chapter 14

Case Studies

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Highlights

Around the world, there are both successful and unsuccessful bioenergy project deployment cases. It is important to collect information about the most important cases and analyze them. Driving forces including local conditions, technology adaptations and public policies are key issues to be investigated.

A country's tradition in cultivating selected feedstocks and technologies available for bioenergy production are important factors for increasing the potential for success, as illustrated by sugarcane ethanol in Brazil and Thailand as well as cassava ethanol in Thailand. On the negative side, jatropha was a disappointment in several projects and did not deliver the expected performance.

Adequate public policies as well as smart and sustained government support for bioenergy are mandatory for the success of bioenergy programs. Investors need a medium term view of business risks to feel confident enough to invest in these long-term endeavors.

Africa has a huge potential in terms of land and water resources availability, but to date this potential has failed to materialize in a manner that will benefit the local communities. The causes need to be identified, studied, and compared with successful cases.

Biogas has a large potential to provide significant amounts of sustainable bioenergy, but its contribution to the global energy supply is insignificant. A comparison of three countries of similar economic and technology levels has shown that different conditions can lead to success in one and to failure in the other two.

Agriculture and forestry residues are perhaps the most obvious feedstocks for cellulosic biofuels. However, their positive impacts on soil, water, and air resources mean that only a portion of these materials can be harvested sustainably. Fortunately, several tools are already available to help determine the fraction to be left in the fields.

Woody biomass, including forestry residues, in the form of wood chips and wood pellets is used to generate both heat and power in Scandinavia. In some countries, these are becoming one of the most important energy sources and in others they have already been used for decades.

Municipal solid waste (MSW) is another bioenergy feedstock that is in short supply in northern Europe where it is used as fuel in large district heating systems. Some plants are retrofitted to also use woody biomass feedstock.

Summary

Production and use of bioenergy have significantly increased in the past few years, motivated by the global need to reduce GHG emissions, ensure energy security, and strengthen rural economies. The main issues related to bioenergy are addressed in Chapters 3-21 of this volume. This Chapter presents several success and failure cases that took place in the bioenergy expansion path in several regions of the world, under different feedstocks, technologies, policies, and contexts. The number of cases that deserve to be analyzed is very large and choices had to be made taking into consideration the lessons learned in the process, the comparison of the same bioenergy alternative in different contexts that resulted in success or failure under different policies, the scale of the projects, and the potential for replication of the case in other regions of the world. The present size of the bioenergy programs and replicability potential of the experience have given a larger room to sugarcane ethanol in Brazil and Thailand (in this case using also cassava as feedstock), surplus power generation in sugar/ethanol mills in Brazil and Mauritius, biogas in Germany in contrast with California and the United Kingdom. The importance of using residues to take advantage of their wide availability, low cost, and low environmental impact is demonstrated in Scandinavia, through the efficient use of municipal solid waste for

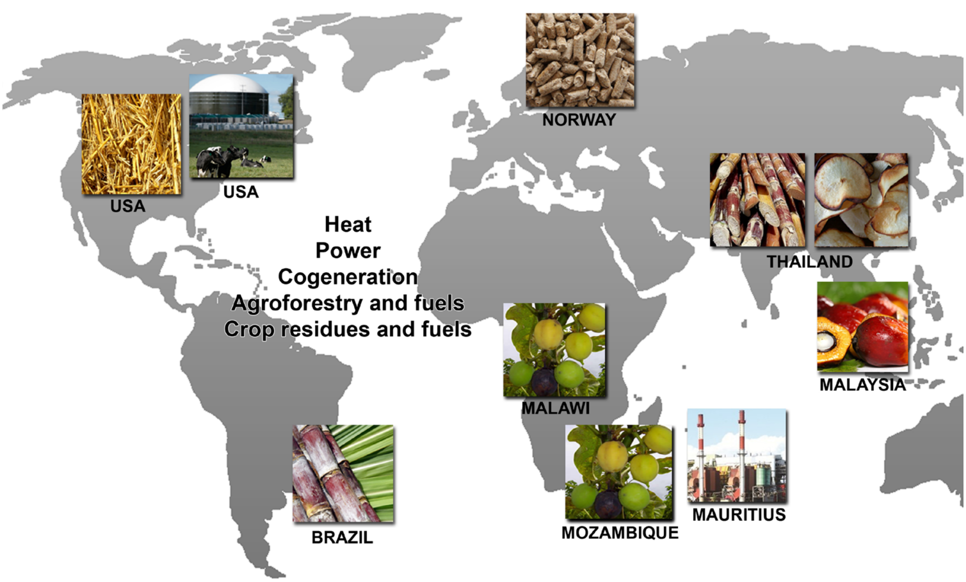

Figure 14.1. The potential of feedstocks for bioenergy production is spread worldwide and needs to be assessed and evaluated for the best alternatives. It is important to learn from available lessons to identify strengths and bottlenecks of each alternative, bearing in mind that local conditions and public policies play a significant role in the success and failure of apparently similar cases.

heat and power by combining with other biofuels, and the economic analysis of the impacts on the use of palm oil production residues. The limitations for a sustainable collection of agricultural residues, such as corn stover, is shown in the work developed in the USA where a model was created to define the minimum amounts of residues that need to stay in the field for soil protection and fertility preservation; this methodology can be adapted to other agricultural residues in other regions, but it will require field experiments and better analysis of the local conditions. The surprising failure of most *Jatropha curcas* biodiesel projects in Africa is commented based on the experiences underway in Mozambique and Malawi in different scales and production models (large and small scales, respectively).

We discuss problems and successes of each case. It is apparent that public policies play a very important role in the final outcome of the bioenergy projects, for instance in the cases of power generation from sugarcane residues in Mauritius and Brazil, biogas in three apparently similar countries and sugarcane ethanol in Brazil and Thailand.

14.1 Introduction

Worldwide, the use and production of bioenergy is growing very fast, driven mostly by concerns about global warming and energy security, and more recently by the enhancement of rural development. As a result, in 2012, ethanol and biodiesel, the main transport biofuels, reached production volumes of 83 and 23 billion liters, respectively, representing approximately 3% of the global transportation fuel requirement. Similarly, in 2011, the production of wood pellets increased to 22 million metric tons (REN21 2013), or some 350 PJ. At the same time, there are controversies concerning alleged negative impacts on food availability and prices as well as questionable statements regarding reduced greenhouse gas (GHG) emissions, due to the emissions resulting from the so called indirect land use change (iLUC).

Ethanol production is highly concentrated in the USA and Brazil, representing around 87% of the total world production. The sugarcane case in Brazil may be widely replicable around the world, since sugarcane is cultivated in more than 100 countries with similar yields, but the success of corn ethanol in the USA will be more difficult to replicate because average corn yields in the world are slightly over one third those in the USA, making the economics highly difficult to replicate sustainably. Also, the GHG abatement potential of corn ethanol, according to the US Environmental Protection Agency (EPA 2010), is very low on average and does not meet the threshold value requirements of the US Renewable Fuel Standards (to qualify as an advanced biofuel) nor those of the EU Renewable Fuel Directive (to be counted towards the Directive mandated values). Besides these two successful cases, there are a few other ones, including sugarcane ethanol in Colombia, Thailand, Guatemala, and Malawi as well as biodiesel in Europe, Argentina, Colombia, USA, and Brazil. On the other hand, bioenergy production failures are abundant, such as the biodiesel from jatropha in many locations worldwide.

Wastes and residues are highly recommended feedstocks for bioenergy production since they can be a source of pollution if not treated or used otherwise. They are generally cheap, available everywhere, and have low GHG emissions in the production chain (normally accounted for in the main product). There are several success stories worldwide including millions of small biogas facilities built in China and India, but it is difficult to assess the long-term results of these large-scale experiences. The use of forestry and wood mill residues to produce solid fuels (pellets, briquettes or in natura) to displace fossil fuels in household and industry heat or power generation (direct or in co-firing) is also growing and indicative of a trend toward becoming a major biofuel.

The strength of driving forces and existence of adequate legal and policy framework are normally the major reasons for success or failure, as illustrated in this chapter. Technology availability and use are also important factors, and although adequate technologies are normally available for feedstock production and processing phases, the question is how to ensure they will be used, especially considering the conservative nature of farmers in developing countries and their reluctance to give up traditional practices. This raises the question of scale, which is very important for the economics, notably in the processing phases, but there are some small-scale projects that have succeeded. However, those projects are highly dependent on planning for local conditions such as land tenure, agriculture production, and deployment capabilities. A combination of small/medium feedstock producers with large-scale processors can be made to work properly without much sophistication, as shown with sugarcane in Thailand, India, South Africa and other countries, but adequate technology must be made available and used by the feedstock producers.

This chapter summarizes lessons learned on several of the problems listed above and takes advantage of the authors' knowledge of the projects. The case studies presented are only examples and not a comprehensive survey. Chapters 8 and 12, this volume, present other interesting cases of bioenergy production and use, thus supplementing the information in this Chapter.

14.2 Key Findings

14.2.1 The Brazilian Experience with Sugarcane Ethanol

Brazil ranks second in global ethanol production (USA is first) but is the primary sugarcane (*Saccharum officinarum* L.) and sugarcane ethanol producer. A brief summary on ethanol in Brazil is presented in Chapter 8, this volume, and in this chapter, only some key issues are described aiming at providing information about the ups and downs of the ethanol trajectory in displacing gasoline toward reaching a market competitiveness without subsidies through technology improvements, as well as adequately balanced conditions between cane producers and millers, and reduced demand for chemical fertilizers via waste use and better use of the land with crop rotation between cane cycles.

The Role of Private Sector in Technology Development and Transfer

The main drivers for recent ethanol production policies include: substitution for imported oil (1975); employment and reduction of local air pollution (1980s); mitigation of GHG emissions (1990s), and demand for electricity (2000s). Accordingly, support for R&D (Macedo and Nogueira 2010) came from different agencies, and always with strong participation of the private sector. Private stakeholders (cane producers, distillery owners, equipment manufacturers, input suppliers, engineering companies and automakers) and government institutions (funding agencies, research institutions) have all contributed to technology development/implementation.

From 1980 to 1990, the primary advances included new cane varieties, milling and fermentation improvements, stillage recycling, biological controls and agricultural equipment (Macedo and Nogueira 2010); since 1990, harvest mechanization, logistics, industrial automation, and flex fuel cars have been the primary improvements. Developments contributing to these advances include transgenic varieties, precision agriculture, electricity production from biomass wastes, second generation ethanol (2G) and new co-products. Table 14.1 summarizes the key results of technology improvements.

Table 14.1. Overall results, from 1970 to 2010[(1)].

	Productivity t cane / ha	TRS in cane kg TRS/t cane [(3)]	Industrial Conversion %	Ethanol t TRS/ha	Cost R$/L ethanol [(2)]
1970	49	87	82	3.5	3.0
2010	85	145	87	10.7	1.0

[(1)] Data from CTC and UNICA (Brazilian Sugarcane Industry Association), presented in (CTC 2013a)
[(2)] Constant R$, basis Jan 2011
[(3)] TRS: Total Recoverable Sugars

Implementation of Self Benchmarking Programs

The rapid growth of ethanol production in different regions and with different constraints called for well planned and reliable data acquisition and diffusion, to support technology development and implementation. Benchmarking programs for cane production and processing started after 1991 at the Sugarcane Technology Center (CTC) (CTC 2013b). This system has now 180 mills, and its database includes hundreds of parameters. A varietal census, covering 6.5 million ha of cane and 300 mills, completes the system indicating the commercial use of sugarcane varieties in the different cane producing areas in Brazil. Data acquisition is on line and analytical procedures are established by the CTC (CTC 2007). There are also checks for consistency with results published monthly / yearly, for the associated mills (regional and global averages, time evolution, dispersion). These programs have been very important for technology development/ diffusion throughout the country.

The Cane Payment System

Brazil has approximately 70 thousand independent cane producers and 440 processing industries. The sugarcane industry has specific conditions (high transportation/production cost; need for fast processing after harvest) that lead to a strong interdependency among cane producers and the processing industry; worldwide, different local policies and market organizations are used for price formation models.

After a period during which prices were set by the Government, the private sector in São Paulo established the most successful price formation model in Brazilian agriculture in 1998: a council (Consecana) of cane producers and sugar millers who developed the concept that actual revenues be distributed among the two sectors according to respective costs and cane quality (Machado Neto et al. 2011).

The Consecana model in São Paulo includes 19,400 suppliers producing 130 million t cane (UNICA 2013). Rules, operations and evolution can be consulted (CONSECANA 2006). Similar models are extended to most producing regions.

Recycling Vinasse through Fertigation

Environmental legislation during the last 30 years has determined site specific application guidelines for vinasse (m^3/ha), eliminating soil/water contamination (CETESB 2007) and regulating vinasse storage and distribution (impermeable tanks and channels; in some cases, pipelines). Engineering solutions starting in 1978 (Elia Neto 2007; Souza 2005) led to efficient recycling of stillage (K as fertilizer and water); and also included filter cake and boiler ashes. Vinasse became an important, cost-effective nutrient source, potentially providing 2.45 kg/t in K_2O savings (Donzelli 2005). However, two decades of developments on stillage bio-digestion, including commercial systems and stillage drying for mineral fertilizer formulations, still lack proven economic results.

Use of Idle Land between Harvest and Planting of New Cane

Sugarcane is planted once and harvested after 12 to 18 months of growth depending on when the crop is planted. After the first harvest, the cane re-grows as a ratoon crop that, on average under Brazilian conditions, can be harvested four more times, before the cycle is terminated and the cane replanted. With the 18-month cane growth period, there are a few months between the last harvest and the planting of the new cycle. During this period, it is normal to rotate with nitrogen fixing or other crops such as soybean [Glycine max (L.) Merr.], dry beans [Phaseolus vulgaris], peanuts (*Arachis hypogaea*), sunflower (*Helianthus annuus*) and hemp (*Crotalaria juncea*) (Penariol and Segato 2007). In the Center-South region of Brazil, planting of rotation crops takes place from September to December and harvesting is from January to March. The green material is incorporated in the soil to increase organic matter and nitrogen contents. This procedure has shown significant increases in yields and economic gains from the sale of crop products (soybeans, beans, peanuts, sunflower seeds) and from renting the land to independent growers (Alleoni and Beauclair 1995; Dinardo-Miranda and Gil 2005).

Present Problems

The Brazilian sugarcane sector was growing at a rate of approximately 10% per year between 2001 and 2008 (UNICA 2012a), but during the 2008 financial crisis, the sector found itself highly indebted and unable to obtain money from the banks to finance operational costs. Consequently, mills had to cut expenses. They did so by reducing the application of fertilizers and herbicides, postponing sugarcane field renewals, and laying off personnel. These actions had an immediate and lasting impact on cane yield and quality. Furthermore, the fast increase in mechanized harvest to comply with regulations phasing out cane burning, as well as weather problems in 2009 to 2011 (excess rain in 2009, drought in 2010 and frost and cane flowering in 2011), and poor agriculture management (use of low quality seeds in planting – old cane with diseases and pests) also affected the crops (Sanguino 2013). The compound outcome was a reduction of cane yield from the 20 year historical average of 84 t of cane/ha to 69 t of cane/ha in the 2011/2012 season (UNICA 2012b). Other production costs, such as the price of renting land, chemical inputs and labor, however, sharply increased mainly because of higher oil prices and shortage of qualified labor (UNICA 2012a).

Fortunately, the sector identified the problems associated with past actions and contexts, and started correcting them by accelerating cane field renewal, taking precaution to plant better quality seeds, and reducing the negative impacts of mechanization (soil compaction and ratoon damage). The government also helped by making money available to finance the cane planting activities. With this, the yield is slowly increasing, reaching 72 ton/ha in 2012 and 78 ton/ha in 2013, in the Center-South region (CONAB 2014). On the political side, the situation remains unresolved since the central issue is the government's policy to maintain gasoline price for the domestic market below the international prices, thus reducing competitiveness of ethanol at filling stations.

Conclusions: Brazil has a long history of bioenergy production. Public/Private sector cooperation was essential for identifying problems associated with past actions and for developing effective strategies to correct them. A benchmark system based on well planned and reliable data acquisition and diffusion is crucial for supporting biofuels technology development and transfer. Recycling residues decreased the demand for chemical fertilizer and the planting of crops in rotation with sugarcane at the end of the five harvest cycle added economic viability to sugarcane ethanol. Finally, a payment system based on cane quality and fair division of profits between growers and millers is the reason behind the socioeconomic sustainability of the system.

14.2.2 Surplus Power Generation in Sugar/ Ethanol Mills: Cases in Brazil and Mauritius

Surplus power generation is becoming a trend in several sugarcane producing countries, especially in Brazil, India, Mauritius, and Reunion. However, the Brazilian and Mauritian experiences differ in realization of the potential, including what makes these cases worth exploring.

Bioelectricity from Sugarcane in Brazil: Evolution and Current Situation

Currently, hydroelectricity and natural gas are Brazil's primary sources of electricity, accounting for almost 80% of installed capacity (Figure 14.2). Bagasse and straw from sugarcane are in third place, representing 7% of Brazil's installed electric energy matrix (ANEEL 2014).

Bagasse and straw are the main sources of biomass for bioelectricity, accounting for 81.5% of Brazil's biomass-based installed capacity in 2013. The sugarcane sector with its 9,156 MW, in addition to being self-sufficient in steam and electricity for manufacturing sugar and ethanol, has been able to generate surpluses of bioelectricity to the grid since the middle 1980s.

In 2012, bioelectricity from sugarcane was responsible for almost 3% of the total consumption of electricity in Brazil. However, there is a potential to reach 18% by 2020/21 (EPE 2013). Nevertheless, the sugarcane and bioelectricity sectors need long-term policies to stimulate investment.

One of the main barriers to cogeneration projects is connection to the National Grid. In Brazil, the connection cost has to be paid in full by the bioelectricity supplier and, in some cases, it represents 30% of the total project investment. In order to reach the potential, the country needs to establish a free or co-shared cost policy for building the bioelectricity transmission system (Souza 2013).

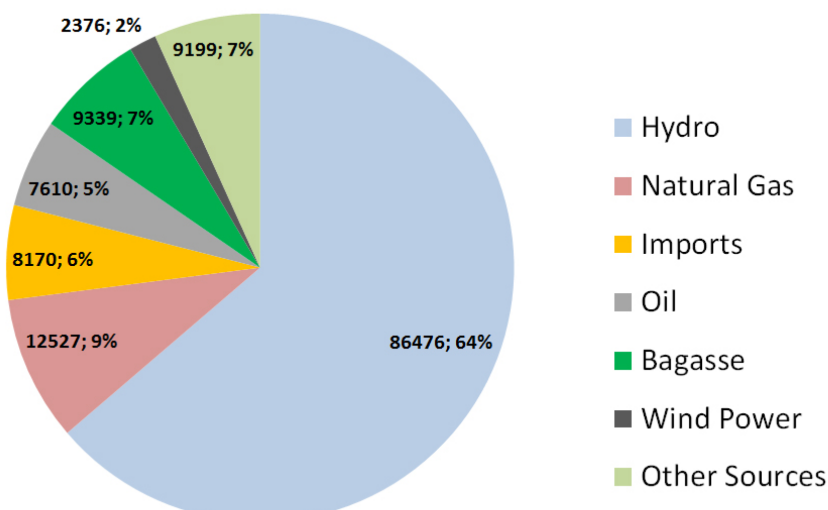

Figure 14.2. Brazil installed capacity by source, March 2014 (MW). Source: ANEEL (2014).

According to Souza (2012), another significant barrier is the commercialization in regulated auctions, promoted by the federal government.

For example, on March 15, 2004, the Law n. 10,848 (New Model of Electric Sector), which specifically focuses on altering the trading environment, was passed. Its main focus is the creation of two distinct energy trading environments in which a generator can act: (1) an environment for contracting energy aimed at distribution companies, called RCE – Regulated Contracting Environment, and operating from energy auctions as the pool for contracting; and (2) a market with more flexible commercialization rules, for producers, free consumers, and energy commercialization enterprises, called FCE - Free Contracting Environment (Souza 2012).

Under RCE, distribution companies purchase electric energy for their markets through public auctions regulated by ANEEL (National Energy Agency - in charge of regulating the sector) and operated by the Electric Energy Commercialization Chamber (CCEE), under the procedures of the Ministry of Mines and Energy (MME) (Souza 2012).

The energy needs, estimated by distribution companies for a horizon of five years, are analyzed by the MME. This represents the demand to be contracted through auctions, characterized as reserved auctions of purchase. On the supply side, there are companies with existing mills and those aiming to build new mills, even if they still do not have concession contracts or authorization to do so. These auctions are called “Auctions of Purchase New Energy and Existing Energy”. According to the new electric sector model, new energy auctions should take place five, three and one year before the effective supply of electric energy to contracting distributors. Therefore, these auctions are called A-5, A-3 and A-1 (regular auctions), while other non-regular auctions are for reserve energy and alternative sources (Souza 2012).

The use of reverse auctions to improve the renewables industry is frequent in Latin American countries, mostly in Brazil, Chile, Peru, Colombia, and Panama (Maurer and Barroso 2011). In Brazil, these auctions are the primary long-term method for selling bioelectricity.

In the Brazilian power sector, reverse auctions have resulted in significantly lower prices, which represents one aspect of success for the consumer (Table 14.2), but this situation has resulted in contracting fewer types or sources of generation and limiting contracts to those whose structural and situational aspects are favored (wind power in particular). Despite the appeal of low tariffs, achieved through competitive auctions, in the long run, this policy should be adjusted to avoid restrictions on development of other renewable sources and their associated industries (Souza 2013).

The generic auctions in the Regulated Environment, without discrimination of the location of enterprises or type of power generation, has limited the ability of the Federal Government to compose the energy matrix according to the needs and potential of each region and source of generation, bringing costs and more losses in power transmission and adding possible variables of uncertainty into the management of energy supply (Souza 2012).

Table 14.2. Price and volume of bioelectricity contracted in regulated contracting environment, 2005-2013 (US$/MWh).

Auction date	Contracted energy (MWh/year)	Current price (US$/MWh)*
Dec-05	849,720	76.44
Jun-06	508,080	81.86
Oct-06	534,360	82.96
Jun-07	1,007,400	81.76
Aug-08	4,756,680	85.81
Sep-08	306,600	79.58
Jul-09**	87,600	76.24
Nov-09	8,760	41.79
Aug-10	1,669,656	71.37
Dec-10	8,760	53.58
Aug-11	713,064	48.04
Dec-11	183,960	45.78
Aug-13	1,170,336	56.65
Total	11,804,976	

Source: Souza (2013).* US dollar exchange rate of August 31, 2013. ** Since 2009, wind power is presenting significant competitiveness in the reverse auctions leading to a decrease in the average prices

Regulated auctions should take the potential of each source or region into account. For sugarcane biomass, the potential is mainly in the Center-South region of Brazil, which also happens to be the number-one energy consuming region in the country. It would be an encouragement if the Brazilian government changed its strategy of contracting power via “generic” auctions that blend sources which are unmatched even by the intrinsic qualities of each one (Souza 2011). Furthermore, it’s necessary to refine the pricing model of regulated auctions to incorporate the positive and negative impacts (externalities) not only of biomass but of other sources as well, which would certainly promote the development of bioelectricity in the Brazilian electric matrix.

Bio Electricity from Sugarcane in Mauritius: Progress and Prospects

Mauritius was the first country to export electricity from a sugar factory to the grid when in 1957, the St. Antoine Sugar Factory in the North exported some 0.28 GWh to the Central Electricity Board (CEB). This was the beginning of a fantastic opportunity for the industry. Since then, the amount of electricity cogenerated by sugar factories from bagasse has been in constant progression. In this evolution there are three distinct phases, namely:

Intermittent, when electricity was exported to the grid from 17 out of 21 sugar factories as available surplus electricity after meeting sugarcane processing requirements.

Continuous, when with the acquisition of appropriate equipment and elementary energy saving devices in 1977, a given amount of electricity to be supplied to the grid was agreed upon. For example, the Medine Sugar Factory in the West with an installed capacity of 10 MW, guaranteed to supply 6 MW to the grid.

Firm, when in 1982 with the acquisition of medium pressure boilers of 44 bars and 475^{o}C steam, the FUEL factory in the East supplied electricity throughout the year, from bagasse during the crop period and from coal during the inter-crop period.

The establishment of the Independent Power Producers (IPP) and the construction of bagasse-fired power plants not necessarily linked to sugar factories in the form of independent power companies further consolidated this firm approach. A significant step forward was the development of the Centrale Thermique de Belle Vue (CTBV) in the North of Mauritius with two high pressure boilers of 82 bars, with steam at 525^{o}C, and an installed capacity of 2 x 35 MW. In 2007, the Centrale Thermique de Savannah (CTSAV) in the South (now Omnicane Energy Operations Limited, La Baraque) was established with an installed capacity of 2 x 45 MW using two high pressure boilers with steam temperature similar to those at CTBV.

The success behind cogeneration of electricity from bagasse in Mauritius and selling to the grid is a result of a continuous and sustained Competitiveness Improvement Program initiated in 1985. The program comprises five phases as detailed below. The Sugar Sector Action Plan (1985), the Sugar Industry Efficiency Act (1988), the Bagasse Energy Development Programme (1991), the Blueprint on Centralization of Sugar Factories (1997), and the Multi-Annual Adaptation Strategy Plan (2006) are of particular importance. These programs which were supported by law, allowed the industry to enhance its competitiveness by increasing its revenues from diversification of its purely sugar activities. The power purchase agreements between the IPPs and the CEB were instrumental to the success of large-scale electricity production from bagasse during the cropping season and coal during the inter-crop period. In 2012, bagasse supplied 16% of the electricity needs of Mauritius.

In 2002 the share of electricity from bagasse amounted to 340 out of 2484 GWh produced in Mauritius, i.e. 13.7%. The growth of this source of electricity is shown in Figure 14.3,. It shows that there was a major growth of the coal share due to its successful combination with bagasse to generate electricity year round.

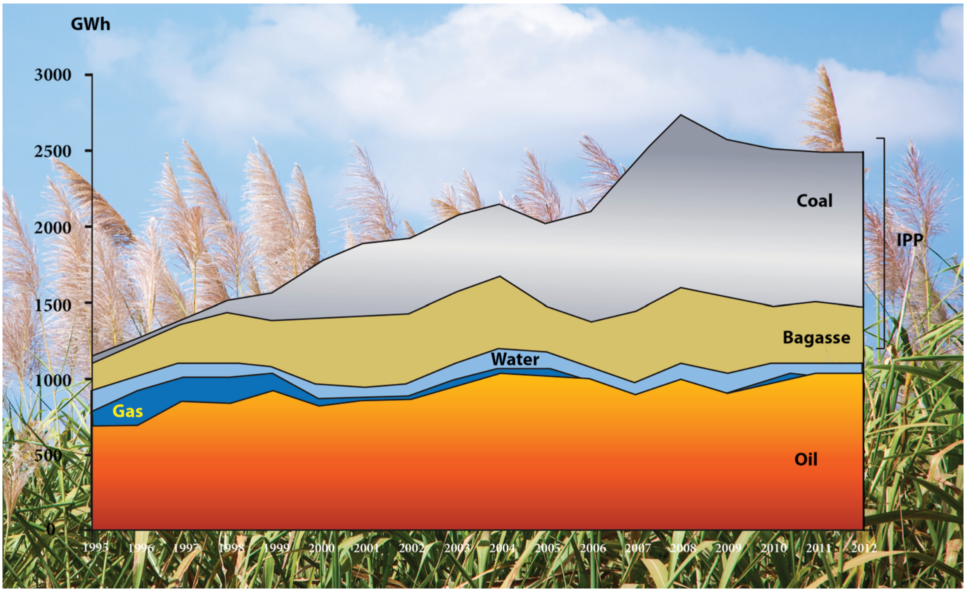

Figure 14.3. Electricity production by source in Mauritius.

At the end of 2013, the centralization process was finally completed with the closure of the sugar mill at Beau Champ in the east of the island, leaving only four factories in operation in Mauritius (one in each geographical section of the island) and with all the bagasse used in high pressure boilers, such as in CTBV and CTSAV, some 550 GWh will be produced from a sugarcane output of approximately 4 M tons. More details are provided by Deepchand (2008) and Kong Win Chang et al. (2001).

National Competitiveness Improvement Programs in Mauritius:

1985	Sugar Sector Action Plan – Restructuration, Modernization Bagasse Energy Policy evoked – Tax free revenue, Export duty rebate on bagasse saving and capital allowance on bagasse energy investment
1988	Sugar Industry Efficiency Act – System of performance linked export duty rebate to improve efficiency in farms, mills and power plants. Tax incentives to produce special sugar, save energy and optimize use of bagasse
1991	Bagasse Energy Development Program – Modernization, technology development, pricing policies such as tax rebate on electricity produced from bagasse and refund of export duty for the installation of energy efficient equipment
1997	Blue Print on Centralization – Facilitate closure of small inefficient factories, linking closure with optimal energy use from bagasse, while offering the right compensation package to leaving employees
2006	Multi-Annual Adaptation Strategy Plan – Drastic restructuration from 11 mills to 4 efficient ones, right-sizing of labor, intense modernization, construction of power plants, distillery and refineries coupled with aggressive marketing

Conclusions: The Brazilian story in surplus power generation had all the ingredients to be successful due to the sector's expansion and building new and large scale mills with high pressure boilers; however the present rules of power contracting at auctions and the lack of government action to solve the high cost of connection problems is jeopardizing the opportunity to develop the huge potential available. The success behind cogeneration of electricity from bagasse in Mauritius and selling to the grid is the result of continuous and sustained Competitiveness Improvement Programs initiated in 1985 with full support from the government and private sector. The track record of Mauritius in terms of bioelectricity production is laudable. However, with the decrease of the area under sugarcane plantation the participation of bagasse in the national energy mix tends to decrease. To maintain or increase the bioelectricity production, the sugarcane sector is looking into the recovery of sugarcane straw (normally called trash), the use of high fiber cane to increase bagasse yield and, ultimately, introducing the biomass gasification/ combined cycle (BIG/CC) technology in the mills to replace the conventional steam cycle.

14.2.3 The African Experience

Despite extensive interest in biofuels, to date there has been very limited production of biofuels in Africa with Malawi being the notable exception because their ethanol has been blended with petroleum since 1982 (Batidizirai and Johnson 2012). At the global level, the total contribution of biofuels from Africa is trivial (IEA 2011), this despite the continent's vast areas of land that are climatically suited for biofuel feedstock production (Smeets et al. 2007; Watson 2010). A large number of African countries have recently developed biofuel policies that envision a contribution of biofuels to the national energy mix (Mitchell 2011). This is seen as being beneficial as a large proportion of foreign exchange is spent on petroleum imports, and in addition the biofuel can contribute to rural upliftment (Diaz-Chavez 2010 and 2013). Biodiesel from *Jatropha curcas* is where there has been the largest investment in biofuels, with GEXSI (2008) estimating over 94 projects and 119 000 hectares being allocated to jatropha in 2008. However, Locke and Henley (2013) found that only 3.6, 12.9 and 3.2 percent of authorized land was actually planted to a biodiesel feedstock (prominently as jatropha) in Mozambique, Zambia and Tanzania, respectively. Several studies reported large-scale collapse of both small- and large-scale jatropha projects (Gasparatos et al. 2012, Locke and Henley 2013; von Maltitz et al. 2012), and none have been found to document extensive oil production from any project or country. This outcome was despite the many jatropha projects established in the mid 2000s. Extensive interest has also been shown for sugarcane based biofuels, but progress to date has been slow, and many proposed projects have stalled in their implementation. Ethiopia, Sierra Leone, Zambia, Zimbabwe and Mozambique are all currently developing plans for ethanol production (Batidizirai and Johnson 2012).

Therefore, Africa's rich history of successes and failures in the implementation of bioenergy projects deserve to be told and discussed. Two interesting examples are included here promoting the same feedstock (jatropha), but with different production models.

Jatropha Projects in Southern Africa

Southern Africa was identified by many investors as an ideal location for jatropha based biofuel development. At least 52 projects were initiated in the region (GEXSI 2008), but most failed and have been abandoned by their investors (Gasparatos et al. 2012). There are multiple reasons, but jatropha's low yields and higher maintenance costs compared to investors' expectations were a major factor.

Jatropha was promoted for its tolerance to dryland conditions and potential ability to grow on wasteland. However, experience has shown these early assumptions were flawed. More recent data suggests that although the tree will grow in low rainfall areas, good yields will require an annual precipitation of over 800 mm. However, the tree also responds poorly to waterlogged soils (Trabucco et al. 2010) so rainfall distribution is also important.

As a result, investors tended to plant jatropha on good soils rather than on wastelands. Furthermore, management costs for jatropha were also found to be relatively high, with seed picking and dehusking in particular being very labor intensive (von Maltitz and Setzkorn 2012). Despite these limitations, a few projects continue to expand and their developers are cautiously optimistic regarding long term successes (von Maltitz et al. 2014). Two projects with contrasting management models were visited in March 2013: one large-scale plantation project in Mozambique and a small-scale hedgerow based project in Malawi (von Maltitz 2014; von Maltitz et al. 2014). Key features of these two projects are summarized in Table 14.3. Despite the fundamental differences in management models of these two projects, both show signs of potential long-term success. Clearly, jatropha is not the high value, low input crop that had initially attracted investors (Gasparatos et al. 2012). However, where expectations are more modest and input costs are low, there seems to be a potential for long-term economic success. In both projects, economics are based on yields of three tons per hectare or less. The plantation type project would seem well suited to areas of relative land abundance, whilst the hedgerow project is better suited to areas with a high farm density. The intense poverty in both areas is another reason why a relatively low valued crop may succeed. Though the two projects use very different production pathways, both, if successful, can have significant positive impact on fuel security in both countries. Long-term success is, however, not guaranteed. A lot will depend on jatropha's ability to actually deliver even the more modest yield on which these projects are based. Something that only time will tell. Also, the financial viability of the projects under real world management is still unknown.

Table 14.3. A comparison of two jatropha projects, the Malawi BERL project and the Mozambique Niqel project. (based on von Maltitz 2014; von Maltitz et al. 2014).

	BERL Malawi	**Niqel Mozambique**
Project type	Small growers planting jatropha as hedgerows. Trees managed by the farmer's household	Large-scale commercial block plantation. Trees managed by paid labor
Project extent	90 field extension staff employed to train and establish over 6 million trees with 30,000 smallholders. BERL ceased extension of planting activities in 2013. Now waiting for the 6 million trees to mature	2,000 ha planted of a proposed 5,500 ha at Grudja. 250 permanent staff plus casual labor for harvesting
Current demography and smallholder farming practices	High population density. Wall to wall permanent small farms of 0.1 to 2.5 ha (1.7 mean). All farmers grow maize, with a wide mix of other crops. Mean income from agricultural sales US$ 38, with most households having 4.1 ± 2.7 (SD) months of food shortage per year	Low population density. Less permanent farms with slash and burn opening of new fields. Only 11.5 % of total land under cropland, the rest woodland. Farms range from 0.5 to 14 ha (3.97 mean), with households reporting a median income from agricultural sales of US$83. Most households having 5.9 ± 4.5 (SD) months of food shortage per year
Role of investor	Providing extension support, purchaser of seeds and oil extraction	Growing trees, harvesting and extracting oil
Processing	BEREL has an oil extraction plant based in Lilongwe. Seeds are purchased from farmers by BERL then transported to Lilongwe for extraction. BERL will sell as pure plant oil. First season oil extracted, but not yet sold	Niqel intends to extract oil at the plantation, extraction plant due to be installed in 2014. Niqel will sell as pure plant oil At the time of the study, no oil yet extracted
Proposed destination of final product	Oil to be directly blended into national diesel fuel to a maximum of 9%. To date this has not happened due to policy delays around the acceptance of the standard	Oil to be exported to Maputo – will probably undergo transestification for blending. Niqel aims to produce 25% of total Mozambique bio diesel needed to achieve 3% blend with diesel
Harvest, yield to date and hoped for yield.	2012/13 first harvest (Jan to Mar) yield ranges hugely, median 0.07 kg/tree, but with 5 farmers reporting over 0.4 kg/tree. BEREL target is 1.5 kg/tree per year at maturity which is equivalent to 1.9 t/ha (at 1250 trees/ha)	2012/13 first formal harvest. Yield increased from 0.16 t/ha in the first year to 0.4 t/ha from two year old trees. Target is 3 t/ha at maturity

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	BERL Malawi	Niqel Mozambique
Proportion of farm land converted to jatropha	A 500 tree jatropha hedge takes up 7% of the average farm at present. This might increase slightly as trees grow	Approximately 6% of the total village's area is converted to jatropha, reducing the potential land area per farmer from an estimated 27 ha to 25 ha. This is far more than the average 4ha used per farmer, and nearly all farmers said they had sufficient land
Impact on food security	At present seems minimal though some cropland land is lost to jatropha trees and there is possible competitive interaction between trees and crops	The plantation does not limit land for home food production Plantation policy limits labor to one family member per household, and respondents say they can maintain their crop production
Impacts on woodlands and woodland products	No or minimal impact	Will be 5500 ha of woodland lost, however, given the ratio of woodland to households the impact of this loss will be minimal in terms of the provisioning services it provides
Infrastructure benefits	BERL has established an oil pressing plant in Lilongwe	Niqel has established 200km of all-weather road. This allows community members from surrounding villages to access the tar road during the wet season – something they could not do in the past. They are also building a new primary school and have created small dams for community water provision

Conclusions: Africa has seen several failures and a few successes in the implementation of biofuel projects. The two projects presented here show some interesting lessons to be learned: Jatropha has demonstrated to be a risky feedstock and not as successful as anticipated because of erroneous initial assumptions regarding crop growth, development and yield potential. It is important to follow and evaluate the installation and operation of such projects to identify the main causes of failure and success and the results properly disseminated, since there is a very broad worldwide interest in this crop.

14.2.4 The Asia Experience

Asia is showing a fast growth in energy demand and bioenergy may or may not play an important role depending on results of the first bioenergy projects and the corresponding experiences and lessons learned. Thailand as the fourth largest sugarcane producer and second largest cassava producer in the World, has launched its ethanol program based on these two feedstocks and is proceeding successfully creating a production system that can be used as reference by other Asian countries with similar conditions. The growing production of oil palm, especially in Malaysia and Indonesia, for food, chemicals and biodiesel is creating a vast source of residual biomass that can be used to generate modern forms of energy such as electricity and second generation biofuels. As is the normal case in the use of residues for bioenergy, there is a question of logistics to recover, transport, store and process the feedstock and also the decision of the scale to be used in the processing. Malaysia is used here as an example of how the whole value chain of palm oil can be optimized by appropriately using the residues for energy products, in an adequate scale.

Thailand's Experience in Bioethanol Promotion

In 2012, bioethanol production in Thailand reached half a billion liters (Figure 14.4), thanks to a strengthened legal and policy framework over the past decade. A major driver is the desire to make biofuels a significant substitute to imported petroleum in the transport sector (Silalertruska and Gheewala 2010; Bell et al. 2011), which accounts for 36% of Thailand's total energy use. Other factors include the potential to reduce GHG emissions (Table 14.4) as well as the expected social benefits of biofuels, such as rural employment (Gheewala, 2012; Silalertruska et al. 2012) (Table 14.5).

The impetus for biofuels promotion began in 2000 when ethanol was designated a commercial fuel, plants to produce fuel ethanol were legalized, and a National Ethanol Committee was set up (Morgera et al. 2009; Jenvanitpanjakul and Tabmanie 2008). The initial goal, set in 2003, was 1 ML/d (million liter per day) consumption by 2006, which was later increased to 2.4 ML/d by 2011. The present target in the Alternative Energy Development Plan is 9 ML/d by 2021 (DEDE 2012a).

Fuel specifications were announced, first for E10 gasohol with 10% ethanol blended with unleaded gasoline octane 91 (or ULG91) and unleaded gasoline octane 95 (or ULG95), in 2006, then for E20 and E85 (based on unleaded gasoline octane 95 or ULG95) in 2008. Ethanol blending is not mandatory, but ULG91 was phased out in January 2013, leaving ULG95 as the sole unblended gasoline. The main incentive for ethanol producers and consumers is price: excise tax is currently being exempted from the ethanol component of gasohol and lower contribution rates to the Oil Fund from gasohol sales. Incentive packages to stimulate investment into the ethanol industry are also in place. In addition, excise tax rates are lower for cars with engines compatible with E20 or higher blends (Morgera et al. 2009).

Thai ethanol is produced mainly from molasses (62%) and cassava (38%). Because of the farmers-millers profit sharing requirement under the Cane and Sugar Act, millers are implicitly discouraged from producing cane juice-ethanol and adopting the more efficient, integrated production models practiced in Brazil. Compared to molasses-ethanol, the cost of cassava-ethanol is more expensive and more vulnerable to feedstock cost fluctuations (Morgera et al. 2009; Damen 2010). The problem of surplus ethanol production has partly been solved since pulling ULG91 off the market, with production surging to 2.3 ML/d on average in the first half of 2013 (DEDE 2013). Since the liberalization of export regulations, ethanol export has reached 170 ML in 2012 (Sikhom 2012). The planned reduction of excise tax rate for flexible fuel vehicles (FFVs) in 2016 will further raise demand for ethanol (Wongtareua 2013).

Fortunately, competition for land and water resulting from increased crop production can be avoided by improving sugarcane and cassava yields and by installing irrigation systems where feasible (Morgera et al. 2009; Damen 2010); adequate policies will be required.

Greenhouse gas (GHG) emissions reduction resulting from the substitution of gasoline by ethanol is estimated to be substantial (Table 14.4) especially in the case of sugarcane as feedstock.

Table 14.4. Life cycle GHG performance of bioethanol from molasses and cassava in Thailand (Source: Gheewala 2012).

Feedstock	Estimated GHG emissions ($kgCO_2eq$/liter biofuel)	Net avoided GHG emissions compared to gasoline****
Molasses*	0.68	64%
Cassava/dried chip**	0.96	49%
Sugarcane juice***	0.5	72%

* Average of three ethanol plants, Allocation Factor (AF) of sugar:molasses = 4:1

**Average values from various studies; plants that use biomass as fuel may emit only 0.77 $kgCO_2eq$/liter (TEI 2007)

*** Sugarcane in Brazil

**** Estimation based on energy content of ethanol = 21.2 MJ/L, and of gasoline = 31.4 MJ/L

Another important issue related to biofuels production, especially in developing countries such as Thailand, is the jobs created by the whole value chain in terms of direct and indirect employment. The benefits in this area from the Thai ethanol program were simulated for 2022 using the target of 9 ml/d in that year and are summarized in Table 14.5.

Table 14.5. Projections of employment caused by ethanol target of 9 ml/d in year 2022 (Source: Silalertruksa et al. 2012).

Feedstock	Employment coefficients for high yield assumption (person-years per million liters of ethanol)			Employment caused by ethanol target in 2020 (person-years)
	Direct	Indirect	Total	Range of 4 scenarios*
Molasses	10	46	56	35k – 70k
Cassava	36	40	76	180k – 277k
Sugarcane	47	32	79	23k – 35k
Total				238k – 382k

* The scenarios depend on factors such as assumptions on crop production yield, agricultural practices, mechanization, etc.; figures rounded off from the reference

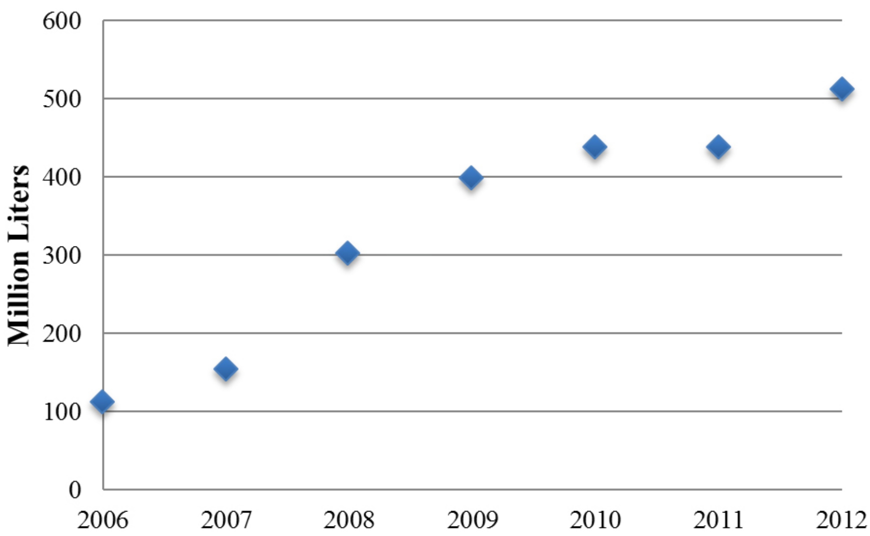

Figure 14.4. Ethanol production trend in Thailand. (Source: DEDE Energy Situation Reports, 2013, 2012b, and 2011).

Conclusions: Introduced in 2000, ethanol production in Thailand has now developed into a relatively mature industry, thanks to a strong legal and policy framework that includes blending standards and mandates, and favorable price mechanisms. The market for ethanol, produced mainly from molasses and cassava thus far, can expand considerably with incentives for flex fuel vehicles (FFVs). Ethanol supply can also grow with crop yield improvements and conducive framework conditions for cane juice-ethanol production. However for the latter it will be necessary to introduce relevant modifications in the cane payment system to create conditions to implement the joint production of ethanol and sugar model used in Brazil.

Palm in Malaysia: Combined Effects of Scale on Biomass Logistics and Conversion Costs

The vegetable oil sector (palm, soy, sunflower, and others) is producing roughly 300 million tons per year of oils, primarily for food and consumer products, but hardly for biofuels (1-2% of total volume). It is not expected that much more oils will be used for biofuels given the other demands. But oil producing plants like oil palm produce one order of magnitude more lignocellulosic residues – for instance in the case of oil palm, these are the fronds (leaves), trunks, empty fruit bunches, and the liquid wastewater effluent of the oil mill, that are today mostly wasted. This excess biomass could provide a substantial feedstock for renewable biobased chemicals, fuels and energy. Using them also considerably reduces the emissions of the sector. To use excess biomass, technologies such as fermentation, Fischer-Tropsch and other may be employed.

Biorefineries for the conversion of biomass into one or several products are often conceptualized as large, integrated facilities that benefit from economies of scale and/or cover the demand for a large market. Bioethanol, power, and sugar/starch from sugarcane in Brazil or corn in the USA or France give clear examples of large-scale operations. As the (relative) capital cost increases with the complexity of biomass processing technology, the optimum scale is larger when economies of scale have larger impacts (Searcy and Flynn 2009). For instance, Wright and Brown (2007) report optimum scales that increase depending on the complexity of the conversion process, e.g. pyrolysis bio-oil has an optimum at a biomass annual processing capacity of 1.08 million tons versus cellulosic bioethanol at 4.57 and FT (Fischer-Tropsch) diesel at 7.69 million tons.

However, as economies of scale for conversion and logistics have opposing effects on production cost, the optimum will be based on both factors. For cases of seemingly abundant biomass availability, especially in Asia such as palm biomass in Malaysia (Palmeros et al. 2013) and Indonesia and specific biomass uses in other situations such as bioenergy in India (Pantaleo and Shah 2013), the scalability of biomass conversion chain is substantially limited by economics and technology for transportation as well as market structure. An often overlooked effect in logistical costs is tortuosity, which is a measure for the degree of development of local infrastructures versus a simplified straight-line model. Tortuosity can be about 1.2 for developed agriculture regions where roads are laid out in rectangular grids or as great as 3.0 for less developed regions. Tortuosity leads to a proportional increase in logistical costs (ranging from 20% to 200% from developed to less developed situations). In practice, average transportation costs are further impacted by seasonal influence on softness of soils, degree of actual coverage with biomass, the non-circular nature of actual plantations, remoteness etc. In those case studies, the biomass supply and value chains including operational and investment models have to be re-designed.

Palmeros et al. (2013) provide a detailed case study for oil palm biomass use in Malaysia, which is an example that demonstrates the general case. Palm biomass (residues) is currently generated at mills as a result of oil extraction from fresh fruit bunches (FFB), namely empty fruit bunch (EFB), fibers, and shells. Additionally, oil palm fronds (OPF) and trunks (OPT) become available at the plantations, and the case is to use both streams. A simplified (approximate) biorefinery model as well as a more detailed plant design have been considered in two cases, namely (1) biomass derived from milling operations (M), and (2) biomass derived from plantation and milling operations (M+P). The scale effect is introduced by centralized processing of M or M+P biomass to fermentable sugars of *n* mills, benchmarked against current technology and economic numbers. Generation of heat and power, and treatment of wastewater from the biomass conversion and other palm oil mill operations, are taken into account to calculate Total Production Cost (TPC in $/metric ton) in the below figure 14.5 (*n* ranges from 1-20). TPC decreases in both cases with increased production scale (effect of relative CAPEX-reduction), and then increases due to the logistical costs. Increased learning effects in production technology (Van den Wall Bake et al. 2009) will even lower conversion costs and push the minimum to (single) mill integrated processing.

Further profitability analyses for palm biorefineries were performed at two different scales of central biomass processing, derived from three and ten mills and plantation as 15 year

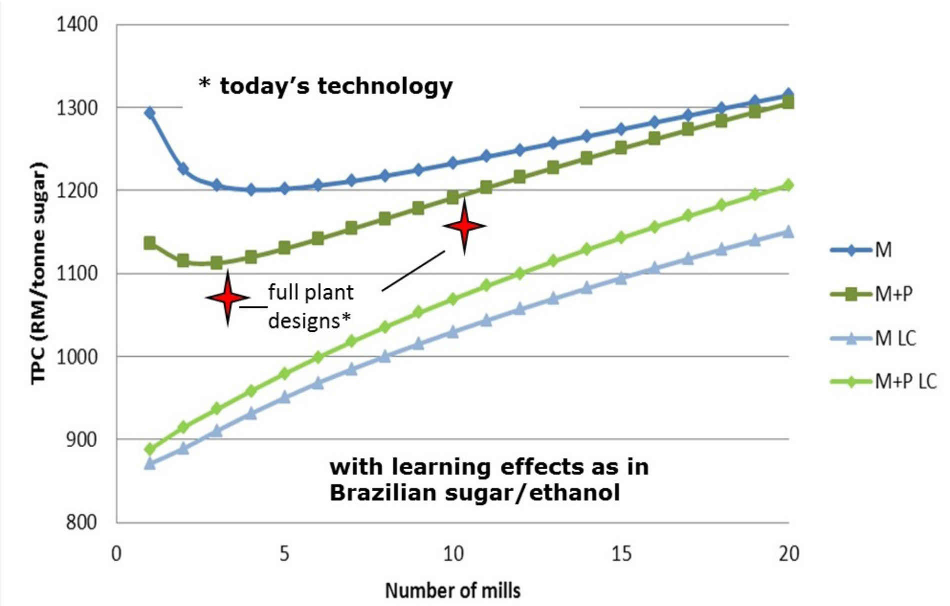

Figure 14.5. Impacts of the mill scale on the Total Production Costs (TPC) of lignocellulosic palm biomass to sugars (Palmeros et al. 2013).

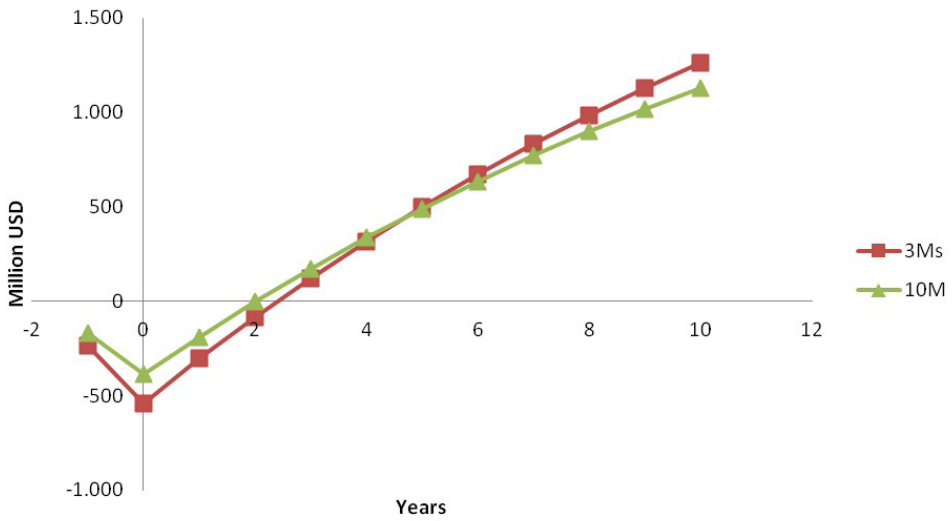

Figure 14.6. Cumulative and discounted cash flows of a single biorefinery compared with multiple biorefinery alternatives (Palmeros et al. 2013).

projects, Evaluation was done in terms of NPV (Net Present Value), with actual operation starting in year 3 after the start of the project. The two situations were scaled to the same feedstock processing capacity, i.e. a single biorefinery processing biomass from 10 mills and plantations (10M) versus a larger number (10/3) of biorefineries processing the same amount of feedstock (3Ms). The cumulative discounted cash flows are presented in Figure 14.6. The economies of scale have a positive impact on the payback time for the investment. As a result, the payback time of the 10M case is shorter than for the multiple mill 3Ms case. However, due to the differences in total production cost (Figure 14.6), multiple smaller biorefineries are more profitable than a single biorefinery processing the same amount of feedstock over the whole project lifetime.

Conclusion: The experience with this case study directs towards small scale, single-mill-integrated processing of biomass, for palm and comparable cases with high logistic costs. This is in opposition to the current tendency in (increasing scale) technology development. One important conclusion is that the case of optimum scale is highly dependent on the local conditions and contexts. Developing regions such as Southern Africa, Southeast Asia and others may have similar situations as the Malaysia oil palm biomass case.

14.2.5 Biofuels from Agricultural Residues: Assessing Sustainability in the USA Case

The production of bioenergy in developed countries often encounters different problems than in tropical countries because of geographic diversity and well-developed industries for multiple feedstock sources (Braun et al. 2010). The use of wastes, on the other hand, can benefit from a better organized collection and transport infrastructure and good technology available for conversion (Brick 2011). Furthermore, because of regulations regarding waste handling and disposal, using those materials for bioenergy production can reduce waste handling costs and thus improve the economic competitiveness of using wastes as bioenergy feedstock. The developed countries also have several functional technologies for recovering agriculture residues and substantial knowledge regarding the impact of harvesting them so that the real potential for using agricultural residues as bioenergy feedstock can be rigorously assessed. This knowledge is also extremely important for developing countries as it defines a scientific basis framework for sustainable recovery of agricultural residues taking into consideration not only the economic issues, but also the agricultural impacts of the residues in terms of soil protection against erosion and soil organic matter (SOM) stock; this system needs only to be adapted to the local conditions in developing countries to determine the optimal conditions for agricultural residues harvesting.

The anticipated 2014 launch of three full-scale corn stover to ethanol conversion facilities is a strong U.S. market signal that sustainable feedstock supplies must increase dramatically to supply 242 million Mg yr^{-1} for each facility producing biofuel at 252 L Mg^{-1} (Congress US 2007; Humbird et al. 2011; Schroeder 2011). To achieve that

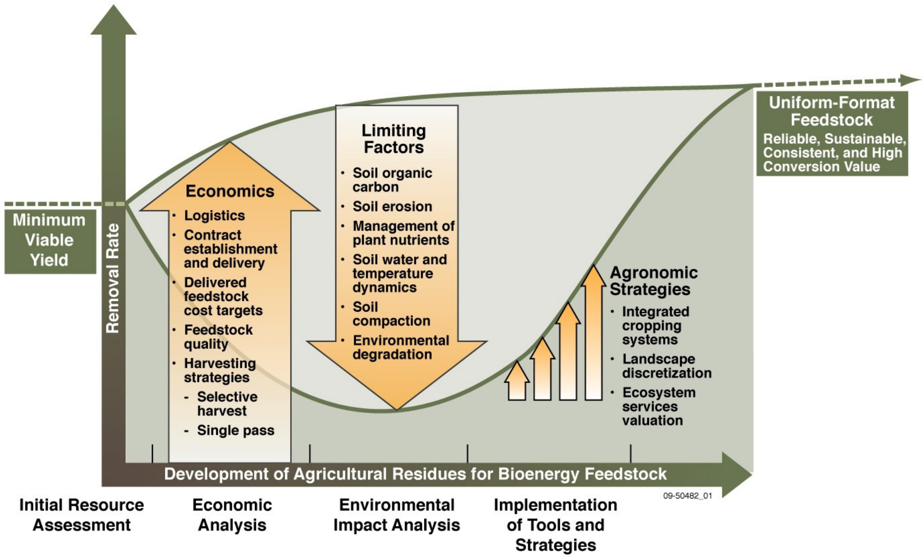

Figure 14.7. An illustration of competing economic drivers and environmental sustainability forces that must be balanced to achieve sustainable cellulosic feedstock supplies to support the transition from fossil to renewable fuels (With permission from Wilhelm et al. 2010).

goal without degrading soil quality (Andrews 2006; Reijnders 2006; Wilhelm et al. 2004; Wilhelm et al. 2007; Wilhelm et al. 2010), improved agronomic practices are needed. The conceptual framework guiding development of those practices (Figure 14.7) illustrates how economic drivers focused on feedstock supply and limiting environmental factors must be balanced (Wilhelm et al. 2010). The environmental factors were addressed by requiring soil erosion to be kept at or below the annual tolerable (T) rate of soil loss as defined by USDA-Natural Resources Conservation Service (NRCS), and by using the Soil Management Assessment Framework (SMAF) (Andrews et al. 2004; Karlen et al. 2011a; Karlen et al. 2011b) to monitor SOM and other soil quality indicators (Andrews et al. 2004; Karlen et al. 2011a, Karlen et al. 2011b).

Initially, extensive literature reviews were used to determine the amount of surface residues required to not only protect against wind and water erosion but also sustain SOM because of its effect on aggregation, soil structure, water entry and retention, nutrient cycling, and biological food webs. This provided general U.S. Corn Belt guidelines showing that an average of 5.25 or 7.90 Mg ha^{-1} of corn stover should be left in the field to sustain SOM for continuous maize (*Zea mays* L.) or maize-soybean [*Glycine max* (L.) Merr.] rotations. Assuming a 1:1 dry grain to dry stover ratio, these guidelines mean that continuous maize fields yielding 8.5 Mg ha^{-1} (160 bu ac^{-1}) of grain could sustainably provide an average of 3.25 Mg ha^{-1} (1.25 ton ac^{-1}) of stover.

Since 2008, coordinated, multi-location field trials have added 239 site-years of data from 36 replicated field experiments, to help make the general guidelines more site specific. Those studies had grain yields ranging from 5.0 to 12.0 Mg ha^{-1} and showed N, P, and K removal was increased by 24, 2.7, and 31 kg ha^{-1}, respectively, with moderate (3.9 Mg ha^{-1}) stover harvest or 47, 5.5, and 62 kg ha^{-1}, respectively, with high (7.2 Mg ha^{-1}) stover harvest. The field studies also quantified removal effects on SOM, microbial communities, trace gases, economics, and other factors (Karlen and Johnson 2014).

Simultaneously, an integrated data management and modeling framework, identified as the Landscape Environment Assessment Framework (LEAF) (www.inl.gov/LEAF) was developed and verified using the literature guidelines and field data. LEAF was designed to perform feedstock availability assessments and explore alternate agronomic strategies for increasing feedstock supply without compromising soil, water, or air resources. The framework (Muth et al. 2013) integrates the Revised Universal Soil Loss Equation 2 (RUSLE2) (USDA 2013a), Wind Erosion Prediction System (WEPS) (USDA 2013b), Soil Conditioning Index (SCI) (USDA 2013c), and DAYCENT model (Parton et al. 1998). Each model runs in an optimized manner with inputs and outputs seamlessly linked through the LEAF framework to produce landscape plans (Brick 2011) that if implemented could supply feedstock and protect soil resources.

To date, four key products have been delivered: 1) a revised national assessment for the Billion Ton Study Update (USDOE 2011), 2) a sub-field assessment framework used to characterize effects of surface topography, soil characteristics, and grain yield on sustainable residue removal, 3) an analytical assessment and toolset for designing precision agricultural residue removal equipment, and 4) multiple deployments of decision support tools being used across the public and private sectors. In summary, the strategy for developing sustainable feedstock supplies in the U.S. has been to develop trans-disciplinary teams of field researchers, computer modeling engineers, and private industry partners. Together they have made progress that could not have been achieved independently by any of these groups.

Conclusions: Sustainable biomass feedstock supplies must increase dramatically to develop viable biofuels industries. Public-private partnerships are evolving to provide the crucial data needed to support these endeavors by balancing economic drivers from the industry perspective with natural resource and social concerns of those supplying feedstock materials. Rigorous field data and simulation modeling are both crucial and easy to use tools to make this simulation a very important component in the process.

14.2.6 Comparison of Biogas Production in Germany, California and the United Kingdom

An examination of biogas case studies reveals the importance of consistent leadership and adaptive policy support for the adoption of renewable energy. Biogas production can be implemented in very low technology, small-scale systems or in very high technology, large-scale systems. The gas has a variety of end-uses including direct combustion for heat and cooking, electricity generation, or as transportation fuel (Abbassi et al. 2012).

Despite these advantages, biogas contributes very little to current bioenergy portfolios of most nations. The reticence to adopt biogas technologies is not technical; factors such as cost, public acceptance, knowledge and expertise, environmental policy and energy security seem to drive striking differences.

The status of biogas in Germany, California, and the U.K., three regions with similar per capita GDP and energy use, is informative (Table 14.6). All three regions began implementing agricultural biogas in the 1970s. Today, Germany has over 7,500 medium- to large-scale plants, more than three times the rest of the EU combined and nearly 40 times more than in the U.S. Germany's success can be largely traced to a steady drip of adaptive policy supports starting in 1991 (Figure 14.8) (deGraaf and Fendler 2010). Despite similar biogas potentials, California and the U.K. trail

Table 14.6. Biogas in Germany, California, and the U.K.

	Germany	**California**	**U.K.**
Per capita GDP ($USD)	41,514	47,482	38,514
Per capita energy use (kWh)	7,081	6,721	5,516
Per capita fossil natural gas consumption (m^3)	918	1,695	1,249
Dairy Cows (million)	4.2	1.8	1.8
Biogas facilities*	7,589	11**	106
Biogas Electricity capacity* (MW)	3,179	3	88
Current Feedstocks	85% Dedicated energy crops, 15% manure and other waste	90% Manure, 10% food waste	50% Food waste, 50% manure
Primary Driver	Energy Security	Environmental Impact – Water	Environmental Impact - GHGs
Secondary Drivers	Farmer Support	Environmental Impact- GHGs	Landfill Limitations
Biogas Potential (billion m^3)*	20	18	5-18
Percentage of Fossil Natural Gas Use	21%	28%	23%

* not including wastewater treatment facilities

** The U.S. has 201 agricultural biogas generating facilities in total

Source: World Bank (2014a, 2014b), IEA (2014), EIA (2014a, 2014b), California Energy Commission (2014), European Commission Farm Accountancy Data Network (2013)

Germany with a little more than 1% of its capacity. Recent E.U. Directives, a desire to limit landfill, and a steady decline in offshore natural gas production have spurred the U.K. to start investing in biogas, establishing a feed-in tariff and other incentives (Biogas UK 2013). The combination of initial policy supports, economies of scale, conversion efficiencies, and farm economics resulted in large-scale systems, many of which used maize for feedstock. While this provided farm support, it nudged up against an unacceptable feed for fuel scenario. As economics for large-scale systems improved, it was possible for policymakers to implement incentives for heat capture, use of wastes and small-scale systems and thus allow for a more desirable path for biogas.

California, on the other hand, has struggled with sporadic programs and inconsistent regulations (Sanchez 2013). Unlike Germany, which has a feed-in tariff based on the retail electricity rate, California's feed-in is determined by the wholesale rate, which is very low and variable. Whereas Germany has enabled upgrading and connections to natural gas pipelines, California biogas producers are hampered by high connection costs and variable acceptance criteria. Cheap new sources of domestic natural gas, financial constraints, and incentivized on-farm use over grid injection have not helped. While the California Energy Commission had assisted on-farm biogas installations in the past, changes in NOx emissions standards forced many to shut down, leaving farmers reluctant to reinvest (Zhang, 2007). As a result, less than 1% of the state's 1600 dairies recover biogas from their herds. Finally, a preference for composting over anaerobic digestion in many communities has discouraged biogas from food waste. Thus, rather than grow, the number of biogas facilities in California fell by half between 2008 and 2012 (Sanchez 2013).

Biogas is also important as a clean-burning energy source for rural communities lacking access to conventional energy distribution. In the BRIC nations, China and India have embraced biogas, while Brazil and Russia have not. China has over 50,000 medium- to large-scale digesters and over 40 million household digesters. India has over 4 million household digesters and several large-scale projects. In both cases, government was critical in adopting biogas, lowering financial barriers and promoting usage. In Brazil, with clean, centralized hydroelectricity, and Russia, with large supplies of natural gas, there has been little incentive to invest in biogas. Brazil has 22 biogas facilities. While there are plans to build biogas plants in Paraná, Brazil (Osava 2013) and the Belgorod region of Russia (BD Agrorenewables 2012), the projects face tough economics without clear policy supports. In 2012, the Brazilian Energy Agency (ANEEL) called for strategic R&D projects related to biogas to support the 2010 National Solid Waste Law aimed at reducing landfill and encourage projects dealing with agricultural waste and wastewater.

International development programs play an equally important leadership role for developing nations (Table 14.7). The programs provide investment capital, organizational capability, knowledge and expertise, which are all essential for adoption of new bioenergy options. For example, early programs for households digesters in China (1970s to early 1990s) often failed because of poor installation and lack of local expertise in care and maintenance. When systems became more widespread and local knowledge grew, success and adoption rates increased. Non-profit agencies can fill some of this need, as demonstrated by the Netherlands Development Group -SNV (2012). They work with local governments to train masons and maintenance operators to build and repair local biogas system for cooking and heating using household and farm waste.

Table 14.7. Biogas plants installed in Africa and Asia by non-profit group (SNV), in cooperation with the World Wildlife Fund, the Asian Development Bank and the World Bank. (Netherland Development Group SNV 2012).

Country	Program Start Date	Number of Digesters*
Nepal	1992	268,418
Vietnam	2003	140,698
Bangladesh	2006	23,611
Cambodia	2006	17,450
Lao PDR	2006	2,715
Rwanda	2007	2,171
Ethiopia	2008	3,232
Tanzania	2008	3,334
Pakistan	2009	2,097
Indonesia	2009	5,572
Uganda	2009	2,325
Kenya	2009	4,917
Burkina Faso	2009	1,117
Cameroon	2009	111
Benin	2010	42
Senegal	2010	334
Bhutan	2011	155
Total		**487,359**

*as of June 2012

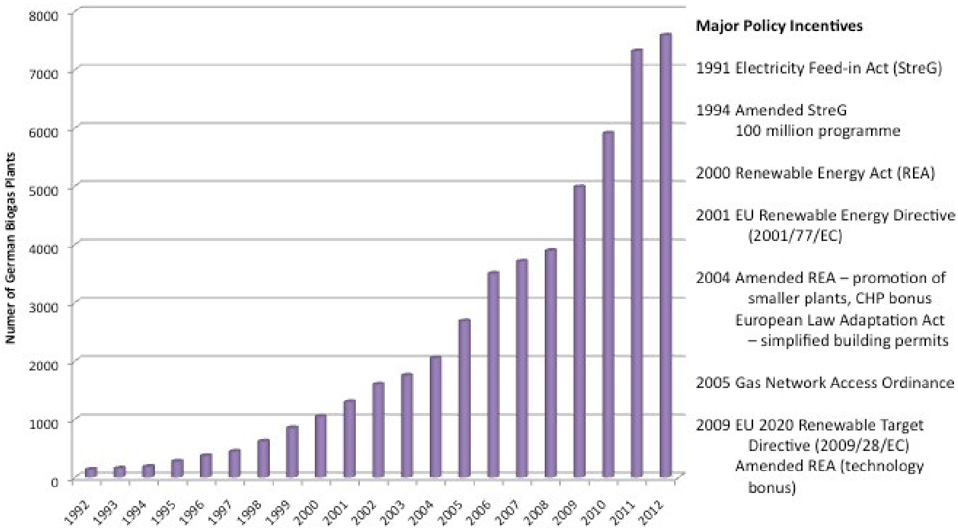

Figure 14.8. Adoption of biogas in Germany with major policy incentives (deGraaf and Fendler 2010; German Biogas Association 2013).

Conclusions: Biogas contributes very little to current bioenergy portfolios of most nations even though it has many well-defined advantages. Barriers to adoption are socioeconomical rather than technical, including factors such as public acceptance, knowledge and expertise, energy and environmental policy, energy access and security as well as financial considerations. Successful programs share consistent and adaptable leadership, whether at the local, regional or national level.

14.2.7 Wood Pellets and Municipal Solid Waste Power in Scandinavia

In population dense communities of Scandinavia, district heating systems have been introduced to provide heat and hot water to office buildings, schools, apartment buildings, etc. Hot water is distributed from a central thermal energy station. The fuel used in many plants can be municipal solid waste (MSW), wood pellets or wood chips.

MSW can only be used in larger plants since the waste, due to hygienic requirements, cannot be stored and must be combusted immediately upon arrival at the plant. In small plants the heat demand during summer is so low that it would be impossible to run a plant without storing the waste during hot periods. Therefore, these plants run on woody biomass or bio-oil.

The demand for MSW in the Nordic countries is now so large that there is not enough MSW available in the local markets. To cover the demand, MSW is imported from other parts of Europe. Some of these plants are or will be retrofitted to run multifuel.

The use of bioenergy has increased steadily in Scandinavia and has reached about 20% of the total energy supply in Sweden (see Figure 14.9). Most of the bioenergy comes from forests.

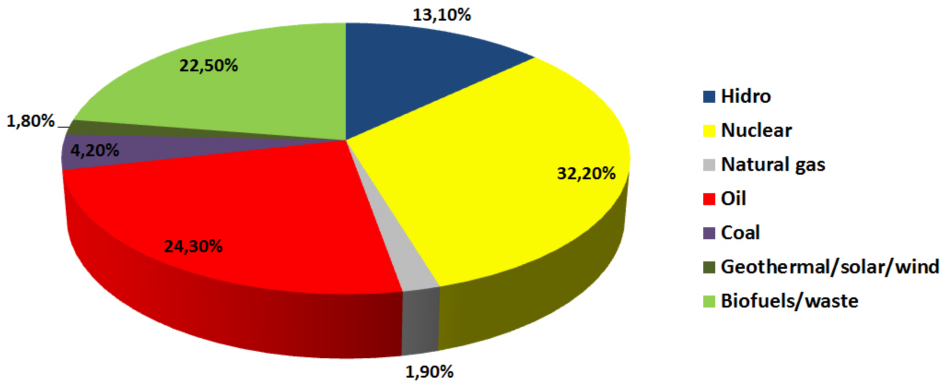

Figure 14.9. Total Primary Energy Supply (TPES) in Sweden in 2012 (Source: IEA 2014). Notes:1. Sweden TPES in 2012= 50 162 ktoe (thousand tons of oil equivalent);2. Shares of TPES excludes electricity trade;3. In this Figure, peat and oil shale are aggregated with coal, when relevant.

Figure 14.10. Akershus energy park in Norway.

One of the most modern utilities is the Akershus energy park in Norway (Figure 14.10). The plant provides heat to some 10,000 persons and local institutions. It opened in 2011. It was considered to run this plant on MSW, but the summer demand for heat is too low. Instead it runs on wood chips, bio-oil and gas from the local landfill.

The plant has 2 furnaces that use chipped wood, mainly from local suppliers. Each furnace has a power of 8 MW and the heat in the flue gas is recovered by condensing the water vapor, thus making each furnace effectively 10 MW. There are cleaning systems for the flue gas and the ash is collected from the bottom of the combustion chamber. These 2 furnaces are essentially used for base load and they are not operated during summer months when the demand is low.

There is a 1.5 MW gas burner that burns the gas that is piped down from the landfill. However, this gas has a low caloric value and the methane and CO content is rather low.

Finally, the plant is equipped with some 10,000 m^2 of solar thermal collector panels, providing 7 MW additional capacity. In combination with a water accumulation tank, this heat can be stored for later use.

Conclusions: MSW is an attractive fuel for energy production and the demand is increasing in Nordic countries to the point that the demand exceeds the offer, requiring the use of supplemental fuels such as wood chips and pellets. Wood pellets and wood chips are already increasingly being used directly for heat generation in Scandinavia and other northern European countries. The heat is distributed as hot water through pipes that connect to major office and apartment buildings in dense areas. In Sweden, bioenergy including waste covers about 20% of the primary energy supply. Demand for sustainable supplies of wood pellets is currently ahead of that for biofuels in many countries.

14.3 Overall Conclusions

Even for apparently similar situations, the implementation of bioenergy in several countries has resulted in different problems and production models that are strongly influenced by the local context and supporting policies. This is the case for ethanol production in Brazil and Thailand where technology developments and management practices evolved slowly in the former, to make it the largest sugarcane ethanol producer in the world, while they served as starting point for the latter, adapting them to local conditions. Strong and adequate policies were key factors for success in both cases. The use of jatropha as a feedstock for biodiesel production has failed in several projects, but it is shown that the production model (scale, land tenure, interfaces with the local community, etc.) can be adapted to local conditions to increase the chances of success.

An important by-product of sugarcane ethanol production is surplus electricity to be sold to the national grid or to large consumers directly. The cases of Brazil and Mauritius have shown that government support and wise policies make the difference in determining the role that this option plays in the national power generation matrix of each country; the potential is far from being reached in Brazil and is fully exploited in Mauritius.

The use of wastes and residues has an enormous potential for bioenergy generation, but has failed to become a significant source. The case studies show some of the reasons why and also point out that adaptive policies as well as the combination of different fuels in an integrated manner can help achieve success. While most people believe that agricultural residues can be freely collected and used, detailed studies in the USA have demonstrated that there are optimal recovery strategies that depend on the local conditions; these findings should be used more broadly in other countries in order to develop successful strategies for the use of agricultural residues. The case of scale of the processing plants and the existing logistics for transport can play a significant role in determining the best model for implementing the projects.

Last, but not least, the lessons that can be learned from these very different cases are that proper government policies are essential to increase the chances of success of bioenergy programs and projects, and the local conditions and context (technology level, driving forces, public support) should be carefully evaluated in the development of these policies. There is no single solution that fits all cases.

14.4 Recommendations

The multiple causes for success and failure in the deployment of bioenergy projects need to be evaluated and the data organized in a manner that can be used to guide selection of the most viable alternatives, and to help develop public policies that will support implementation of bioenergy programs. These data must be made widely available and disseminated in order to take advantage of the lessons learned.

It is important to identify issues that are strongly dependent on local conditions and treat them adequately. Land and water availability, agriculture technology levels, and needs for improvement in land tenure, infrastructure and energy systems at both regional- and country-scales are all crucial.

The impact of project scale on economics and social indicators need to be better understood and the tradeoffs optimized.

All alternative strategies to promote bioenergy should be identified and extensively evaluated to determine short, medium and long term effects. Direct subsidies, mandates, soft loans, R&D support, infrastructure building and capacity building are some of the alternatives that can have different impacts and effectiveness under different conditions.

Build policies that incorporate clear, consistent, and cohesive targets and standards for bioenergy production.

14.5 The Much Needed Science

After producing high yields of feedstocks, they must be processed efficiently. Most processing technologies for first generation (1G) biofuels are fully mature, but there is still room for improvement, especially in the energy balance.

The full use of feedstocks must be sought to make sure the primary energy content of the material is converted to useful products. Here second generation technologies can be a great help when integrated with the first generation plant.

Understanding the dynamics of land use change (LUC), both direct and indirect, is very important for the assessment of several key impacts on the biofuel sustainability. There is no consensus on the methodology to be used and there is a critical shortage of reliable, reasonably disaggregated data in time and space. Both of these difficulties must be overcome.

Impacts of agroforestry residues on the soil resources, pest populations and disease dynamics must be better understood.

Second generation biofuels are very important alternatives, but they need to reach economic viability to start to participate in the biofuels pool. Technologies need further improvements.

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