costs related to the auditing process and *indirect* costs related to measures that need to be taken to meet the sustainability criteria; these indirect costs can be high especially if attainment of these criteria results in reduced biomass harvests, for instance if certain areas need to be protected and therefore become unproductive. Per tonne of certified biomass, the direct certification costs for large biomass companies producing more than, say, 50,000 tonnes of biomass per year, are expected to be limited [48]. The relative costs of certification can form a serious barrier to smallholders producing, say, less than 5,000 tonnes of biomass per year[17]. A possible solution is to allow group certification, in which the costs of certification can be shared by a number of small producers. A main point of attention is that a group needs to be organised. In forestry, the resource manager is a forester or group of foresters that manage forestlands for independent landowners. Resource managers can be hired to act as a group umbrella and organise certification [49]. This is the least complex way of organising forest or biomass group certification. Another option is to use an existing cooperation or association to organise the group certification. Setting up a new cooperation or association just for the sake of group certification would seem to be too time and effort consuming.

## 6.5 Current status of biomass certification

Several initiatives are ongoing to certify that food crops can be used for energy purposes as well, like the Round Table on Responsible Soy (RTRS), Better Sugarcane Initiative (BSI) and Roundtable for Sustainable Palm Oil (RSPO). Of these initiatives the RSPO is presently most advanced. The RSPO has developed a complete certification system of principles, criteria and indicators [50] and the first tonnes of certified palm oil are trickling in. The used criteria and indicators are very similar to forest certification criteria and are fine-tuned on a national level. A carbon balance is currently missing, but RSPO has indicated to consider its development if there is sufficient demand for it [51]. It has to be taken into account that RSPO has not been developed to only serve the biomass energy market, but to serve all potential users of palm oil. The experience gained with RSPO teaches that it takes considerable effort to develop sustainability criteria and a certification system for a single type of biomass.

Governments with ambitious targets for the share of renewable energy, biofuels and carbon emission reductions have been criticised for promoting unsustainable biomass production and are considering the introduction of obligatory certification of biomass. The Netherlands, United Kingdom and Germany have been active in the formulation of sustainability criteria and the issue of biomass sustainability is being addressed on European level as well. On December 17, 2008 the European Parliament adopted the *'Directive on the promotion of the use of energy from renewable sources'*. Box 9 summarises the environmental sustainability criteria and verification requirements for biofuels and other bioliquids, as found in this *'Renewable Energy Directive'*. Biomass that does not meet these criteria will not be regarded as a contribution to the EU targets and subsequently will most likely not receive any financial support from member countries. A European Standard (CEN/TC 383) is under development to support the implementation of the EU sustainability criteria.

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[17] In case of 50,000 tonnes biomass/year with an energy value of 10 GJ/tonne, audit costs of 10,000 US$/year would result in increasing biomass costs of 0.02 US$/GJ or 0.2 US$/tonne; in case of 5000 tonnes/year this would be 0.2 USD/GJ or 2 USD/tonne, in case of 500 tonnes/year this would be 2 US$/GJ or 20 US$/tonne.

***Box 9: EU sustainability criteria for biofuels and other bioliquids in the Renewable Energy Directive***

1. Greenhouse gas emission savings from the use of biofuels and other bioliquids shall be at least 35%, and shall be 50% after 2017. After 2017 the emission savings shall be 60% for biofuels and bioliquids produced in installations whose production has started from 2017 onwards.
2. Biofuels and other bioliquids shall *not* be made from raw materials from land with high biodiversity value:
    a. Primary forest and other woodland, that is to say forest and other wooded land of native species, where there are no clearly visible indications of human activities and the ecological processes are not significantly disturbed;
    b. Areas designated by law or by the relevant competent authority for nature protection purposes, and areas for the protection of rare, threatened or endangered ecosystems or species recognised by international agreements or included in lists drawn up by intergovernmental organisations like IUCN; *unless* evidence is provided that the production of that raw material does not interfere with those nature protection purposes.
    c. Highly diverse grassland, that is to say grassland that would remain grassland in the absence of human intervention and which maintains the natural species composition and ecological characteristics and processes; or highly biodiverse *non natural* grassland[18], *unless* evidence is provided that the harvesting of the raw material is necessary to preserve its grassland status.
3. Biofuels and other bioliquids shall not be made from raw material obtained from land with high carbon stock, i.e. wetlands and continuously forested areas that had that status in January 2008 and no longer have this status.
4. Agricultural raw materials cultivated in the EU used for production of biofuels and other bioliquids need to meet with the standards and provisions referred to under the heading "Environment" in part A of Annex III, to Council Regulation No. 1782/2003 under the heading "environment" and in accordance with the minimum requirements for good agricultural and environmental conditions defined pursuant to Article 5(1) of that regulation.

Installations already in operation in January 2008 need to conform to the greenhouse gas savings requirement by 1 April 2013. January 2008 is the reference date for the status of the areas mentioned under point 2 and 3.

During verification, next to compliance of the above-mentioned obligatory sustainability criteria, *reporting* is required on measures taken for soil, water and air protection, the restoration of degraded land, and avoidance of excessive water consumption in areas where water is scarce.

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[18] That is to say grassland that would cease to be grassland in the absence of human intervention and which is species-rich and not degraded.

Next to the above-described sustainability criteria and reporting obligations, the European Commission shall report every two years on the impact on social sustainability of increased demand for biofuel, and on the impact of the EU biofuel policy on the availability of foodstuffs at affordable prices, in particular for people living in developing countries, and will also report on wider development issues. Attention will be paid to land use rights and compliance with ILO conventions on forced or compulsory labour, freedom of association, right to organise, equal remuneration of men and women, minimum age of employment and child labour. The European Commission might introduce an information obligation on these aspects at a later stage.

## 6.6 Problems and limitations of biomass certification

Society will benefit from sustainable biomass production if it leads to better environmental protection of areas with high conservation value, better local environmental conditions, greenhouse gas reductions, better labour conditions, etc. However, when evaluating the use of biomass certification, some limiting factors need to be considered.

Biomass certification is expected not to tackle all identified issues, in particular those related to the competition with food and other indirect effects of change of land use to biomass production. Taking the example of palm oil; if all palm oil in a country would be certified, no oil palm would be planted on the grounds of a previous rainforest or wetland anymore. However, pressure on land because of oil palm plantations could force the growing of other crops on these protected grounds, thus leading to adverse indirect land use change effects.

Biomass producing countries and companies might respond to the imposition of sustainability criteria by shifting its biomass exports to less demanding markets. Alternatively, only the already sustainable areas might get certified while other areas would continue serving less demanding markets. This way the change toward sustainable biomass production methods would be marginal. Moreover, biomass-exporting countries may perceive these criteria as a form of eco or labour protectionism. The impact of sustainability schemes will be lowered dramatically if key biomass exporting countries are unwilling to cooperate.

Some organizations point to the danger of introducing weak sustainability standards representing business-as-usual while the public has the impression that the products are very sustainable. Another concern is that some companies will only certify part of the biomass and use that for promotion purposes, while in reality most biomass is still produced in an unsustainable way. Since biomass certification systems will not be able to fully guarantee that all sustainability principles are met, part of the NGO community pleads for lower targets rather than to introduce sustainability certification schemes; especially the EU target of 10% biofuels for transport in 2020 is highly debated. Also, entrepreneurs have expressed their concern that imposing very stringent sustainability criteria and the additional paperwork makes the use of biomass extra difficult, while nobody expects fossil alternatives to meet sustainability criteria.

The Renewable Energy Directive contains binding criteria on greenhouse gas emission savings, biodiversity and carbon stock value of the land. Criteria on local environmental effects to soil, water and air are limited to a reporting obligation. Social criteria are not set on company level, although the European Commission will report on these factors.

The main reason for the introduction of reporting obligations instead of solid criteria is that imposing obligatory local environmental and social principles to third countries would most probably conflict with WTO rules. The question of what is accepted or not according to WTO rules can ultimately only be solved by dispute settlement. Voluntary certification is not subject to WTO rules since these systems are introduced voluntarily by organizations and companies rather than by national or supranational entities. Therefore, voluntary systems can formulate stricter criteria related to biodiversity, local environmental and social effects. However, their impact is potentially less powerful since voluntary certification cannot be enforced.

The present biomass certification initiatives have been criticised for having top down approaches that lack support from small producers or involved communities. Biomass owners and policy makers in biomass rich developing countries should become actively involved in the development of biomass certification systems, also to secure that part of the financial benefits of biomass certification will be passed on to the sustainable biomass producers. The success of sustainable biomass production highly depends on their efforts and cooperation.

## 6.7 The future role of biomass certification

The coming decade biomass certification is expected to become integral part of the sustainable energy policies of many countries. The EU sustainability criteria should be regarded and presented as *minimum* criteria to ensure that rational carbon savings are achieved and that detrimental environmental impacts are avoided. The EU-wide obligatory sustainability criteria can be seen as a good starting point toward sustainable use of biomass. It creates a substantial demand for sustainably produced biomass in all the EU member countries and thereby sets the international standard. In addition, voluntary biomass certification should play an important role to better cover social and local environmental and economic effects.

# 7 COMPETITION WITH FOOD

## 7.1 Introduction

The last few years have seen large increases in the world market food prices. Following a steady increase of 25 percent between 2003 and 2006, the FAO food price index[19] rose by 57 percent between March 2007 and March 2008 (Figure 7-1). Prices on cereals and oils and fats had the highest growth rates. Since mid 2008 the food prices have dropped again substantially.

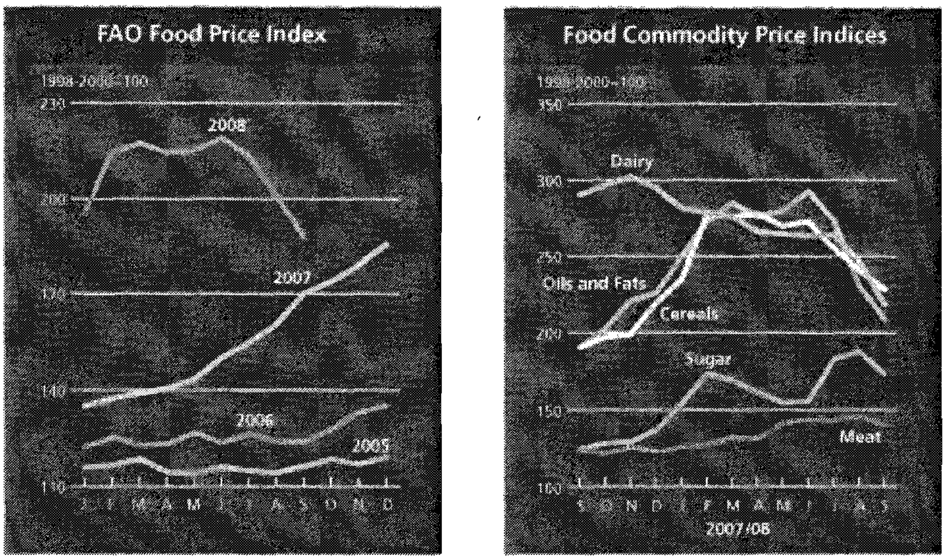

**Figure 7-1 FAO** Food Price Index and Food commodity Price Indices
Source: http://www.fao.org/worldfoodsituation/FoodPricesIndex/en/

The impact on households' well-being is determined by various factors: whether a particular household is a net producer or consumer of food, and by the magnitude of the price increase, which is affected by exchange rate movements, national policies and local market conditions determining the pass-through from world market prices to local prices. Rising food prices tend to negatively affect lower income consumers more than higher income consumers. Lower income consumers spend a larger share of their income on food, and staple food commodities such as corn, wheat, rice and soybeans account for a larger share of food expenditures in low-income families.

The increased prices of food and feed coincide with the recent expansion of biofuel industries. Because rising food prices are a matter of high concern, a great sense of urgency accompanies efforts to explain these fast price changes. Biofuels have been touted by many as the main culprit for the recent increases in prices of basic agricultural commodities. However, a closer inspection reveals that the relation between the two is

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[19] The FAO Food Price Index consists of the average of 6 commodity group price indices (dairy, oils, fats, cereals, sugar and meat) weighted with the average export shares of each of the groups for 1998-2000.

not so straightforward. A rushed policy response could unnecessarily disrupt the development of the biofuels industry without achieving a reduction of food prices.

This paper contains a closer inspection of the relation between biofuels production and food prices, and provides an outlook on the future role of biofuels and biomass without irresponsibly affecting food production and price levels.

## 7.2 Drivers of the food crisis

Reports from the leading food and agricultural research institutes like IFPRI [52], FAO [53] an others [54], [55], suggest that the high food prices are created by the interaction of a range of factors, summarised in the following points.

***Demand related factors***

- Long-run growth in food demand has outpaced the growth in food supply, gradually reducing the average surplus of food production and available food stocks;
- The rapid growth in the production of cereal-based biofuels, fuelled partly by the increasing price of fossil fuels and partly by public subsidization, has further reduced the supply of grains available for food production.

***Supply related factors:***

- Recent consecutive seasons of below-average harvests in major food exporting countries, combined with historically low food stocks, produced sharp increases in food prices;
- High prices of fossil fuels added to the costs of food production and transportation, putting a further pressure on food prices;
- Government policies put in place by some countries in efforts to control domestic food prices, such as export bans or price controls, have contributed to higher world market prices.

Furthermore, speculation also has an effect on the food prices. If everybody expects high prices, then future prices tend to be higher than the spot prices. So, part of the high prices can be attributed to this 'bubble'. Furthermore, the crises on the financial markets are diverting funds away from traditional financial institutions leading to a large pool of funds available for investments in other markets. However, the impact of speculation is difficult to quantify and hampered by data and methodological problems, including the difficulty of identifying speculative and hedging-related trades [54].

There are different stories behind the recent large increases in global prices for maize, wheat and rice. The most important causes can be summarised as follows [55]:

- Demand growth in the maize market was largely driven by the long term structural shifts in global food demand towards the greater dietary content of meat and dairy, which absorbs large quantities of maize as feed. More recently, rapid growth in the biofuel industry using maize as a feedstock, has added to the increasing demand.
- The current high wheat prices are mainly caused by three consecutive years (2005-2007) of weather-induced harvest shortfalls in some of the most important exporting

regions, Australia, Europe, Former Soviet Union and North America, at a time when wheat stocks are historically low.

- The soaring price of <u>rice</u> is primarily a result of hoarding by some of the most important actors in the international rice markets, including Thailand, India and Vietnam, which have imposed severe export restrictions in attempts to secure rice supplies. The sense of urgency in rebuilding rice stocks is partly stimulated by events in the maize and wheat markets.

## 7.3 The current role of biofuels

Several studies attempted to quantify the impact of the biofuels industry on agricultural commodity markets. The IFPRI [52] estimated that the increased biofuel demand during 2000-2007 accounted for 30% of the increase in weighted average grain (wheat, rice and maize) prices.

- The biggest impact was on <u>maize</u> prices, for which the increased biofuel demand is estimated to account for 39% of the increase in real prices. This impact is relatively high due to the fact that most US ethanol production is corn based.
- The found impact of biofuels in rice prices (21%) and wheat prices (22%) was lower [52]. The direct use of these commodities is limited but indirect effects of the land use affects the world price level [54].
- The cereal-based bio-ethanol industry in Europe only consumes about 1.4% of total cereal end-use [56]. Clearly, a sector that consumes such a small proportion of the total cereal use, cannot cause the found price increases. However, increased corn production sets pressure on land available for wheat production.
- Rice is hardly used as biofuel, and maize and rice are not in direct competition for land as they have different climatic requirements. High maize prices will, however, make consumers look for alternatives like rice. However, as stated before, the soaring of rice prices is mainly the result of severe export bans of main rice producing countries in attempts to secure rice supplies and rebuild stocks.

Experts point out that it is hard to quantify the separate impacts on food prices. They have criticised the above numbers; some find them too high, others too low. However, all studies point out that a combination of factors was responsible for the rise, including the increased use of biofuels.

## 7.4 The future role of biofuels

As indicated above, increased biofuels production for transport did partly contribute to higher food prices. However, many short-term effects like weather influences, oil prices, outside investor influences, market expectations (nervousness) leading to hoarding by some countries have contributed to the real peak in food prices. Some experts state that high prices are their own worst enemy. Higher prices induce more production as planted areas increase and available arable land will be used more intensively. Therefore, the current situation is not structural and as a result prices will go down again. However, stocks have to be rebuilt, which will take some time.

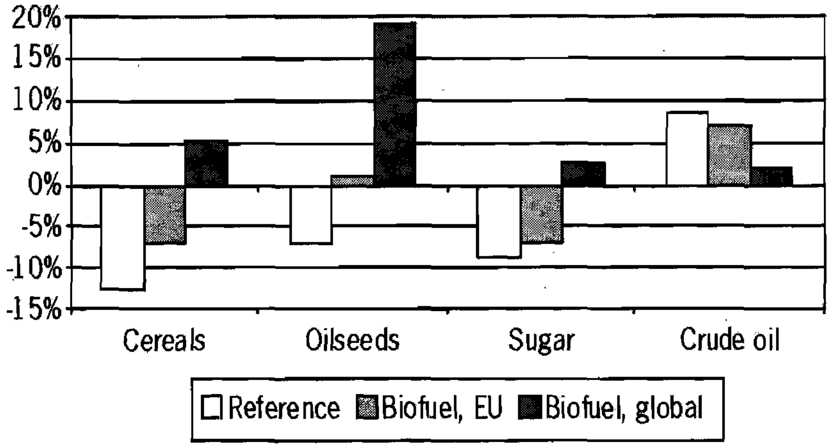

**Figure 7-2** Change in real world prices, in percent, 2020 relative to 2001 [57].

Some studies that compare future scenarios with and without biofuels, estimate that rather than increasing the food prices, in the long term biofuels would rather slow down further decreases in real agricultural prices. Figure 7-2 shows that the implementation of biofuel targets will particularly impact the oilseed prices. Other sources like FAO/OECD (figure 7-3) show that the long-term food prices (including the use of biofuels) will stabilise but at a price level higher than before.

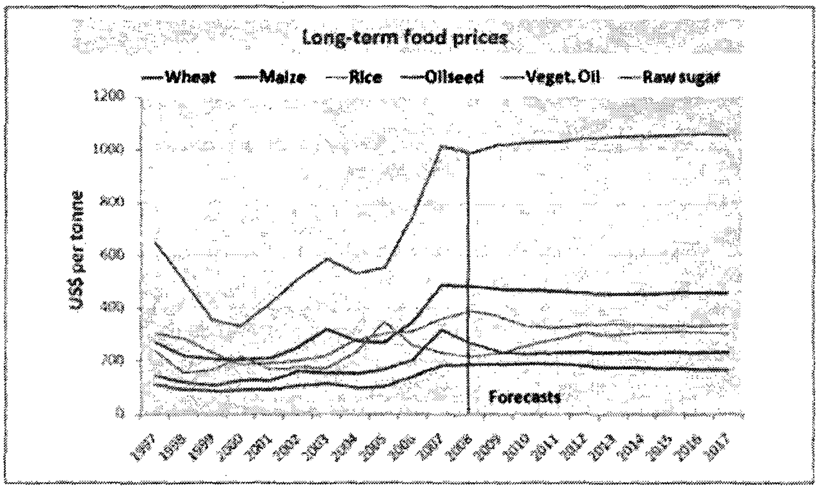

**Figure 7-3** Long-term food prices. Source: http://www.agri-outlook.org

Long-term effects on food demand include income and population growth (both increasing, albeit at a slow rate) as well as increased use of biofuels. The most important determinants of long-term supply are yields and areas of agricultural land, which are both slowly increasing [54]. R&D investments to improve yields in agriculture become more profitable with higher food prices.

Considering increasing long-term oil and energy prices, it could be expected that - even if present ambitious biofuel targets will be lowered - markets for biofuels are expected to stay. In the long term, the potential for high output growth in Europe and North America is probably limited. Agricultural land in these regions is fixed and producers are already highly productive suggesting that further improvements require large investments. However, considerable potential for output growth exists in countries in the former Soviet Union, particularly Russia, Ukraine and Kazakhstan, as well as Sub-Saharan Africa and South America, if infrastructural and institutional barriers can be overcome [55]. Policy measures should especially enable the poor to be able to participate in the economy, and thereby enable the poor countries to generate income within a world market. However, income generation with biofuels production in these countries should not be done at any expense, but attention should be paid to issues such as security of supply to domestic food markets and sustainability.

## 7.5 Biomass sources not competing with food production

Biomass grown on agricultural land, or agricultural commodities being diverted to the energy sector (like wheat, corn etc.) could lead to higher food prices. However, many biomass resources do not compete with food production and are available for energy production:

- Biomass processing residues like rice husks, bagasse, sawdust, prunings, residues from the wood processing industry etc., do intrinsically not compete with food or fodder production and can be used for energy production.
- Biomass residues that are usually left behind on the fields or in forests could be used for energy production, provided that the condition of the soil (structure, nutrients, carbon stock, erosion, etc.) and biodiversity are maintained.
- Waste products like demolition wood, kitchen and garden waste and the organic part of municipal solid waste can be used for energy production as well. The discussion around energy and food production could lead to increased appreciation of energy production from waste.
- If cultivated on degraded and marginal lands not suitable for food production, crops, like jatropha, do not compete with land for food production. Please note that marginal lands are often not very productive and biomass production on these lands is not always financially feasible. Attention should also be paid to the irrigation needs, as competition for water with food crops should be avoided. Furthermore, the crops should not be grown on lands with high conservation value, or on 'marginal' lands, informally used by the poorest to sustain their lives.
- Biomass produced in existing forests does not compete with food but should meet social, environmental and economic sustainability criteria. Wood production on agricultural lands could, however, leads to competition with food crops for land.

In general, traditional biomass electricity and heat applications use the above mentioned-biomass resources, which do not compete with food crops. Advanced bioenergy technologies like second-generation biofuels production and bio-refineries are also expected to utilise such biomass residues, thus avoiding competition with food.

# 8 CLEAN DEVELOPMENT MECHANISM

## 8.1 Introduction

The Clean Development Mechanism (CDM) is an arrangement under the Kyoto Protocol allowing industrialised countries with a greenhouse gas reduction commitment (called Annex B countries) to invest in projects that reduce emissions in developing countries as an alternative to more expensive emission reductions in their own countries. Most developed and developing countries have signed the Kyoto Protocol[20] with the United States being the most striking exception[21].

The emission reductions achieved by a CDM project are called Certified Emission Reductions (CERs), also commonly referred to as carbon credits. Each CER presents a greenhouse gas emission reduction of 1 tonne of $CO_2$-equivalent. Generally, CERs are sold to companies and governments with an emission reduction target under the Kyoto protocol, but can be sold to the voluntary market as well. The whole procedure from project idea to certified emission reductions is known as the CDM project cycle.

## 8.2 CDM project cycle

CDM projects follow two main phases. First the project development phase prior to the implementation of the physical project; and second, the project implementation phase when the physical project has started operating.

To start a CDM project, project participants must prepare a **project design document** (PDD), which includes a description of the baseline and monitoring plan to be used, an analysis of environmental impacts, comments received from local stakeholders and a description of the additional environmental benefits that the project will generate. The PDD contains a calculation of expected emission reductions and a method to monitor the real emission reductions after implementation of the project. These are based on approved baseline and monitoring methodologies that are presented on the UNFCCC website[22]. Alternatively, if a project activity is not yet covered by existing methodologies, project participants can propose a new methodology. The PDD should also provide proof of **additionality**: a CDM project activity is additional if anthropogenic emissions of

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[20] For the most recent overview of participating countries please turn to http://unfccc.int/kyoto_protocol/status_of_ratification/items/2613.php.

[21] The United States Senate had the opinion that the United States should not be a signatory to any protocol that did not include binding targets and timetables for developing as well as industrialised nations, or that would result in serious harm to the economy of the United States (Byrd-Hagel Resolution).

[22] See http://cdm.unfccc.int/methodologies/index.html. Note that UNFCCC, the United Nations United Nations Framework Convention on Climate Change, is the international treaty on climate change. The Kyoto Protocol is an addition to this treaty. All information on the treaty, reports from participating countries etc. as well as all relevant CDM and JI (Joint Implementation) project information can be found on the UNFCCC website (http://unfccc.int/).

greenhouse gases by sources are reduced below those that would have occurred in the absence of the registered CDM project activity.[23] This is in general proved by a financial analysis showing that in absence of the CDM, the project would not be financially feasible.

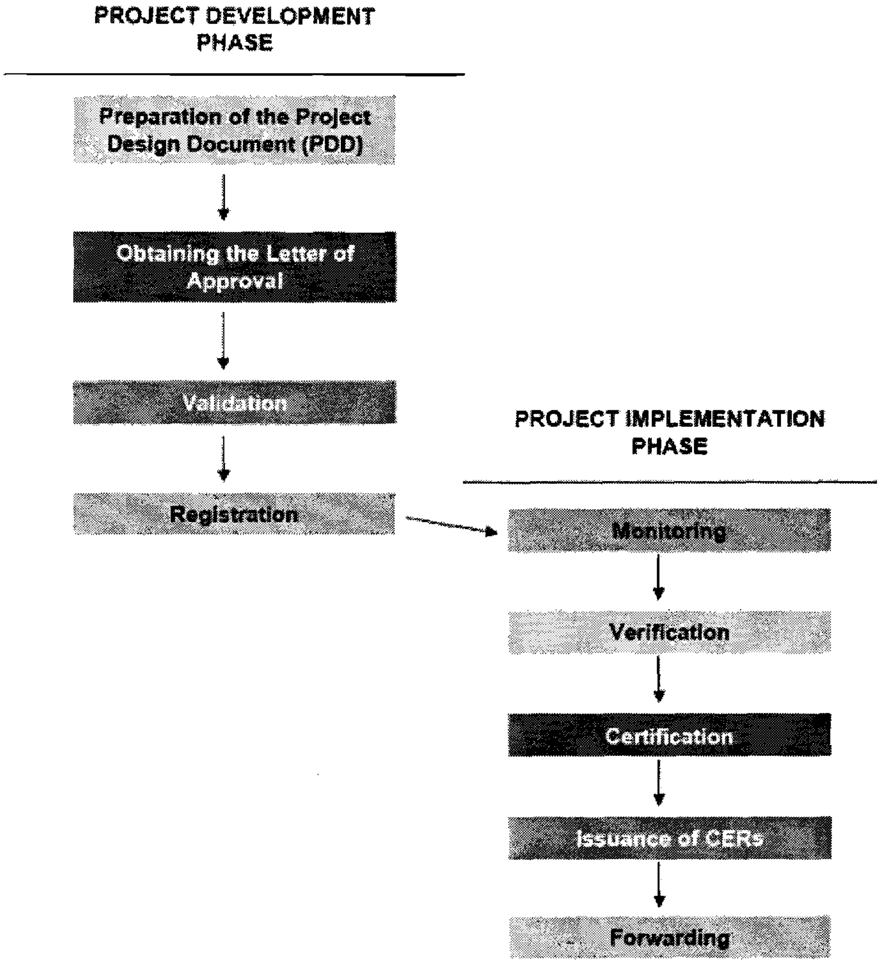

**Figure 8-1** The phases of the CDM project cycle.[24]

The CDM project needs to be approved by the host country, in which the CDM project is located. The Designated National Authorities appointed by these countries should hereto provide a **Letter of Approval**. Each country has its own procedures for providing host country approval.

An accredited independent third party, called a designated operational entity (DOE) in CDM speak, will then review the PDD and, after providing an opportunity for public

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[23] FCCC/KP/CMP/2005/8/Add.1, art 43, p 16. 30 March 2006
See http://cdm.unfccc.int/Reference/COPMOP/08a01.pdf#page=6.

[24] Source: http://www.cdmrulebook.org

comment, decide whether or not to **validate** it. If a project is duly validated, the operational entity will forward it to the Executive Board (EB)[25] for formal **registration.**

Once a project is up and running, project participants, the entities that proposed the project, are responsible for the CDM project, will **monitor** the project. They will prepare a monitoring report including an estimate of the number of Certified Emission Reductions (CERs) generated by the project and will submit it for **verification** by a designated operational entity.

Following a detailed review of the project, which may include an on-site inspection, the designated operational entity will produce a **verification** report and, if all is well, it will then **certify** the CERs as legitimate. In sequence, the EB will **issue** the CERs and distribute them to project participants as requested.

The exact procedures can be found on the website of UNFCCC at http://cdm.unfccc.int/index.html. The frequently updated publication 'CDM in Charts' (http://www.iges.or.jp/en/cdm/report_kyoto.html) also provides a useful overview of these procedures.

### CDM projects

So far, CDM is the most successful project-based emission reduction mechanism. More than 4,400 projects have entered the CDM pipeline, potentially generating more than 2.8 billion CERs. However, Table 8-1 shows that the number of registered projects that have actually issued CERs is limited to 441 projects so far. These projects have generated 240 million CERs, which is 8% of the total potential up till 2012 (situation January 1, 2009).

**Table 8-1** Status of CDM projects (situation Jan 1, 2009) [32]

| Status of CDM projects | Number |
|---|---|
| At validation | 2,720 |
| In the process of registration | 344 |
| Withdrawn or rejected | 111 |
| Registered, no issuance of CERs | 859 |
| Registered, CER issued | 441 |
| Total number of projects (incl. rejected & withdrawn) | 4,475 |

Most CDM projects are located in Asia and Latin America; China, India, Brazil and Mexico are hosting 73% of the CDM projects. In absolute numbers and per capita, Africa has the lowest number of CDM projects as shown in Table 8-2 and Figure 8-2.

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[25] The CDM Executive Board (EB) supervises the CDM, under the authority and guidance of the COP of the Kyoto Protocol.

**Table 8-2** Regional distribution of CDM projects (situation 1 Jan 2009) [32]

| Total in CDM Pipeline | Number of projects | | kCers 2012 | | Population (million) | 2012 CERs per capita |
|---|---|---|---|---|---|---|
| Latin America | 837 | 19.2% | 427,801 | 14.9% | 449 | 0.95 |
| Asia & Pacific | 3339 | 76.5% | 2,299,604 | 79.9% | 3418 | 0.67 |
| Europe & Central Asia | 43 | 1.0% | 18,992 | 0.7% | 149 | 0.13 |
| Africa | 90 | 2.1% | 92,511 | 3.2% | 891 | 0.10 |
| Middle-East | 55 | 1.3% | 38,003 | 1.3% | 186 | 0.20 |
| Total projects | 4364 | 100% | 2,838,108 | 100% | 5093 | 0.56 |

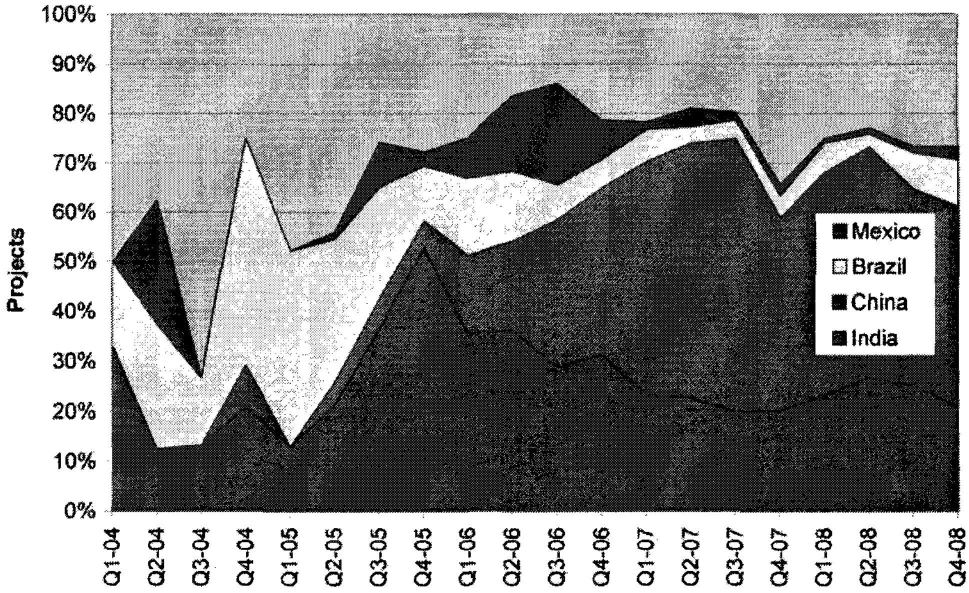

**Figure 8-2** The share of India, China Brazil and Mexico in the total pipeline of CDM projects [32]

One way of promoting CDM projects in Africa is to ensure that Designated National Authorities (DNAs) are in place, and are using clear rules for providing host country approval. This would reduce the CDM registration risk that project developers face.

## 8.3 Biomass CDM projects

Many biomass, biogas and landfill gas projects have applied for CDM registration. As shown in Table 8-3, the CDM pipeline contains more than 1,250 CDM biomass projects including biogas and landfill gas projects, which is 29% of the total number of projects that can potentially generate 528 million CERs, 19% of the total potential.

- The number of biogas projects that issued CERs, is still low.
- The issuance success of landfill gas projects, i.e. the CERs issued divided by the CERs expected for the same period of time is quite low, indicating that the emission reductions from landfills are often overestimated.

- Biomass energy projects using mainly biomass residues for electricity or combined heat and power production have a higher issuance success.

**Table 8-3** CDM pipeline for biomass energy, biogas and landfill gas projects (Jan 2009) [32]

| | **All CDM project in pipeline** | | **CDM projects with CERs issued** | | |
|---|---|---|---|---|---|
| | Projects | 2012 kCERs | Projects | Issued kCERs | Issuance success[a] |
| Biogas | 275 | 61,437 | 7 | 1,111 | 63% |
| Biomass energy | 660 | 203,783 | 99 | 11,128 | 88% |
| Landfill gas | 321 | 262,476 | 29 | 5,600 | 36% |
| Total biomass project | 1,256 | 527,696 | 135 | 17,839 | |

[a] Issuance success: the CERs issued divided by the CERs expected for the same period of time.

In case renewable electricity is generated and the plant is connected to a grid, the project participants have to calculate the carbon intensity of the (national) electricity grid. Thus, the number of CERs a project receives for each MWh of electricity depends on the carbon intensity of the (national) electricity production park. The CDM project Camil Itaqui Biomass Electricity Generation Project is an example of a successful biomass CDM project and is presented in chapter 9 on success stories.

In landfill gas and biogas projects, the emissions of methane from the decay of organic waste or wastewater are prevented. Also, if piles of decaying biomass are prevented or removed by controlled combustion, methane emissions are avoided.

A methodology exists for plant oil production and use for transport applications[26], although up till now no project was approved and only one project reached the validation stage. This methodology is only applicable to plant oil that is used in blends of up to 10% by volume or used in its pure form. In case pure plant oil is used, it shall only be used as a fuel in converted vehicles. Moreover, the methodology requires that it is exactly known on which fields the oil seeds are grown. Only a limited number of potential projects will meet these criteria. Moreover, most pure plant oil is converted into biodiesel, which is not covered by this methodology. Several methodologies have been proposed to include biodiesel or bio-ethanol production and use, but the CDM methodology panel has approved none of them. The development of appropriate calculation and monitoring of all factors related to farming, processing, and use of biodiesel or bio-ethanol in a sufficiently accurate way to meet the CDM requirements, proved to be very difficult.

## 8.4 CDM contracts and CER prices

CERs generated from CDM projects can be sold to governments that need them to meet their national Kyoto targets and to companies that operate under the EU Emission Trading Scheme (EU-ETS). A third option is to sell the CERs to organizations and companies that want to offset their emissions on a voluntary base. However, the most important market driver is EU-ETS. Under EU-ETS, companies in the European Union receive a certain number of emission allowances (EUAs). If companies produce more

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[26] Referred to as methodology AMS III T.

emissions than allowed, they need to buy EUAs from other companies, or alternatively they can buy CERs up to a certain maximum allowed share.

Project participants can sell their CERs in advance to a buyer against certain prices and conditions that are to be established in an Emission Reduction Purchase Agreement (ERPA). This will generally generate certainty for the seller on the price and conditions and thus on future income. The second option is to wait until the CERs are issued and sell them as secondary CERs on the spot market, which will usually generate higher prices since the delivery risk for the buyer is lower, but for the seller it is more uncertain; the CER prices depend to a certain degree on the EUA-prices, which have proven to fluctuate considerably during previous years.

## 8.5 Problems and limitations of CDM

CDM is mainly used for compliance markets that have obligations related to the Kyoto Protocol. The procedures to develop a CDM project are time consuming. The average time lag between the start of public comment period (validation) and submission of request for registration is 274 days nowadays [32]. Moreover, the number of requests for review of registration has increased a lot during recent years, adding to the time before registration and forming a considerable part of the executive board's workload. Although requests for review can be necessary to guarantee the quality of CDM projects, the associated time lags can have a serious effect on the number of carbon credits created by the project. The International Emissions Trading Association (IETA) have called for a review of CDM, including an appeal procedure for developers, full time staffing of the Executive Board, and for the board to take a larger policy role instead of implementing the rules. A separation between rule making and decision-making is seen as essential to improve the efficiency of both the executive board and the CDM secretariat.

CDM project developers suffer from the uncertainty of the value of CDM credits after 2012, since no climate framework for this period has been established yet, which means that the window of opportunity for developing new CDM projects with certain benefits is closing. On the other hand, although uncertain, it is very likely that a market will exist after 2012, since a post Kyoto agreement can be anticipated and even in case no agreement is made, CERs can be sold as a high quality carbon credit in the voluntary markets. See box 10 for more information on voluntary carbon markets.

While project developers have suggestions for improvement on the efficiency of the whole CDM process, CDM knows more fundamental criticism. CDM is not a cap-and trade mechanism, but rather an emissions-reduction-credit system. That is, when an individual project results in emissions below what they would have been in the absence of the project, a credit - which may be sold to a source within a cap-and-trade system - is generated. This approach creates a challenge: comparing actual emissions with what they would have been otherwise. The baseline - what would have happened had the project not been implemented - is unobserved and fundamentally unobservable [58].

***Box 10: Voluntary Carbon Markets and Standards [59]***

The voluntary carbon markets function outside of the compliance market regulated by the Kyoto Protocol. They enable businesses, governments, NGOs, and individuals to offset their emissions by purchasing offsets that were created either through CDM or in the voluntary market. The latter are called VERs (Verified or Voluntary Emission Reductions). Unlike under CDM, there are no established rules and regulations for the voluntary carbon market. On the positive side, voluntary markets can serve as a testing field for new procedures, methodologies and technologies that may later be included in regulatory schemes. Voluntary markets allow for experimentation and innovation because projects can be implemented with fewer transaction costs than CDM or other compliance market projects. Voluntary markets also serve as a niche for micro projects that are too small to warrant the administrative burden of CDM or for projects currently not covered under compliance schemes. On the negative side, the lack of quality control has led to the production of some low quality VERs, such as those generated by projects that are likely to have taken place anyway. In order to guarantee that emission reductions are real, a number of voluntary carbon standards have been developed like the Gold Standard (GS) developed under leadership of WWF, Voluntary Carbon Standard (VCS) promoted by the International Emissions Trading Association (IETA) and VER+ developed by TÜV-SÜD, etc. Many of these standards make use of approved CDM methodologies. A good overview of the different voluntary standards can be found in 'A comparison of Carbon Offset Standards' of WWF http://assets.panda.org/downloads/vcm_report_final.pdf.

In fact, there is a natural tendency, to claim credits precisely for those projects that are most profitable, and hence would have been most likely to be executed without the promise of credits. This so-called "additionality problem" is a serious issue. CDM will need to compete with alternative approaches in a post-Kyoto regime.

One of the objectives of CDM is to assist developing countries in achieving sustainable development. In accordance with the modalities and procedures agreed upon in Marrakech in 2001, many host countries have established and published criteria to assess whether a project contributes to sustainable development. However, these criteria are often very general. Although many CDM projects directly or indirectly reduce air pollution or contribute to the diffusion of environmentally sound technologies, and have indirect benefits for the overall economy, only very few projects directly contribute to poverty alleviation. The global CDM project portfolio is mainly determined by the economic attractiveness, the CER-potential and risks of the mitigation options, and not by its contribution to sustainable development. If all host countries would reject projects with few benefits for sustainable development, the global CDM portfolio would be impacted positively, as investors and project developers would have to focus on projects with high benefits for sustainable development. If only one or few countries have more ambitious criteria for sustainable development, this will lower their overall CDM market share, as the investors and project developers can still develop projects with low benefits for sustainable development in other countries [60]. Lessons learned should be taken into account in the development of a post-Kyoto regime.

## 8.6 CDM after 2012

The Kyoto Protocol covers the period from 2008-2012 and no binding agreements have been made on future climate targets yet. Countries have agreed that in Copenhagen in December 2009, an ambitious climate change deal will be clinched to follow the first phase of the UN's Kyoto Protocol. The role of CDM in this climate deal is, however, still unclear. Presently, CDM is used and designed for projects in countries without an emission target that sell the CERs to countries and companies with a target. It is not yet known which countries, including key CDM countries like China, India and Brazil will take on some form of GHG emissions cap, which could affect their eligibility for CDM. However, capped developing countries could still have the potential to undertake projects under any successor Joint Implementation-like[27] regime. Furthermore, sectoral crediting whereby a sector is credited for performance rather than individual projects could be part of a post Kyoto mechanism. Reducing emissions from deforestation and degradation in developing countries (REDD) is formally launched as part of the international post-2012 framework in the Conference of Parties in Bali in December 2007 (see also box 11).

***Box 11: REDD***

Deforestation forms a large source of emissions, which is not addressed very well in the first commitment period of 2008-2012. Methodologies exist for CDM afforestation projects but no project has reached registration so far. The emissions released or captured by forests are described in national communications that countries have to submit to the UNFCCC, but these methods need to be refined.

Reduced Emissions from Deforestation and Degradation in developing countries (REDD) refers to a post-2012 commitment related to financial schemes for adaptation and technology transfer and a blueprint for reducing emissions from deforestation in developing nations. REDD was formally launched as part of an international climate change framework post-2012 in the COP in Bali in December 2007. It is envisioned that demonstration activities will take place in the following two years to gain experience with different approaches before making decisions at the COP 15 in Copenhagen in December 2009.

Since the time to negotiate a post Kyoto climate agreement is relatively short, there is not much time to develop alternatives to CDM, and given the success of CDM so far, it is expected that (an adapted form of) CDM will play an important role after 2012.

Besides CDM, other mechanisms might play a role in a post Kyoto climate agreement. Achieving long-term climate change policy goals will require a ramp-up in the innovation and deployment of energy-efficient and low-carbon technologies. Financial mechanisms like CDM can leverage foreign direct investment to promote less carbon-intensive development. However, putting a price on carbon may not facilitate new investment flows

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[27] Joint Implementation is a mechanism comparable to CDM, but designed for projects in countries with an emission obligation under the Kyoto Protocol.

and associated technology transfers to developing countries with weak market institutions. If a country has difficulty attracting capital generally, changing the relative prices of carbon-intensive and carbon-lean capital will not resolve this problem. In this case, additional policy efforts would be required to stimulate the transfer of technology to developing countries [58]. These policies will need to drive the invention, innovation, commercialization, diffusion, and utilization of climate-friendly technologies. The next international climate agreement can provide several carbon mechanisms to facilitate the development and deployment of climate-friendly technologies. Examples include providing a venue for countries to pledge resources for technology transfer and R&D and coordinating agreement on principles for allocating resources. Likewise, barriers to the transfer of climate-friendly technologies could be reduced through a World Trade Organization (WTO) agreement that lowered tariff and non-tariff barriers to trade in environmental goods and services. Finally, strategies could be put into place to resolve impediments to knowledge transfer in the context of policies for the protection of intellectual property [58].

# 9 SUCCESS STORIES

Around the world, there are numerous examples of successful bioenergy projects, including industrial Combined Heat and Power (CHP) installations, biogas production and utilisation, carbonisation, densification and gasification.

This chapter offers a brief description of a small selection of such success stories. The selection by no means covers the full spectrum of technological options, biomass resources or relevant sectors, nor does it touch upon all the different aspects of each project. However, it does show examples of successful applications that may have a great potential for replication in many countries around the world.

## 9.1 Rice husk fired CHP in the Brazilian rice industry

***Background***

Rice is one of the world's most important food crops. It is produced in more than 100 countries on all continents. Total world production was more than 600 million tonnes in 2006, about half of which was produced in China (29%) and India (22%) [61].

Processing of rice results in the production of considerable residues, in particular rice husk. Each tonne of rice produced, results in the production of about 0.22 tonnes of husks. These husks are relatively dry, and, despite their high ash content, have a good heating value. Some husks are used for producing energy for drying purposes, or as an additive for building materials. However, very often a large part of the husks are not used at all, and are disposed of through dumping or uncontrolled combustion.

With an annual rice production of about 11 million tonnes, Brazil is in the top-10 of rice producing countries [62]. One of the country's largest rice processors is CAMIL Itaqui, located in the state of Rio Grande do Sul. In the year 2001, the company installed a rice husk fired CHP installation to cover their need for process heat and electricity.

***Technology***

Over the years, rice husk has increasingly been used as a fuel for Combined Heat and Power (CHP) installations. In such installations, production of heat for industrial processes or district heating is fully integrated with electricity production. This means that the heat is either produced as a by-product of electricity production, or that the electricity is produced at times when heat demand is low.

The CHP plant at CAMIL Itaqui is a conventional condensing steam power plant with a capacity of 4.2 MWe, which is more than sufficient to cover the company's own electricity demand of 3.5 MWe. The excess electricity is supplied to the national grid. The installation also supplies process heat for rice production, with a capacity of up to 7.8 MWth. Under nominal operational conditions, the installation consumes 7.5 tonnes of rice husk per hour.

Although the CHP installation started in 2001, it was not until 2005 that the company was legally allowed to supply electricity to the grid. Since then, the installation has been operating at full load. Around 90% of the husks that are produced at the rice mill are now used for electricity generation. In 2007, the unit generated nearly 27 thousand MWhe, of which about 23% was supplied to the grid.

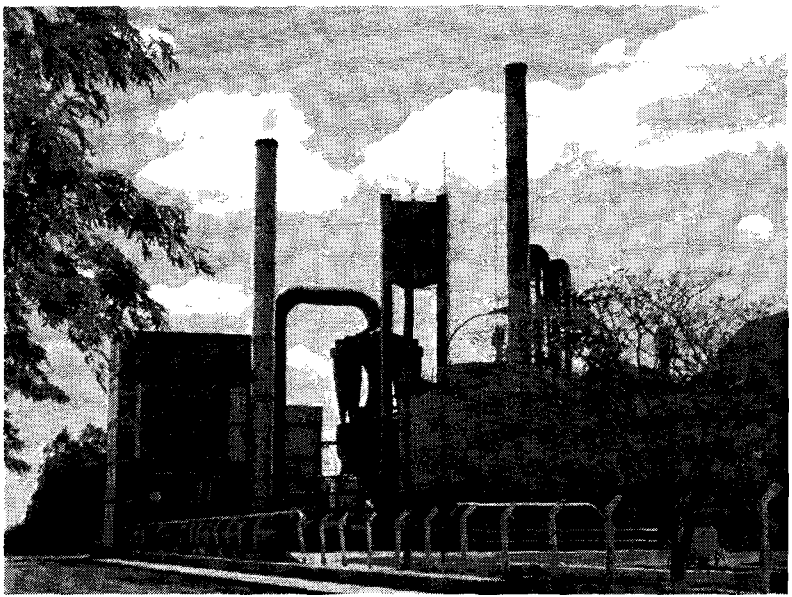

**Figure 9-1** The CHP plant at CAMIL Itaqui [63].

***CDM component***

Rio Grande do Sul state is one of the two states in Brazil that use coal fired thermal power plants complementing the energy demand in the integrated south Brazilian electrical grid. By the replacement of power from the grid and by supply of electricity to the grid, carbon from the coal combustion in electricity plants is avoided.

Apart from this, the use of rice husk for power generation prevents the dumping of residual rice husk, which was the common method of disposal prior to the implementation of the project. As such, the implementation of the project avoids emissions of methane from decomposing rice husk.

The project has successfully applied for CDM registration. In the period of July 2001 to December 2006, the emission of about 260,000 tonnes of $CO_2$ equivalents has been avoided [64]. The generated CER's have been sold to the Dutch company Bioheat International, generating additional income for the project.

***Other benefits***

The plant has a demonstration function in the region and attracts the interest of many rice mill owners. Capacity building for operation and maintenance of the plant is also being promoted. Specialised service companies are introduced and act as carriers of know how; carrying out training of plant operators, specialised maintenance and tuning of the equipment. Knowledge is transferred in the region, thereby developing the use of this technology in Brazil.

*Success factors*

Specific success factors are the following:

- Involvement of a viable industry, with a capacity to invest;
- Application of proven technology;
- Additional income from CDM, which was possible because of the large enough scale of the installation and the portfolio approach.

## 9.2 Wood fueled CHP at TANWAT, Tanzania

***Background***

The Tanganyika Wattle Company (TANWAT), located in Njombe, Tanzania, was founded by the Commonwealth Development Corporation (CDC) in 1949. The company's core business is the production of tannin from wattle (acacia) bark, which is used in the leather processing. In addition, TANWAT is involved in sawmilling and tea production.

In 1995, the company started producing its own electricity and process heat using a wood-fueled CHP plant. The main reason was the limited capacity of the local grid: the national electricity company TANESCO operates a mini grid in the area. The grid was, and still is, fed by diesel generators of 640 kW each, and a small hydro plant. In order for TANWAT to pursue the manufacturing of new products (e.g. irrigation of tea plantations, tea processing), more power was required than available. As the company had quite an amount of woody residues at its disposal (wattle logs, and pine offcuts from the timber sawmill), wood seemed the most economical fuel available [65] [66].

***Technology***

The CHP plant at TANWAT has an electrical capacity of 2.5 MWe. It consists of two wood-fired boilers with a capacity of 15 tonnes of superheated steam per hour. The steam is expanded through a condensing steam turbine which drives a generator. The plant is fitted with a cooling tower to provide cooling to the condenser.

Apart from electricity, the plant supplies process steam to the wattle factory (for tannin extraction) and to the sawmill (for kiln drying). The steam is taken from the boiler, and reduced in pressure and temperature. Under normal conditions, the combined steam consumption is about 12-13 tonnes per hour, which is about 9-10 MWth.

The power plant is fueled with wood chips. These chips are produced on-site using a drum chipper. The chips are stored in two silos, from which they are automatically transported to the boilers.

The fuel for the bioenergy plant is produced by the TANWAT itself. The company produces its raw materials in its own forests (8000 ha of wattle trees, 4000 ha of pine and 1000 ha of eucalyptus). Most of the fuel is produced from the wattle wood. The wattle bark is used for the production of tannin, and the wood is effectively a by-product. Fuel wood production from this source is about 60,000 tonnes/year. Other sources are the wattle bark from which the tannin has been extracted, and residues from the sawmill.

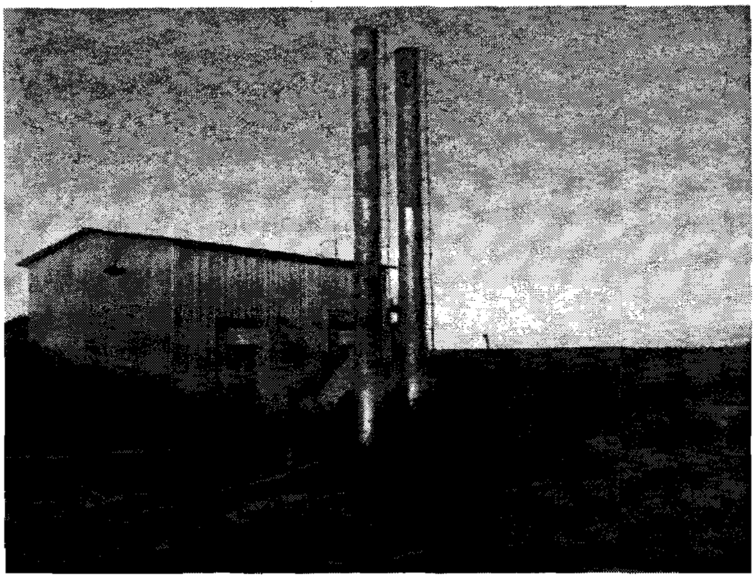

Figure 9-2 The TANWAT Power plant [67]

*Power supply and costs*

Apart from supplying its own production processes, TANWAT is an important supplier to the local electricity grid. The national power company TANESCO purchases about 40% of the power, which it distributes locally through a mini grid. Prior to the implementation of TANWAT's power plant, the grid was powered by three diesel sets and a mini hydro power plant. The power supplied by TANWAT has enabled TANECO to reduce the amount of diesel generated electricity, and to move one diesel set to another location.

Because of the isolated grid and the limited production capacity of TANESCO, the TANWAT CHP plant needs to adapt its power to the instantaneous load. This means that the plant is not always operating at its fullest capacity. During night time the plant operates below capacity; during the evening peak hours the maximum available steam is used for electricity production. Apart from daily fluctuations, seasonal fluctuations also occur. The rain season enables TANESCO hydropower to operate at full capacity, requiring less power from TANWAT.

All in all, the availability rate is high (>95%) [68]. The main reason for the power station for not delivering energy is faults in the TANESCO grid, causing the plant to be disconnected. Internal power consumption nevertheless proceeds.

An indication of the power production costs (2002) shows that total per-unit production costs, at a capacity utilisation rate of 90%, are about 9.4 US$c/kWh. Of this, the variable costs (fuel, O&M costs) are estimated at 4.17 US$c/kWh.

*Success factors*

The CHP plant at TANWAT has been operational for over 13 years. Critical success factors are:

- Implemented and operated by a strong industrial organisation
- Institutional framework allowing for grid power supply
- Control over the fuel supply
- Dedicated professional technical staff.

## 9.3 Building a domestic biogas sector: the Biogas Support Program in Nepal

***Background***

The majority of Nepalese households rely on traditional biomass energy sources like firewood and crop residues. However, fuelwood consumption exceeds natural growth, and overexploitation of forests increasingly leads to deforestation and erosion. In addition, declining resources lead to increasing costs, which leads to an increased use of other energy sources like crop residues and animal dung. Use of such materials for energy production instead of fertilizer leads to declining crop yields and decreased soil fertility.

Biogas has proven itself as a widely applicable domestic energy source. Biogas is a combustible gas that is produced by bacteria, producing methane from biodegradable organic materials in the absence of oxygen (anaerobic conditions). The gas mainly consists of methane (50-70%) and $CO_2$ (30-50%). It can be used as an engine fuel, but also as a household fuel for cooking and lighting.

Biogas provides a clean source of energy, replacing wood, dung and crop residues. It greatly reduces indoor air pollution caused by the smoke from cooking fires. Time spent on household chores (particularly collecting fuelwood and cooking meals) is reduced. Moreover, the effluents from biogas installations have a high fertilizer value.

Because of the household energy problems in Nepal, and the obvious advantages of biogas, a Biogas Support Program (BSP) was launched in Nepal in 1992. The program, which was executed by Nepalese and international organizations, was aimed at promoting and supporting family scale biogas units. The program has proven to be highly successful in building a viable domestic biogas sector.

***Technology***

The principal type of biogas unit that is installed in Nepal is a fixed-dome plant "GGC 2047". This standardised installation was developed within the framework of the BSP and has proven to be extremely successful: 97% of installed plants are operational. The plant is available in 4, 6, 8 and 10 $m^3$ capacity varieties.

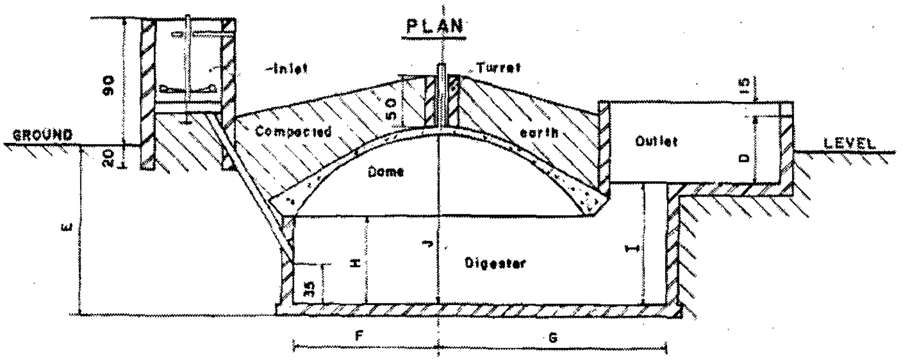

Figure 9-3 Cross section of a GGC 2047 biogas plant [69]

Animal dung is mixed with water in the inlet tank. The slurry then enters the digestion through the inlet. The biogas is captured and stored under the dome, from where it is taken through a gas pipe. The digested slurry exits the digester through the overflow into the outlet tank, from where it can be put in a composing pit.

The installation is constructed using very common materials that are available worldwide (particularly gravel, sand, cement, bricks and piping materials). The construction requires skilled and unskilled personnel: part of the work can be done by the recipient.

***The Biogas Support Program***

Despite the large potential for family scale biogas estimated at 1.5 million, in the early 1990s there were only 6 thousand units installed [70]. Performance of the plants was good, but costs were high due to improper plant sizing. There was a limited supply infrastructure, a lack of promotion and incentives, and support policies were inconsistent.

In 1992, the BSP was launched by Dutch NGO SNV and a range of Nepalese private sector organizations, supported by the governments of Nepal, Germany and The Netherlands. The BSP provided technical assistance to the biogas construction sector, introduction of quality control measures and standards, and dissemination and promotion activities. In addition, a system of investment subsidies and loans was introduced.

The program has proven to be highly successful. To date, about 190,000 biogas units have been installed in Nepal [71]. A viable biogas sector has been established, with several dozens of construction companies and biogas appliance manufacturers. In 2003 the sector employed 11,000 people.

***Success Factors***

Critical to the success of the BSP were the following factors [72]:

- Supportive government policy;
- Proper donor support, allowing long term assistance and investment support;
- Collaboration of international organizations;
- Institutional setup: including key organizations from the public and private sectors;
- Selection of appropriate technology, in combination with quality, standards and after sales service guarantees;
- Successful programme management.

## 9.4 Biogas from wastewater treatment in the Costa Rican coffee industry

### *Background*

The coffee sector has always been an important economic sector in Costa Rica. In the early 1990s there were almost 100 coffee processing plants, processing approximately 875,000 tonnes of coffee beans per year [73].

Coffee mills generate large amounts of waste water, containing high concentrations of organic compounds. A common waste disposal method is discharging in the rivers, provoking enormous pollution, threatening organic life and causing a very bad smell. In 1992, the Costa Rican government and the coffee sector agreed to substantially reduce the pollution caused by waste water discharging.

The stringent environmental legislation required the coffee processing companies to apply waste water treatment prior to discharging. Anaerobic treatment was identified as one of the most appropriate technologies for reducing the organic load of the wastewater. Apart from an effective biological treatment, anaerobic treatment results in the production of biogas, a clean renewable fuel that can be used to generate electricity and process heat.

After a successful pilot project at one of the larger coffee processing companies in 1996, several other large companies decided to install anaerobic wastewater treatment systems at their plants. By 2000, in total 9 systems have been successfully installed.

### *Technology*

The system that was implemented at the coffee companies was based on the Upstream Anaerobic Sludge Bed (UASB) process, which had been developed in the late 1970s at the Wageningen Agricultural University in the Netherlands.

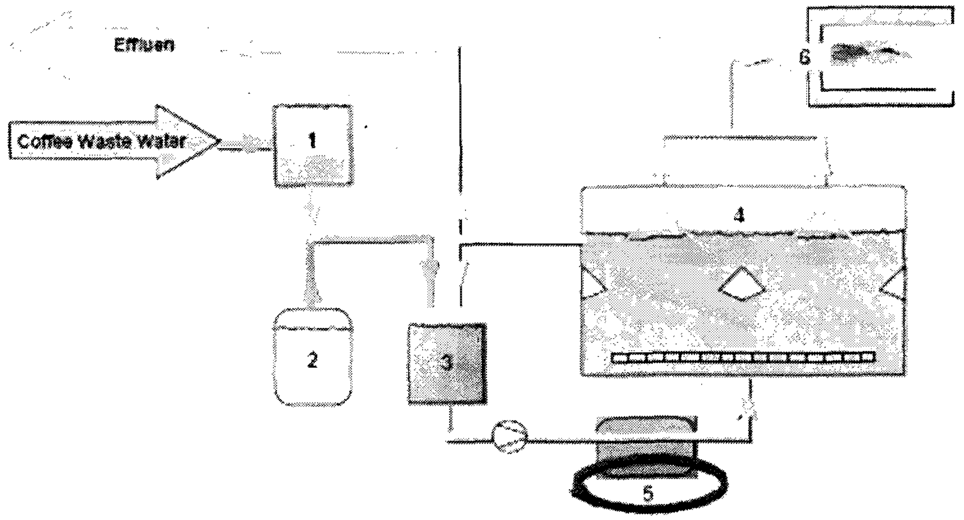

**Figure 9-4** UASB process diagram [73]. 1. acidification tank, 2. alkaline stock, 3. feed tank, 4. anaerobic reactor, 5. heat exchanger, 6. biogas burner [73].

The UASB reactor is basically a concrete basin, with a layer of methane producing bacteria in a sludge blanket on the bottom. The wastewater is pretreated (screened, brought to the right temperature and pH) and enters the reactor from the bottom. On its way upward, it passes through the sludge blanket, where most of the organic compounds are removed by the bacteria. Part of the overflowing, treated waste water is mixed with the "raw" waste water and re-enters the reactor, while another part can be safely discharged.

The biogas that is produced by the bacteria in the sludge blanket goes upward, is captured in the reactor cover, and led to the gas application. In all plants, the biogas is used for the production of energy. In some cases the gas was burned for heat production for drying purposes. In three cases, CHP units were installed that produce electricity (typically 200-300 kWe) and process heat for the coffee factory.

The UASB process is modular based; each module of 250 $m^3$ is able to process 2500-3000 kg COD[28] per day and produces 800 $m^3$ of biogas (75% $CH_4$) per day. This modular concept allows for simplified design procedures and low cost production, facilitating rapid project implementation. The installations have reactor volumes in the range of 500 to 1500 $m^3$, with biogas production between 1000 and 4000 $m^3$/day [74].

***Success factors***

Critical success factors are the following [75]:

- The stringent environmental legislation that was introduced in the early 1990s was a prerequisite for the introduction of wastewater treatment in Costa Rica. The coffee industry was obligated to adopt water treatment measures, and the UASB system was the most viable system available.
- The technology was well-designed for the application. It was flexible with respect to varying organic contents. Modular design and choice of construction materials made implementation easy, at modest investment costs. At the same time, its complexity did not surpass that of other technologies used in the coffee plants.
- The circumstances for producing power for the electricity grid were favourable, and the feed-in tariffs were high.

The dramatic decrease of coffee prices in the early 2000s has taken its toll among coffee processors in Costa Rica, and a number of companies have since then gone bankrupt. In addition, the world market situation has prevented other coffee processing countries to introduce more strict environmental legislation, in order not to damage their coffee industries. In effect this has prevented the more widespread implementation of the technology.

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[28] COD means Chemical Oxygen Demand, a measure of the amount of organic compounds in water, indicating the mass of oxygen consumed per unit of time or volume.

## 9.5 Ethanol as automotive fuel – the Brazilian case

***Introduction***

In recent years, the interest in biofuels for transport has risen sharply. Environmental concerns, the threat of energy dependency, and volatile oil prices have greatly increased the demand for non-conventional energy sources. More and more governments are setting targets for the use of biofuels; recently, the EU has indicated its intent to strive for 10% bio-transport fuels in 2020.

One of the world's best known biofuel programmes started in Brazil, in 1975 already. As a reaction to the 1973 oil crisis, the Brazilian government decided on a large scale programme to produce a domestic transport fuel, in order to decrease the country's dependency on imported fossil fuels, while at the same time supporting the sugar sector which at that time was in heavy weather.

***The PROALCOOL programme***

The start of the PROALCOOL programme consisted of two separate stages [76]. The first was the issuance of an Executive Decree, with an extension through 1978, when distilleries were built and the automotive industry became involved in the production of automobiles running on ethanol, even as ethanol was blended wholesale into gasohol. Low-interest loans were provided to the industry, and targets for gasoline-ethanol blends were set. The second stage, which began in 1979, involved large-scale production of E95 fuel ethanol for vehicles running on straight alcohol. This initiative reached its peak in 1985. See figure 9-5.

Until the mid-1980s, ethanol fuel production grew steadily, reaching a peak value of 12 million $m^3$ in 1985. At that point, oil prices started to decrease, sugar prices went up and government resources for further extending the programme were lacking. Production levels remained stable throughout the years, increasing again at the start of the 21st century. Current interest in the environmental benefits of ethanol, and the introduction of flex-fuel cars that can handle different gasoline-ethanol blends, have provided a new impulse to ethanol production.

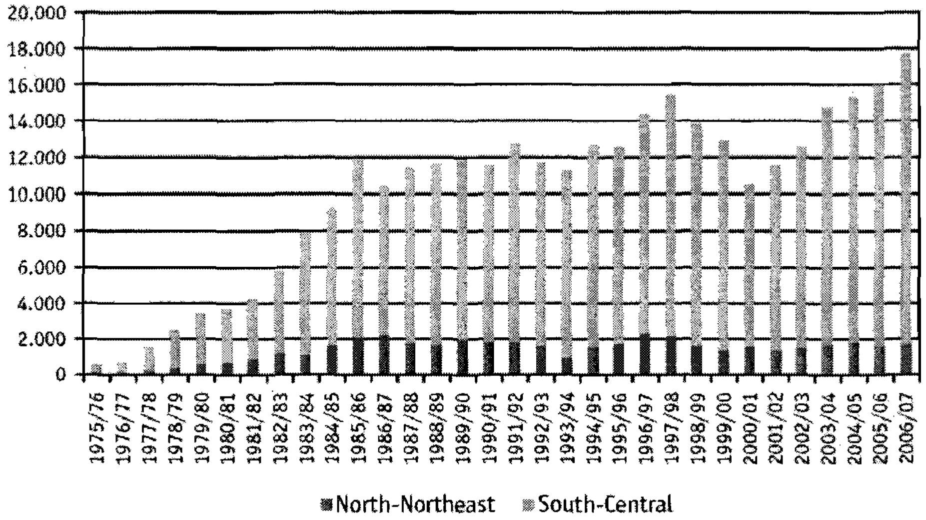

**Figure 9-5** Ethanol production in Brazil (thousands m$^3$) from 1975 – 2007 [76].

***Greenhouse gas reductions***

Although many “first generation” biofuels are criticised for contributing little or nothing to reducing the emissions of greenhouse gases, Brazilian sugar-cane ethanol seems to be an exception. The yield per hectare is high, at a low fertiliser input, and the energy requirements for ethanol production are limited: each unit of energy from ethanol costs 0.12 units of fossil energy [77]. All in all, replacing gasoline with ethanol provides an 85% reduction of greenhouse gases.

***Relevance for developing countries***

Having brought Brazil to its current position as one of the world’s largest ethanol producers, the PROALCOOL programme can be considered highly successful. However, the extent to which it can be replicated in the developing world is limited. The circumstances for the development of an ethanol industry in Brazil were just right: the country was highly dependent on imported oil, and at the same time had an enormous resource base for ethanol production, i.e. a large sugar industry. Secondly, the international market circumstances were favourable: oil prices increased dramatically in the early 1970s and 1980s, while sugar prices were at an all-time low. And finally, the programme has come at high financial costs that would be prohibitive to most developing countries.

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