Back to contents Phalla

Co-generation of energy and feed / food in integrated farming systems for socio-economic and environmental benefits

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Table of contents

1. Introduction

The world population is rising dramatically, particularly in Cambodia where the population is growing at a rate of 2.4 % per year. Eighty-five percent of the population is concentrated in rural areas, based on agriculture for livelihood. The country is rich in natural resources, of which forest serves as one of the most important, supplying wood fuels, timber and other forest products. The country faces a growing need for energy to support the economic growth and social development of the growing population (Sovanndara, 2004).

The US Department of Energy reported that increases in population and energy consumption, accompanied by growing concerns about global change and atmospheric pollution, will create a major opportunity for fibrous biomass to play a greater role in energy production (Skog and Rosen, 1997).

Energy drives the world economy. It is derived from oil, natural gas and other fossil fuels, hydro, wind, wave, solar power and biomass. In Cambodia, the energy use is based on wood 82 %, charcoal 1.2 %, other biomass 1.7 % and imported petroleum products (Sovanndara, 2004). In the Philippines, in 1996, annual biomass consumption for energy generation was estimated at the equivalent of 72 million barrels of fuel, of which about 65% consisted of fuel wood and charcoal used predominantly by households and small businesses for cooking (PRESSEA, 2000).

In 1998, it was predicted that fossil oil supplies were close to their peak and would soon decline (Campbell and Laherrère, 1998). It is now widely accepted that the peak in production will occur within the next 5 years, and that this will cause a crisis of energy consumption and will seriously affect world socio-economic development due to the high price of oil and the dependence on this commodity for all aspects of economic development. Many economists emphasize the need to prepare replacements for fossil fuels for energy consumption (see Preston and Leng 2004)

The other problem related to use of petroleum products is the effects on the environment, especially global warming (the green-house effect), pollution and incidence of natural disasters such as drought and flooding.

Biomass utilization for energy has the potential to be a sustainable system, as growing plants have the capacity and ability to capture power from the sun in order to transform carbon dioxide into biomass by a photosynthesis reaction,

$$CO_2 + 2H_2O \underset{heat}{\overset{light}{\longleftrightarrow}} ([CH_2O] + H_2O) + O_2$$

The two alternative ways to use biomass for energy are through conversion to ethanol and to a combustible gas (a mixture containing hydrogen and carbon monoxide). The former is by way of fermentation of sugar while hydrogen can be obtained by gasification. Ethanol production is criticized because it has been estimated that the fossil energy requirement to produce ethanol is higher than the energy that ethanol contains (Paztek, 2004). In any event the real (unsubsidized) price of ethanol is still above $1 per litre at present (Elaine, 2004).

Gasification seems to offer a moré sustainable pathway as a means to extract energy from renewable biomass. Gasification is the way to convert solid fibrous biomass by pyrolysis into producer gas which contains H_2 18-20 %, CO 18-20 %, CH_4 1-2 %, CO_2 12-14 %, and N_2 45-48 % with a calorific value of 4.5-4.8 MJ/m^3 (IISc, 2003).

The gas can be used as fuel for internal combustion engines and gas turbines, as well as a source of heat. Economic studies show that biomass gasification plants can be as economical as conventional coal-fired plants (Badin and Kirschner, 1998). Additional benefits are that the system is “carbon-neutral” (does not add to global warming), produces negligible amounts of sulphur compounds (the cause of “acid” rain), reduces waste disposal and has fewer negative environmental impacts.

The integrated use of biomass (for food/feed and energy) can be the basis of sustainable farming systems which support both socio-economic needs and a healthy environment. As such this approach is considered to be the key priority for successful development, especially in the developing world (Preston and Leng, 2004). An integrated farming system is a system that reuses and recycles, using plants and animals as partners, creating a tailor-made ecosystem, mimicking the way nature works (http://utafoundation.org). This concept is attracting the attention of young scientists encouraging them to think deeply about the benefits of this system with a broad vision, not just for this generation but for the next.

In Cambodia, the price of electricity is almost double compared with neighboring countries ($US 0.15/kw in Cambodia vs 0.10 in Vietnam). In the small towns of the rural areas of Cambodia, the price may be as high as $US 0.50/kw. However, in rural areas of Cambodia, there is a great potential for the development of rural electricity through gasification due to available fibrous materials including crop by-products and fibrous residues and tree branches around households. The development of rural electricity supply will in fact create more jobs and be a means to get access to information including marketing, which in return will create a better livelihood for the rural community.

2. Objective

- Determine yields of biomass from selected farming systems.
- Determine the feasibility of gasification of the fibrous residues from these systems
- Estimate the overall economic efficiency and environmental impact of the selected farming systems

3. General discussion

3.1 Social and environment issues

The rising up of the world population creates an increasing demand for food and energy. This competition for resources leads to poverty and creates certain problems in society and in the use of natural resources on this earth. In the developing world, food scarcity is still a main problem which has to be solved by increasing productivity.

A related development is the increased concentration in the atmosphere of the gases (CH_4, CO_2, N_xO) which cause global warming. The rise in the earth temperature (Figure 1) is predicted to bring about changes in climate and increases in sea level (Figure 2), both of which are likely to result in increased incidence of natural disasters. The burning of fossil fuel, of which oil is the major component, is considered to be the major cause of global warming; however, deforestation and agricultural activities are also major contributors.

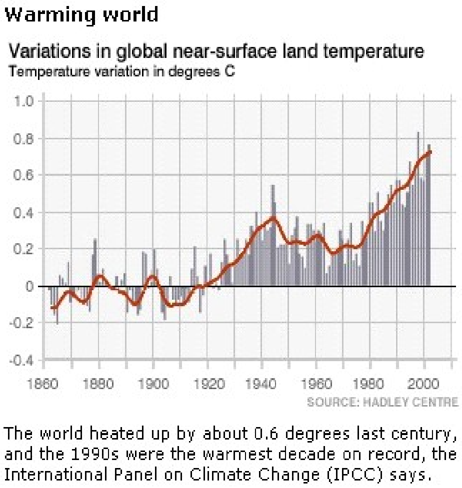

Figure 1: Trends in ambient temperature during the 20th century (IPCC)

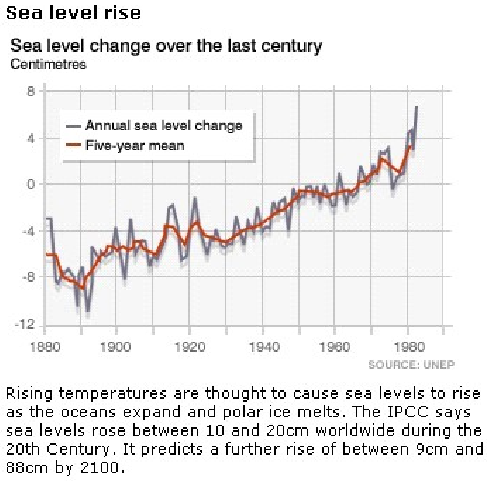

Figure 2: Trends in sea levels during the 20th century (IPCC)

In Paper I, it was shown that gasification produces a pure and clean gas for an internal combustible engine. The system is “carbon-neutral” (does not add to global warming). The growing and processing of biomass for gasification also provides job opportunities for rural farmers for preparation of the feedstock.

3.2 Oil depletion

Fossil oil energy is not renewable. David, (2002) reported that the amount of oil in the earth has a limit that cannot be increased by ingenuity or determination. The world is not running out of oil but it is the end of the abundant and cheap oil (Campbell and Laherrère, 1998).

Peak oil is when demand equals production (Figure 3).

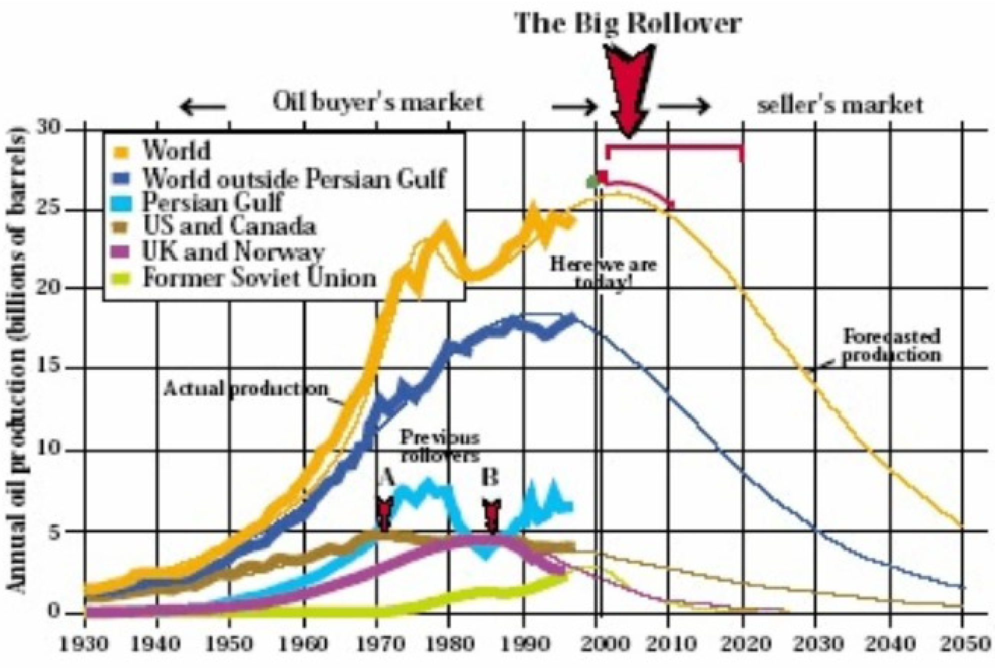

Figure 3: Past trends and forecasts for future oil production (Magoon, no date)

Robert *et al*., (2005) made a similar statement that as peak oil is approached, liquid fuel prices and price volatility will increase dramatically, and, without timely mitigation, the economic, social, and political costs will be unprecedented. It is now apparent that the increase in the demand for oil exceeds the increase in the supply (Figure 3), with the result that the price of oil has increased to over USD 50/barrel (as of April 2005), and is likely to continue to increase. The present fast rate of development and the high population of China and India will demand more energy supply to cope with their living standard.

3.3 Alternative energy supplies

One alternative that is receiving a great deal of attention is the production of ethanol from renewable sources of biomass. However, the production of ethanol is by yeast fermentation of sugar which at the present time is derived either from maize, cassava or sugar cane.

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$$
$$\text{Hexose} \rightarrow \text{Alcohol + Carbon dioxide}$$

In terms of the most commonly used raw materials, the requirements to produce 100 litres of alcohol are:

- 260 kg of maize
- or 360 kg of final molasses
- or 250 kg of high-test molasses (concentrated, partially inverted sugar cane juice)
- or 545 kg of cassava roots (fresh basis)

Thus there is competition between the use of the biomass for food and for energy. It is also claimed (Pimmental 2001) that it requires more energy to produce the ethanol than is present in the final product (Table 1)

Table 1. The energy and fuel balance of producing alcohol from maize as calculated by different authors

Energy costs /gallon alcohol	Wang & Santini [2000] [WS] BTU	Mj	Pimentel [2001] [P] BTU	Mj	Comments
On farm production	26,700	28.2	55,300	58.3	WS assumes higher yields and lower water use
Ethanol factory	44,300	46.7	74,300	78.3	WS assumes state of the art distilleries and higher efficiencies of production
By-product credits	-15,400	-16.2	0	0	No costs of land degradation or pollution costs
Total	55,600	58.7	129,000	136.1	
Net energy balance	20,400	21.2	-53,600	-56.2	
Alcohol energy to oil energy	**1.06**		**0.59**		No credits for by-products in either case
Energy out /energy in	**1.36**		**0.68**		Providing by-product credits in both cases

[1 gallon alcohol =3.785 liters=2.983 kg = 79.93 Mega joules or Mj]

These considerations indicate that the use of ethanol for energy is not sustainable. By contrast, as shown in Paper I, the process of gasification converts inedible fibrous biomass into fuel, thus there is no competition with food and feed, as in crops such as cassava and mulberry, the leaves are used for animal feed and the stems to produce electricity.

3.4 Gasification

The hypothesis adopted in this thesis is to derive energy from biomass through the process of gasification, which has the major advantage that the feedstock can be derived from fibrous material not suitable for human food or animal feed. In this case there is no competition between energy and food.

Gasification is the conversion of solid fuels into a combustible gas mixture normally called "Producer gas" or "Syngas". The process is a combination of partial oxidation of the biomass with the production of carbon which at a high temperature acts as a reducing agent to break down water and carbon dioxide to hydrogen and carbon monoxide, both of which are combustible gases.

$$\mathbf{C_6H_{12}O_6 + H_2O + O_2 \rightarrow CO + H_2 + CO_2}$$

Ligno-cellulose + water + air → carbon monoxide + hydrogen + carbon dioxide

$$C + CO_2\uparrow \rightleftharpoons 2\,CO\uparrow$$

$$C + H_2O\uparrow \rightleftharpoons CO\uparrow + H_2\uparrow$$

$$C + H_2\uparrow \rightleftharpoons CH_4\uparrow$$

Figure 4: The chemical reactions occurring inside the gasifier

Wood has been, and continues to be, the major source of the feedstock used in gasifiers; however, recent developments in India (Phalla and Preston, 2004) have led to the construction of units which use as fuel the residues from crops such as the husks of rice and coconuts, as well as the stems and branches from trees.

This principle was tested successfully (Paper I) using the gasifier model "GAS-9" imported from India (Ankur, 2005). The selected crops used in the test were coconuts, cassava, mulberry and the ornamental shade tree *Cassia stamea*. The shell/husk (coconuts), stems (Cassava and Mulberry) and branches (*Cassia stamea*) were the sources of fibrous biomass. Conversion rates were in the range 1.1 to 1.2 kg of dry matter from the feedstock to produce 1 kwh of electricity.

3.5 Potential biomass residues for production of renewable energy

Renewable energy sources are biomass, wind and wave energy, solar, hydro and geothermal power. The development and use of renewable energy sources can enhance diversity in energy supply markets, contribute for securing long term sustainable energy supplies, help reducing local and global atmospheric emissions and provide commercially attractive options to meet specific energy service needs, particularly in developing countries and rural areas, helping to create employment and well fare for the local communities (Alberto, 2001).

In the Northeast of Brazil, Peres, (1999) reported that the potential for electricity production using coconut husks was 1417 million MWh/year. In Viet Nam the energy potential from biomass residues was estimated to be 1430 MW which could generate up to 9020 GWh of electricity (Nguyen Le Truong and Tran Quang Cu, 2004).

The potential that the gasification system offers is to add value to traditional and new crop/livestock production systems, by making effective use of the fibrous residue that would otherwise be wasted or used inefficiently as in open fires for cooking. An example of this approach is shown in the case of the cassava crop (Figure 5).

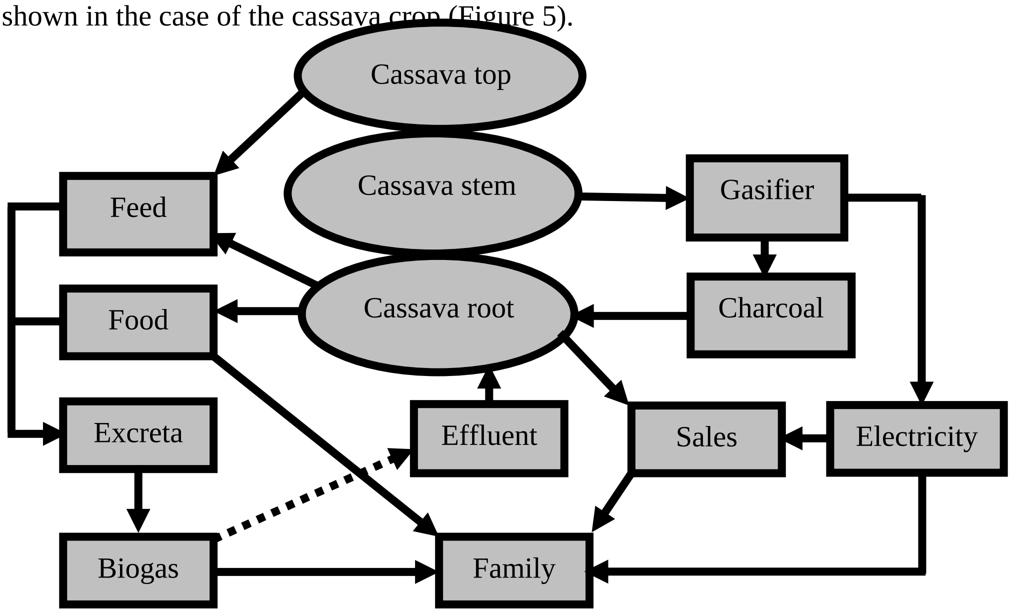

Figure 5: Flow diagram for the integrated use of the cassava crop for human food, animal feed and energy

3.6 Integrated farming system in sustainable development

3.6.1 Ecosystem concepts

The principles of the integrated farm involve three major components; plants (that can capture and store the energy from the sun), livestock (use nutrients in the plants for production of animal protein and give feedback to the plants with manure for fertility) and energy. The integrated system uses plants and animals as partners, with recycling of all residues, creating a tailor made ecosystem, mimicking the way nature works (www.utafoundation.org). The integrated farming system involves the utilization of locally available resources, with a high degree of nutrient recycling and hence reduced energy needs. The total farming system is enhanced through reduction of waste; creating interdependence and overall economic efficiency and the system is made more sustainable ecologically, economically and socially (Dolberg *et al*., 1996).

Integration also promotes biodiversity which boosts ecosystem productivity whereby each species, no matter how small, all have an important role to play; and it is this combination that enables the ecosystem to possess the ability to prevent and recover from a variety of disasters (Anup, 2004; Dolberg et al., 1996). The emphasis in such systems is on optimising resource utilisation rather than maximisation of individual elements in the system (www.utafoundation.org).

In Paper II, it was estimated that through integration by cogeneration of feed/food and energy, the total gross income was higher than from single-purpose use of the crop for food and feed. Food/feed was $ 2852 (coconut), $ 1486 (mulberry), $ 5792 (cassava high yield region) and $ 768 (cassava low yield region) while the income from energy (as electricity) was $ 3484 for mulberry, and $ 6910 for cassava (high yield region). The income from energy represented added value (over food/feed) of 82 % (coconut), 234 % (mulberry), 104 % cassava high yield region and 55 % (cassava low yield region).

3.6.2 Crops/forages and trees

Cassava can be planted at densities between 10,000 and 15,000 plants per ha (Muhr et al., 1995) and it is an invaluable woody shrub in tropical and sub-tropical regions that can be used as feed, food and energy. It is able to grow on marginal lands where cereals and other crops do not grow well; it can tolerate drought and can grow in low-nutrient soils (IITA, 2002). Cassava can yield more than 40 tonnes/ha of roots (IITA 2002). RREDA (2004) reported that cassava stalk residues in India in 1994 were 0.30 million tonnes. Nguyen Le Truong and Tran Quang Cu, (2004) estimated that cassava stem yield that could be a source of renewable energy in Vietnam with an availability of 1.25 million tonnes/year.

In paper II, studies were made of cassava cultivated in different regions, at densities of 15625 stalks/ha (high yield) and 12500 stalks/ha (low yield). The yields were markedly different in the two regions. On a fresh basis, yields of leaves were 9.4 tonnes/ha, of roots 105 tonnes/ha and of stems 60 tonnes/ha per year (in high yield region). In the low yield region, leaves were 1.6 tonnes/ha, roots 5.5 tonnes/ha and stems 4.9 tonnes/ha per year.

According to Nguyen Xuan Ba and Le Duc Ngoan, (2003) the yield of mulberry biomass (fresh basis) was 40 to 45 tonnes/ha/year. Bushes grown under rain fed conditions yielded 4,000–7,000 kg/ha annually of leaves; and under irrigation, from 10,000 to 14,000 kg/ha (James, 1983). Saddul *et al*., (2004) reported that yield of stems increased from 1 to 7 tonnes DM/ha/year when the harvest interval was extended from 3 to 9 weeks, while leaf yield stayed constant at about 5 tonnes DM/ha/year.

In Paper II, a study was made of biomass yield from mulberry at a plant density of 40000 plants/ha fertilized with zero to 700 kg N/ha of biodigester effluent. The leaf and stem yield varied according to the application of fertilizer, from 2.7 to 8.4 tonnes DM /ha/year of leaf and 7.2 to 16.4 tonnes DM /ha/year as stem.

Cassia stamea is a fast growing tree that is cultivated for shade, as a fence, and for improving soil fertility. It is highly tolerant to drought and is considered to be a good source of firewood. In Paper II, it was shown that the biomass yield was equivalent to 7.65 tonnes of DM/ha/year. The observation was made at a critical time of drought and hot climate. The leaves of this tree stay green all the year, and can be a good source of mulch for other crops. The branches had a higher density than the stems of mulberry and proved to be an excellent feedstock in the gasifier. .

Alfredo (2005) reported that nut yield from coconuts was between 70 and 240 nuts/tree/year. A yield of 135 nuts/palm/yr was observed by Rajagopal (2001). In Cambodia, the ADB reported that there were an average of 100 palms/ha and 50 nuts/palm while MAFF assumed a figure of 70 nuts/palm (Vinay, 2003).

The survey presented in Paper II indicated that nut yield was 54 nuts/palm/ha/year (on average), equivalent to 16 308 nuts/ha with density of 25 to 49 m^2/per palm. The husk plus shell of a tender green mature nut (average 6 months), made up 17.9 % of the DM of the nut. The amount of husks plus shell 0.49 kg DM per nut is equivalent to 7.99 tonnes DM/ha.

4. Conclusions

- Conversion of inedible fibrous biomass to a combustible gas through gasification is a more sustainable system than production of ethanol which is produced by fermentation of sugars that can be used as human food or animal feed.
- Integrating energy with food / feed production is a way of adding value to the production system, as by using only the inedible fibrous component of the biomass for energy, there is no competition between energy and food / feed production.
- Integration of feed/food and energy provides socio-economic and environmental benefits for rural communities.

5. Acknowledgements

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Back to top

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