Biofuel *v* fossil fuel economics in developing countries

How green is the pasture?

Marcia M. Gowen

As relative fuel prices change, the attractiveness of biofuels and fossil fuels to different sectors of the economy alters significantly. Given the volatility of oil prices and the subsequent intense attention to biofuel technologies over the previous decade in developing countries, many questions still remain regarding actual financial and economic performance of these fuels. This paper explores sectoral differences between biofuel and fossil fuels with regard to production costs, economies of scale, subsidies, and other economic incentives in developing countries.

Keywords: Developing countries; Energy policies and economics; Biofuels and fossil fuels.

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Over the past decade, interest in biofuel use has followed the roller coaster of oil prices. As petroleum prices soared, a search for economic alternative fuels, such as biofuels, took off. Import-dependent developing countries envisioned that biofuel substitution for fossil fuels would retain energy expenditures domestically, increase indigenous labour demand, create more efficient basic commodity markets, and provide national security benefits through energy diversification. Due to the precipitous drop and then the levelling in crude oil prices, interest by some in alternative fuels such as biofuels has seriously plateaued. Are there economic reasons to believe this trend of interest in biofuels will continue, or in fact will it only be temporary?

Despite intense research over the past decade on the technical feasibility of biofuels – agricultural, forest and cellulosic wastes – there are only a limited number of financial analyses of specific systems and even fewer studies comparing the economics, or full social costs, of biofuels to fossil fuels. For instance, little is known at present about the macroeconomic impacts, such as employment generation, foreign exchange savings, and subsidy issues – often the original economic rationale given by a country for shifting to biofuels. Despite the data limitations, some general patterns about the comparative economics of the fuels, however tentative, can be gleaned. This paper reviews what can be learned from the past with the understanding that these findings are indicative not definitive, and expectations regarding the possible future paths of biofuel economics in developing countries.

Oil prices, the environment and biofuel expectations

For many developing countries, the energy crisis of the 1970s and 1980s is often characterized as consisting of two parts. Due to the double set of rapid oil price shocks in the 1970s, a 'modern' fuel crisis is often described whereby the relative costs substantially changed for 'modern'

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(mostly fossil) fuels needed to produce high-quality energy for the transport and industrial sectors of an economy. For the modern energy sector, the crisis was simply how or if alternative, non-petroleum fuels could substitute for oil. Concurrently in some developing countries, a second 'traditional' fuel crisis occurred for low-quality fuels due to the physical scarcity of fuelwood or other biofuels, such as animal wastes and agricultural residues. Taken together, some countries faced serious, economy-wide energy crises. On the surface both crises' general causes – relative price changes – and solutions – energy substitution or conservation – are similar. However, their distinction and separate analysis is warranted because the available biofuel options to the different economic sectors, and the people who are affected by each crisis, differ significantly.

In the former case the modern fuel crisis immediately affects future economic growth in the transport and industrial/commercial sectors, with only secondary long-term effects on the residential sector. Its solution requires production of high-quality substitutes, usually for large, centralized or privately owned energy demand centres. In the case of biofuel systems, this means advanced technologies used mainly in developed countries such as ethanol plants or efficient cogeneration systems. In contrast, the traditional fuel crisis is about the lack of biofuels, not fossil fuels. It has broad implications for the welfare of the rural and urban poor and, to a lesser extent, middle class.[1] These people have few fuel substitution options. The solution to this crisis requires more efficient use of cheap, low-quality fuels (eg better stoves) or subsidization of household fossil fuels.[2]

Total biofuel consumption as of 1980 was 14% of worldwide developing and developed country energy consumption.[3] Although this appears moderate in a global context, the importance of biofuels to developing countries, both for the rural industrial and residential sectors, is generally much greater (often obscured by such aggregate data). Data in Tables 1 and 2 underscore the dependency of not only the residential sector but, to a large extent, the rural industrial sector in many developing countries on biofuel use. For instance, with admittedly limited, but probably conservative, biofuel consumption data from selected developing countries, it can be seen that biofuel energy represents anywhere from 13% to 99% of total industrial or residential energy use (Table 1). These data suggest that the importance of biofuel energy in low-quality uses has been seriously under-estimated. Detailed data from Thailand on rural energy use suggest a story generally not captured by national energy balances.[4] In 1983, more than 70% of total rural energy consumption in Thailand was met by biofuels (Table 2). Within the rural industrial sector, biofuels provided 98% of all energy. With increasing awareness of the need for better resource management and the disastrous climatic impacts of the greenhouse effect, which is seriously affected by fossil fuel use, the importance of biofuel use is again regaining global attention.

Biofuel and fossil fuel economics: general issues

As relative price changes occur among substitutes, the least costly product is theoretically chosen by the market. During the 1970s it was often implied that higher real prices for petroleum meant a rapid transition to a renewable energy era, particularly in the developing

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[1] Elizabeth Cecelski, *The Rural Energy Crisis, Women's Work and Family Welfare: Perspectives and Approaches to Action*, World Employment Programme Research, WEP 10/WP 35, Working Paper, International Labour Office, Geneva, Switzerland, 1984; Joy Dunkerley and William Ramsay, *Analysis of Energy Prospects and Problems of Developing Countries*, Resources for the Future, Washington, DC, USA, 1983; William Ramsay, 'Biomas energy in developing countries', *Energy Policy*, Vol 13, No 4, August, 1985; Kirk Smith, 'The biofuel transition', *Pacific and Asian Journal of Energy*, Vol 1, No 1, 1986.

[2] Smith, *op cit*, Ref 1.

[3] Robert H. Williams, *Potential Roles for Bioenergy in an Energy Efficient World*, PU/CEES Report No 183, Center for Energy and Environment Studies, Princeton University, Princeton, NJ, USA, 1985.

[4] World Bank, *Prospects for Traditional and Non-Conventional Energy Sources in Developing Countries*, Staff Working Paper No 346, Energy Department, The World Bank, Washington, DC, USA, 1979.

Table 1. Industrial and residential energy demand in selected developing countries.

Country/sector[a]	Biofuels[b]	Fossil fuel[b]	Electricity[b]	Total (ttoe[c])
Bolivia (1981)				
Industrial	31	55	14	483
Residential	74	20	6	1 002
Costa Rica (1981)				
Industrial	35	50	15	421
Residential	75	5	20	566
Ethiopia (1982)				
Industrial	13	67	20	231
Residential	99	1	1	7 436
Fiji (1982)				
Industrial	78	11	11	334
Residential	64	26	10	89
Haiti (1979)				
Industrial	83	15	2	600
Residential	98	1	1	447
Malawi (1980)				
Industrial	93	5	2	1 736
Residential	99	0.5	0.5	1 504
Nepal (1980)				
Industrial	40	54	6	114
Residential	99	1	1	2 797
Sri Lanka (1980)				
Industrial	55	34	11	952
Residential				
Uganda (1980)				
Industrial	95	3	2	734
Residential	99	1	1	3 563

[a] Industry category usually includes commercial, agriculture, public and other, except for Bolivia and Costa Rica.
[b] As percentage of total demand.
[c] ttoe = thousand tons oil equivalent.

Source: World Bank, *Energy Issues and Options in Thirty Developing Countries*, World Bank Energy Assessment Program, Report No 5230, Washington, DC, USA, August 1984.

world. Besides these market incentives, biofuel use was encouraged by many countries because of a mixture of projected national benefits. National economic benefits often attributed to biofuel use included the development of new domestic fuel and agro-industry markets, more efficient utilization of basic commodity byproduct markets, rural employment generation, and foreign exchange savings through imported fuel displacement.

In retrospect, reality has proven otherwise over the past decade. Although the total amount of biofuel use has increased, biofuels have not been widely substituted for oil, particularly for meeting high-quality energy demand. The major exception is in the wood and agro-processing industry where biofuels are waste byproducts that can quite efficiently be utilized for liquid or steam/electric energy production. As more has been learned about interfuel substitution and energy

Table 2. Rural energy consumption in Thailand, 1983 (in thousand tons oil equivalent).

	Traditional fuels					Non-traditional fuels			
Sector	Fuelwood	Charcoal	Residues	Bagasse	Total	Lignite	Electricity	Total petroleum products	Total non-traditional
Household	1 908.0	2 147.6	124.7	–	4 180.3 (44)	–	78.8	302.4	381.2 (4)
Cottage industry	119.8	11.4	248.8	–	380.0 (4)	–	–	–	–
Industry	943.9	60.7	153.4	1 205.0	2 363.0 (25)	38.2	101.9	89.1	229.2 (2)
Agriculture	–	–	–	–	–	–	9.8	440.1	449.9 (5)
Transport	–	–	–	–	–	–	–	1 427.8	1 427.8 (15)
Total	2 971.7	2 219.7	526.9	1 205.0	6 923.3 (73)	38.2	190.5	2 259.4	2 488.1 (27)

Note: Figures in parentheses show percentage of total demand.

Source: World Bank, *Thailand: Rural Energy Issues and Options*, Energy Department, World Bank, Washington, DC, USA, September 1985.

consumer and producer behaviour, it is clear that a combination of technical and economic factors make biofuel *v* fossil fuel substitution more complex than originally envisioned. First, it is evident that the demand for biofuels and commercial fuels is highly segmented (eg low-quality household, low-quality industrial, or high-quality industrial) and the elasticity of substitution may be lower than expected.[5] Possible reasons for such a low elasticity are the higher initial or perceived financial and institutional risks involved with new, non-commercialized biofuel systems and the differences in scale economies for these fuels that tend to favour biofuels at low to medium use (1 kW–50 MW), but the use of fossil fuels (oil, coal, or natural gas) to meet higher energy demands.

Going beyond elasticity arguments, a second contributing factor may be that the eventual private market incentives for some biofuel uses end up being minimal, when compared to alternative biomass uses or fossil fuels, since initial benefits are offset by domestic energy market distortions (eg taxes and subsidies) or swamped by non-economic impacts. Energy pricing studies suggest that changes in market price signals (ie the financial or production costs as contrasted to economic costs) may be less effective in changing supply relationships than expected.[6] As shown by Bhatia for biogas use in India,[7] energy price distortions such as subsidies or taxes in developing countries tend to favour oil use, but act against biofuel adoption despite evidence that suggests the economic (social) costs of some biofuels are well below those of fossil fuels (Table 3). Third, some technical considerations favour fossil fuels over biofuels, such as the typically higher net calorific value of the former per unit dried weight and higher conversion efficiencies which affect the amount of usable energy.[8]

While evidence exists on some of these possible explanations, a severe lack of data prevents adequate measurement of most of these factors. Most analyses of biofuels *v* fossil fuels have focused almost exclusively on the financial or, in most cases, only the engineering costs of biofuels. Studies generally neglect to assess the economic incentives or disincentives to biofuel *v* fossil fuel substitution. While such a focus is appropriate for purely private market orientated economies, in the

Table 3. Annual operating costs of alternative technologies at shadow prices and market prices (in rupees).

	At shadow prices				**At market prices**			
	Electricity from grid	**Diesel oil**	**Diesel and biogas**	**Diesel and producer gas**	**Electricity from grid**	**Diesel oil**	**Diesel and biogas**	**Diesel and producer gas**
Energy/fuel cost								
Electricity	40	–	–	–	10	–	–	–
Diesel	–	91	44	27	–	106	51	31
Lube oils	–	8	6	4	–	7	5	3
Fuelwood	–	–	–	30	–	–	–	30
Cow dung	–	–	–	–	–	–	–	–
Repair and maintenance cost of electric motor/diesel engine	30	45	45	45	30	45	45	45
Repair and maintenance cost of biogas plant or gasifier	–	–	10	68	–	–	10	68
Labour charges for operation	–	30	30	30	–	30	30	30
Total annual operating gross	70	174	135	204	40	188	141	207
Present value of operating costs (assuming 10 year life and 10% discount rate)	430	1 069	829	1 253	246	1 155	866	1 272

Source: R. Bhatia, 'Energy pricing in developing countries: role of prices in investment allocation and consumer choices', in Corazon Morales Siddayao, ed, *Criteria for Energy Pricing Policy*, Graham and Trotman, London, UK, 1985.

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[5] Manmohan S. Kumar, 'Socio-economic goals in energy pricing policy: a framework for analysis', in Corazon Morales Siddayao, ed, *Criteria for Energy Pricing Policy*, Graham and Trotman, London, UK, 1985.

[6] *Ibid.*

[7] Ramesh Bhatia, 'Energy pricing in developing countries: role of prices in investment allocation and consumer choices', in Corazon Morales Siddayao, ed, *Criteria for Energy Pricing Policy*, Graham and Trotman, London, UK, 1985.

[8] Gerald Leach and Marcia Gowen, *Household Energy Handbook: An Interim Guide and Reference Manual*, World Bank Technical Paper No 67, World Bank, Washington, DC, USA, 1987.

developing world as elsewhere most energy use involves many forms of public market intervention, if not control. The problem is that few *ex post* studies exist on biofuel use in developing countries due to the relatively short commercial experiences of most high-quality biofuel energy systems and the limited number of well documented, successful projects. The exceptions are in the agro-processing industries, in particular the sugarcane, rice and wood industries. Thermal and cogeneration use based on such industrial processing wastes has gained increasing success in developing countries.[9] Despite these *caveats*, it is still helpful to draw a general picture of some emerging economic patterns and point to the evolving future trends in biofuel use. Due to the vast diversity in types of biofuels and their conversion systems, the discussion is organized around the key economic characteristics of biofuel use by sector.

Biofuel use in the transport sector

Because transport fuels are almost exclusively petroleum derived, the rapid real price increases for oil in the 1970s left the transport sector in most oil-importing countries extremely vulnerable. As a result, many countries explored biofuel substitution options. Among the developing countries, Brazil's aggressive sugarcane-to-ethanol programme provides the best available data and lessons on the economics of biomass-derived transport fuels.

Brazil's commitment in 1975 to increase its use of ethanol as a petrol extender was started in response to several internal pressures – a tripling of world oil prices, low international sugar prices,[10] and high unemployment in agricultural areas. The rapid expansion of alcohol production and increasing fuel use in Brazil due to the alcohol programme can readily be seen in Figure 1. Estimates of ethanol production costs in Brazil vary from US$0.18 to $0.48/litre(l) or $28–76/bbl petrol. However, most studies estimate the costs at $0.23–0.30/l.[11] Much of this variation is explained by the inclusion or exclusion of economic (as

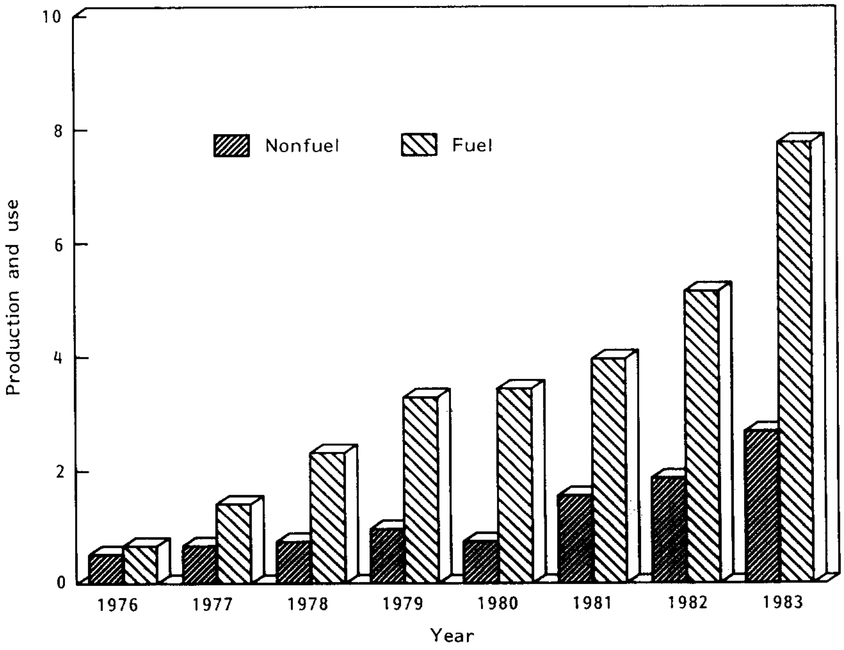

Figure 1. Brazilian alcohol use (in billion litres)

Source: Calculated from Howard S. Geller, 'Ethanol fuel from sugar cane in Brazil', *Annual Review of Energy*, Vol 10, 1983, pp 135–164.

[9] Agricultural and forest processing wastes have shown significant technical, economic and energy potential. Studies that demonstrate these opportunities include: B. Amin-Arsala, M. Gowen, M. Faulkner and D. Waddle, *The Potential for Private Investment in Rice Residue Power Generation: Indonesia 1987 Preliminary Analysis*, Report No 88–05, Office of Energy, US Agency for International Development, Washington, DC, USA, May 1988; AID Office of Energy, *Jamaica Cane/Energy Project Feasibility Study*, prepared by RONCO Consulting Corporation and Bechtel National Inc for the US Agency for International Development, Washington, DC, USA, September 1986; AID Office of Energy, *Electric Power from Cane Residues in Thailand: A Technical and Economic Analysis*, Cane/Energy Assessment Program, prepared by RONCO Consulting Corporation for the US Agency for International Development, Washington, DC, USA, September 1986; AID Office of Energy, *The Sugar Industry in the Philippines: An Analysis of Crop Substitute and Market Diversification Opportunities*, Cane/Energy Assessment Program, prepared by RONCO Consulting Corporation for the US Agency for International Development, Washington, DC, USA, December 1986; Marcia M. Gowen, ed, *Cane Energy Utilization Symposium: A Report from the 2nd Pacific Basin Biofuels Workshop, Vols I and II*, AID Office of Energy, prepared by RONCO Consulting Corporation for the US Agency for International Development, Washington, DC, USA, April 1987; Frank Tugwell, Marcia Gowen, William Kenda and Arthur Cohen, *Electric Power from Sugarcane in Costa Rica: A Technical and Economic Analysis*, for the Office of Ener-

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contrasted with financial) costs, differing technical assumptions, and substantial chronic currency devaluations. If recent oil price savings were passed on to oil processors, the programme would appear to be financially infeasible on a production cost basis at 1987 oil prices.

Beyond a financial assessment, a set of macroeconomic incentives and disincentives from the programme must also be considered. Even assuming conservative sugarcane production yields, the energy balance reportedly favours ethanol production, with external energy inputs accounting for only 30% of the energy content available in ethanol.[12] Also, the foreign exchange savings, which include direct petroleum plus indirect capital savings, are significant to Brazil.[13]

Against such benefits are the large government subsidies spent to encourage sugarcane and ethanol production. In 1984 the government supported the programme through two primary mechanisms. First, it set a floor price by guaranteeing the purchase of all authorized ethanol production at $0.25/l; second, it provided large ethanol investment loans at negative interest rates – 13–17% loan rates – which cost the government about $0.06/l.[14] Even after substantially reducing investment subsidies in 1981, the government still reportedly financed two-thirds of the industry's capital costs.[15] A third controversial issue surrounding the programme is the displacement of food production in Brazil. This dilemma is not solely attributable to the alcohol programme. Although the expansion in basic food production has lagged behind increases in population demand, land devoted to other export crops such as soybeans has seemingly expanded more rapidly than increases in sugarcane production. However many argue that, given national economic price incentives for cash and export crops, basic food crop production has suffered.

Other economic consequences of the programme are impacts on employment, rural industrialization, and capital investment needs. It can be argued that the highly labour-intensive process of cane and ethanol production favours developing economies' factors of production. However, unless accompanied by alternative employment options in the off-season, the temporary nature of labour demands in cane production can create high social costs. Estimates vary for the Brazilian experience, but employment estimates range from 500 000 to 1 million workers. About 75–90% of the labour demand and income created by the programme remains in the rural agricultural sector, although this programme provides only 3% of agricultural jobs in Brazil. In contrast to other countries, the progamme has helped the Brazilian sugarcane industry expand and strengthen significantly. It is now better diversified and healthier financially. In regard to capital requirements, investment costs in the ethanol fuel industry are reportedly much lower than for an oil-refining petrochemical complex.[16]

Besides Brazil, other developing countries such as Argentina, Costa Rica, Kenya, Malawi, Swaziland and Zimbabwe have also committed themselves to ethanol production, with varying degrees of success due to recent changes in oil prices and ethanol import restrictions into the USA.[17] A 1984 study for Thailand showed the proposed ethanol production from molasses to be economic in some regions at a 20% blend, cassava to be a superior feedstock over sugarcane, and a positive net effect on Thailand's balance of payments.[18] Provided US import restrictions are changed, a Caribbean Basin study suggested that exporting fuel alcohol to the USA as octane enhancers for petrol blends

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gy, Bureau for Science and Technology, US Agency for International Development, Washington, DC, USA, July 1988.

[10] H. Rothman, R.N. Greensheilds and F.R. Calle, *Energy from Alcohol: The Brazilian Experience*, Kentucky University Press, Lexington, KY, USA, 1983.

[11] ASTEL, *Proalcool, Avaliacao Social de Projecto*, Assesores Tecnicos Ltd (ASTEL), Rio de Janeiro, Brazil, August 1983; M. Barzelay and S.R. Pearson, 'The efficiency of producing alcohol for energy in Brazil', *Economic Development and Cultural Change*, Vol 31, No 1, October 1982; J.M.M. Borges, *Viabilidade Economica da Producao de Caue e Alcool no Brazil: Uma Abordagem Dinamica*, (ANPEC) Economia x Encountro National – 1982, U Aguas de Sao Paulo, Brazil, December 1982; Howard S. Geller, 'Ethanol fuel from sugar cane in Brazil', *Annual Review of Energy*, Vol 10, 1983, pp 135–164.

[12] J.R. Moreira and J. Goldemberg, 'Alcohol – its use, energy and economics – a Brazilian outlook', *Resource Management and Optimization*, Vol 1, No 3, 1981, pp 231–279.

[13] Geller, *op cit*, Ref 11.

[14] *Ibid.*

[15] B. Johnson, C.A. Fenerich and R. Fischman, *A Extensoo da Safra Canavieira Analise e Recomendacoes de Politicas*, Instituto de Administracao, University Sao Paulo, Brazil, 1983.

[16] Geller, *op cit*, Ref 11.

[17] Henry C. Kelly, 'The economics of renewable energy resources', in R. Bautista and S. Naya, eds, *Energy and Structural Change in Asia-Pacific Region*, Philippine Institute for Development Studies and Asian Development Bank, Manila, The Philippines 1984.

[18] Pryong Netayaraks, *Economics Analysis of Alcohol Production in Thailand and its Implications on Trade with Japan*, unpublished PhD dissertation, Ohio State University, Columbus, OH, USA, 1983.

was economical and provided net employment gains, increased exports, and reduced petroleum imports.[19] In 1980, despite the Papua New Guinea government recommending ethanol production from sago palm based on a financial basis, no financial institutions were willing to commit themselves to the project.

These initiatives suggest that currently only under optimal financial or subsidized conditions is alcohol production for fuel seen as competitive with petrol. The hesitancy of most governments and financial institutions to adopt such programmes as Brazil's implies that the perceived or real risks are still too high and the economic gains too low, given current relative fuel prices. While the costs of some biofuel technologies are expected to fall,[20] unless oil prices rise significantly again (as expected by the mid-1990s), environmental standards change in the developing world, or total cost reductions occur for biofuel technologies, biofuel use in the transport sector is limited. In the past, the decision to follow a liquid biofuel path in the transport sector seems to be based as much on political as on national economic priorities.

Industrial biofuel use

Key economic characteristics that distinguish industrial biofuel from fossil fuel conversion systems are their general cost structures, scale economies, degree and type of subsidies, foreign exchange impacts, reliance on byproduct credits, and environmental externalities. To highlight major differences, the following discussion is organized around this set of economic and financial characteristics that differentiate the viability of biofuel from fossil fuel systems.

Cost composition

In Figure 2, a comparison of average costs for different sizes (20–50 MW) of conversion systems shows the relative importance of the major cost components – fuel, non-fuel and capital. Coal, oil-fired thermal and diesel-electric (at a high of $35.00/bbl and a low of $23.00/bbl oil prices) are compared to wood-electric and gasification (at a high of $20.00/ton and a low of $5.00/ton wood prices).[21] As can be seen, the typical biofuel cost structure is characterized by low feedstock, variable maintenance, but high capital or initial up-front costs as compared to

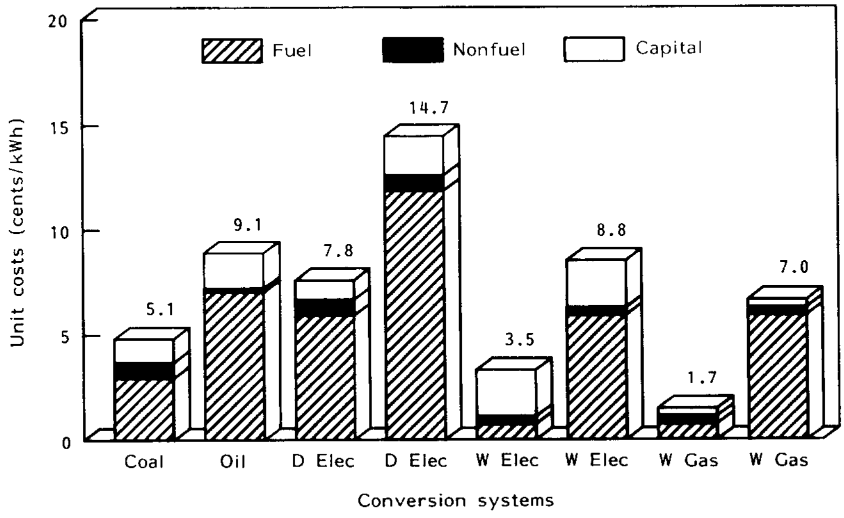

Figure 2. Fuel conversion costs (in US ¢/kWh)

Source: Calculated from Henry C. Kelly, 'The economics of renewable energy resources', in R. Bautista and S. Naya, eds, *Energy and Structural Change in Asia-Pacific Region*, Philippine Institute for Development Studies and Asian Development Bank, Manila, the Philippines, 1984.

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[19] Norman Rask, *Fuel Alcohol from the Caribbean Basin: An Alternative Energy Supply*, Department of Agricultural Economics and Rural Sociology, Ohio State University, Columbus, OH, USA, 1983; Norman Rask, *Fuel Alcohol: A Potential Agricultural Trade Commodity*, Department of Agricultural Economics and Rural Sociology, Ohio State University, Columbus, OH, USA, 1984; M. Moo-Young, C.W. Robinson and Robert Lencki, *Liquid Fuels from Renewable Resources: Technoneconomic Comparisons of Alternative Feedstock Uses*, ESRG-MR4e, Energy Research Group, IDRC, Ottawa, Canada, 1984.

[20] Rask (1984) *op cit*, Ref 19; Moo-Young *et al*, *op cit*, Ref 19.

[21] Kelly, *op cit*, Ref 17.

oil-based conversion systems (but similar to coal-fired plants). The major exceptions are for plantation biofuels – agricultural or wood crops – that have high establishment and transport costs, as shown in the high-priced fuelwood scenarios in Figure 2. In contrast, the typical cost structure for most petroleum (and natural gas) systems, excluding refinery and extraction costs, is characterized by the highest proportion of total costs going to fuel expenditures, a moderate amount to maintenance, but a relatively low percentage to capital costs. Only medium to large coal plants, with similar front-end handling systems, have cost structures comparable to a wood-fired or biomass combustion system. When environmental or emission control technology costs are included, biomass systems are likely to enjoy a comparative advantage over coal systems.

As is evident in Figure 2, the primary factor shaping the comparative advantages between these fuels is feedstock costs. Biofuel feedstocks fall into two main cost categories – those that have minimal or zero resource costs, such as captive, on-site waste products found at wood and agro-processing plants; and those that claim a higher market value, such as plantation-based wood and high-value agricultural crops. The dominant economic characteristic of financially competitive biofuel systems is that they almost always depend on feedstocks that are 'free' (or nearly so) as valued by the private market. Waste products are competitive with fossil fuels when used on-site, in areas away from a central grid, or densified to reduce unit transport costs in biofuel-scarce countries.[22] For instance, in the recent energy assessment for Thailand more than 91% of rural industrial energy was supplied by biofuels with 52% being byproduct wastes of the industries (Table 4). Sugarcane bagasse and field trash are used widely for thermal production and, more recently, for cogeneration in developing countries.[23] These fuels are particularly attractive when displacing oil for cogeneration. Reliance on animal and human wastes for biogas systems in India and China is another example of feedstocks having zero or negative costs; ie these wastes are free or in fact would impose some disposal or sanitation costs on society if not used for energy.[24]

The effects of varying feedstock prices on comparative advantages is readily seen in Figure 2. Large-scale wood combustion or retrofit gasification units are the most financially attractive systems only if low feedstock costs are assumed, as might be the case with waste wood. Quadrupling wood fuel prices up to typical plantation costs of $20/ton (wet weight) results in wood conversion systems that are no longer competitive with oil or coal on a unit cost basis.[25] Given recent low oil prices, the comparative advantage for large-scale systems (over 75MW)

Table 4. Fuel consumption in rural industries in Thailand, 1983 (ttoe[a]).

		Modern fuels			
Industry	**Traditional fuels**	**Petroleum products**	**Electricity**	**Lignite**	**Total**
Food canning and processing[b]	114.2	19.7	42.1	–	176.0
Rice milling[c]	153.4	11.5	5.3	–	170.2
Animal feed[b]	535.5	27.4	12.1	–	575.0
Sugar milling[d]	1 205.0	4.8	10.0	–	1 219.8
Tobacco curing[b]	–	–	–	38.2	38.2
Wood processing[b]	271.6	10.4	31.7	–	313.7
Brickmaking and pottery[b]	83.3	15.3	0.7	–	99.3
Total	2 363.0	89.1	101.9	38.2	2 592.2
Percentage	91.0	4.0	4.0	1.0	100.0

[a] ttoe = thousand tons of oil equivalent.
[b] Mainly fuelwood and charcoal.
[c] Mainly rice husks.
[d] Bagasse.

Source: World Bank, *Thailand: Rural Energy Issues and Options*, Energy Department, The World Bank, Washington, DC, USA, 1985.

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[22] Ken Newcombe, *The Commercial Potential of Agricultural Residue Fuels: Case Studies on Cereals, Coffee, Cotton and the Cotton Crops*, Energy Department Paper No 26, The World Bank, Washington, DC, USA, 1985; and *op cit*, Ref 9.

[23] *Op cit*, Ref 9.

[24] T.K. Moulik, 'The biogas program in India and China: a comparative analysis of experiences', paper presented at symposium on Biomass Energy Systems: Building Blocks for a Sustainable Agriculture, World Resources Institute, Washington, DC, USA, 1985.

[25] The low-price scenario is based on wood fuel costs at about $5/ton, whereas plantation wood in most developing countries generally goes for $20–25/ton (wet weight); Geller, *op cit*, Ref 11.

may still favour fossil-fuel-based systems in the near term for many developing countries.[26] More will be said about scale economies later.

Dependence on low feedstock costs can be both a blessing and curse for some biofuel systems. Low or zero feedstock costs depend upon (a) depressed primary commodity markets, such as those for wood and sugar, (b) few alternative byproduct uses, or (c) an unlimited or on-site resource supply. If alternative markets develop for these resources, their opportunity costs rise. Relative price changes for some biofuels resulted in previously viable systems becoming non-competitive. For example, recently in the Philippines a rapid escalation in charcoal prices due to increasing household and industrial demand caused industries to revert to diesel use from small charcoal-powered gasifiers.[27] In a generic model of dendrothermal plants, Terrado found feedstock prices to be the most sensitive variable affecting the economic viability of these biofuel systems.[28] Severe fuel supply shortages for dendrothermal plants in the Philippines, although primarily the result of poor tree-siting choices, partially led to massive cutbacks for this programme.[29]

Given that biofuel prices will increase with higher biomass demand unless supplies are expanded, biofuel price volatility should be expected over the long run. Such price uncertainty leads to higher risk being assumed by energy producers. Future biofuel price variability, though, may not differ substantially from fossil fuel price volatility. However, many demand and supply analyses exist for fossil fuels; such financial risks are therefore better understood and more predictable. For large-scale biofuel plants without proven track records, as in the wood and sugar industry, many financial institutions have simply not been willing to carry such risk. For this reason, the public sector has often participated in minimizing the risks or has guaranteed biofuel programmes.

Given these general cost relationships between the various fuel supplies, the wisest approach for undertaking industrial biofuel projects in developing countries is initially to harness a country's under-utilized agro-processing or wood wastes. Such resources, although ultimately limited, should be tapped first for high-quality industrial thermal or cogeneration plants before other intensive biofuel production schemes, such as plantations, are encouraged.

Scale economies

Interwoven into the above discussion is the effect of scale economies on the comparative advantages of biomass *v* fossil fuels. Biofuel systems are generally competitive at small to medium plant sizes (up to 50 MW), whereas fossil fuel systems favour larger economies of scale. An important *caveat* is warranted. The available data on scale economies present severe comparability problems. First, financial analyses of energy systems are extremely site-specific. Thus, comparisons across technologies are difficult and often misleading. Second, costs are often reported in different units (eg costs per installed kW as contrasted to costs based on only capital costs). Third, various feedstock conversion systems provide vastly different energy products (eg processing heat *v* electricity). For these reasons, the following data use average values to relate general patterns. In reality, on-site costs may vary considerably.

At the low end of the scale, biogas systems meet mostly household or small-scale industrial/commercial demand. Village and small-firm biogas systems based on animal wastes in developing countries run from

[26] Current oil prices are well below the prices assumed by Kelly ($23/bbl) in Figure 2.

[27] John H. Ashworth, *Renewable Energy Systems in Asia: Current Successes and the Potential for Future Widespread Dissemination*, Associates in Rural Development, Burlington, VT, USA, 1985.

[28] Ernesto W. Terrado, *Technical and Cost Characteristics of Dendrothermal Power Systems*, Renewable Energy Unit, The World Bank, Washington, DC, USA, 1985.

[29] Associates in Rural Development, *Feasibility Reassessment of the Philippines Rural Energy Development Project*, ARD, Burlington, VT, USA, 1985.

$300 to $600/kWe installed and range from 1 to 4 kWe in size. At the upper limit, more expensive digestors go up to about 10 kWe. In contrast, reticulated diesel sets can supply from 3 kWe up to tens of megawatts. At the lower range, small single or multiple diesel sets (about 3–100 kW) cost approximately $400/kWe, whereas prices fall to $200/kWe for larger systems of more than 1 MWe. Biogas systems have had quite mixed success in many developing countries, primarily as a result of operational and social acceptability problems. China, with its history of night-soil use and penned livestock practices, has had the greatest success rate, although most systems provide household rather than industrial energy. In contrast, biogas systems in India have had a more chequered history, and in the Pacific islands few commercially viable systems are currently operating. Small biofuel heat raising or electric systems (10–600 kW) are often more attractive. When run on captive plant or field residues, such as small rice conversion systems, and coffee or tea drying gasifiers, these systems provide important rural industrial source of energy in areas away from the central grid.

At the medium-scale level, biomass combustion systems and gasifiers using wood or crop residues have the greatest long-term potential. Currently, gasifiers are only competitive for direct-heat applications or with diesel at specific locations for electric generation. Capital and operating costs are the critical factors influencing the financial feasibility of gasifiers producing electricity. The wide disparity in quoted capital costs that are based solely on manufacturers' estimates or pilot projects (more than tenfold), when combined with current operational problems, makes many financial assessments very misleading. According to Terrado, in the Philippines and Brazil retrofitting locally produced gasifiers onto diesel-fired engines for electricity generation was competitive with diesel and gasoline engines for about $200/kW, not including the cost of the diesel engine. However, imported North American or European systems, which cost more than $400/kW, could not compete with fossil fuels at 1982 prices.[30]

In contrast to electricity production, direct-heat gasifier systems are currently quite attractive when used for crop drying (eg tea, coffee and copra) in Asia, the Pacific[31] and Africa. According to Terrado, wood-fired gasifier systems producing either shaft power or direct heat are competitive with fuel oil, provided fuel oil prices exceed about $23/bbl and air-dried (15% moisture content wet basis (mcwb)) plantation wood does not exceed $40/ton.[32] Given current oil prices, such biofuel systems are not now very competitive with oil except in remote areas. New gas turbine research holds the potential for revolutionizing the biomass electricity sector by providing medium-scale modular units that are cheaper than diesel systems and more efficient than existing biofuel conversion technologies.

Of more immediate promise are medium-scale thermal or cogeneration (5–40 MW) systems based on wood or agricultural wastes. The US sugarcane and wood industries have a long history of burning their wastes for internal steam-electric use and, more recently, export electricity sales. Such processes hold the greatest potential in the developing world for supplying intermediate high-quality industrial demand from biomass. A recent Costa Rican cane electric power study showed the sale of electricity to the grid to be highly profitable for sugar mills at lower power output levels (1–2 MW) during the harvest season.[33] If additional biomass sources are obtained during the off-crop

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[30] Ernesto Terrado, 'Biomass gasification', paper extracted from *Synopsis of Gasifier Technology Guidelines*, Energy Department, World Bank, Washington, DC, USA, 1983.

[31] PIDP *et al*, *Energy Mission Reports*, Pacific Islands Development Program, East-West Center, Honolulu, Hawaii, 1982.

[32] Terrado, *op cit*, Ref 30.

[33] Tugwell *et al*, *op cit*, Ref 9.

seasons, year-round electricity sales from several mills of 10–12 MW at favourable net returns could be possible. Presently, ongoing interest in Jamaica and Thailand by the cane industry, the government and the electricity utility are exploring the commercialization of such electricity sales.[34]

Scale economies for large (>50 MW) thermal or power systems tended always to favour fossil fuel over biofuel systems until recently. In Terrado's 1985 generic model for dendrothermal systems, decreasing costs are exhibited for plantation-based wood combustion systems, from 3 MW ($2 640/kWe installed) to 100 MW installed ($1 660/kWe installed).[35] When compared with diesel under conservative biofuel yield assumptions (10 oven-dried tons/hectare(t/ha)), electricity generation is estimated to cost 7.0¢/kWh for a 90 MWe diesel system as compared to 8.4¢/kWh for the 100 MWe wood system. The gap appears to be narrowing, with biofuels becoming more competitive but with fossil fuels still outcompeting biofuels for large industrial applications. As previously mentioned, recent field data in the Philippines suggest fuelwood costs may be far higher than predicted if supplies come from wood plantations.[36]

Since financial cost assumptions across systems are often highly variable, and quite site specific, these generalizations must be seen as indicative of biofuel *v* fossil fuel scale economies. They suggest that biofuels are primarily competitive when meeting small- to medium-scale industrial energy requirements (up to 50 MW), depending primarily on the location and cost of feedstocks. In contrast, large-scale energy needs, particularly for electricity, will still be met by fuels such as oil, hydro, or coal.[37]

Subsidies

Biofuel systems are often perceived as heavily subsidized by developing countries. In fact, the amount and impact of subsidies for such systems varies widely from country to country and across different biofuels. Experience in the Pacific and Asia has shown that small-scale biofuel systems may receive substantial aid only for initial capital costs, but that the energy produced is priced higher for biomass users in terms of costs per kWh or a set user charge than energy produced from traditional petroleum alternatives such as kerosene or diesel-based electricity. For instance, it is common in the Pacific and Asia for biomass system users to agree to charges that pay back the full system costs, whereas most industrial users of centralized fossil-fuel-based systems receive subsidized tariffs.

Some large, highly publicized programmes, such as Brazil's alcohol, India and China's biogas, and the Philippines' dendrothermal programmes, received significant financial support from the government due to the importance (social premium) attributed by the country to energy self-reliance. For instance, capital investment loans for alcohol plants in Brazil are reportedly given at negative real interest rates, while the government also guarantees purchase of all excess ethanol.[38] In India the national government can provide up to 50% of the cost for the biogas capital, with state governments providing an additional 8–20%, depending upon the income level of the user.[39] In the Philippines, the government's support of dendrothermal plants gradually decreased from P300 million in 1981 to only P29 million in 1985.[40]

Subsidization does not guarantee programme success. Brazil's

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[34] AID (1986), *op cit*, Ref 9.

[35] Terrado, *op cit*, Ref 28; and based upon 1984–85 data from the Philippines, Papua New Guinea and the USA.

[36] ARD, *op cit*, Ref 29.

[37] In many developing countries where the potential exists, hydroelectricity is attractive for meeting both low and high demands.

[38] Geller, *op cit*, Ref 11.

[39] World Bank, *Thailand: Rural Energy Issues and Options*, Energy Department, World Bank, Washington, DC, USA, 1985.

[40] ARD, *op cit*, Ref 29.

appears successful but is still controversial. India's biogas has experienced quite high failure rates due to the lack of operational training and to significant social barriers. Similarly, the Philippines' programme is floundering as the result of serious fuelwood supply shortages.[41] This pattern suggests that some of the initial biomass programmes were only marginally, if at all, financially attractive. Over the decade, most successful programmes have shifted to on-site byproduct use in agro- or wood-processing industries to meet high demand and generate larger regional benefits.

A government's decision to support these biofuel systems, as with any subsidized good, is rarely based on financial returns, but rather on national economic or welfare goals. A government subsidizes various products either to encourage adoption and commercialization in initial years with the objective of reducing or eliminating subsidies over time or, in the case of many agricultural and industrial products, to subsidize permanently or maintain floor prices for the product based upon internal political priorities placed on income and job creation, rural industrialization, and self-sufficiency. As in the case of Brazil's alcohol programme, the decision to subsidize biofuel systems was based upon the actual financial costs, perceived national vulnerability, expected foreign exchange savings, internal market and income generation capabilities, expected future prices of fossil fuels, and the opportunity cost of using the resources for energy rather than an alternative use. The enormous commitment of the Brazilian government demonstrates the national benefits it perceived from the programme.

Despite the widespread publicity about these subsidized programmes, many successful commercial biofuel systems have not relied upon subsidies. For instance, cash-crop plantations or processing mills in the tropics often use waste products economically without subsidies in direct-heat gasifiers, direct combustion, and steam turbines.[42] Such potential in the developing countries is vastly under-utilized, although ultimately limited. Currently, modern advanced biofuel systems usually represent a small percentage of total industrial energy or biofuel use in a country. In Costa Rica the sugarcane industry could provide up to 55 MW of firm and surplus power to the national grid at costs that favourably compete with the utility's costs of production.[43] Generally, the survival of biofuel systems without subsidies depends upon their distance to the grid, an unreliable or expensive fossil fuel supply, or low biofuel feedstock costs. Given falling energy prices, most developing countries will probably be reticent about adopting highly subsidized, large-scale plantation biofuel projects for the industrial sector in the near future. In contrast, programmes that utilize waste products – wood, crop residues or industrial wastes – and do not require long-term subsidies foster greater national benefits than reliance on imported fuels.

Foreign exchange arguments

If they displace imported energy products, biofuel systems are often perceived to provide substantial foreign exchange savings for a country. In practice the issue is not clear cut. First, unless the biofuel technology is produced internally, foreign exchange is still required for capital investment. Generally, as shown in Figure 2, this is at levels far higher than for fossil fuel systems. Since a biofuel system's capital needs are higher than for petroleum or equal to coal (see Figure 2), there may be

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[41] In the Philippines, although 40 sites were to cover 63 000 hectares (ha), only 8 000 ha have successful plantations; ARD, *op cit*, Ref 9.

[42] *Ibid*, PIDP *et al*, *op cit*, Ref 31.

[43] Tugwell, *et al*, *op cit*, Ref 9.

little or no savings on the initial investment. Rather, it is the operational year-to-year foreign exchange savings from displaced imported petroleum use that provide the substantial net gains to a country. Few studies have chosen to illustrate this point, with a recent exception of the Costa Rican cane electric analysis.

It is possible that saving foreign exchange by reducing petroleum imports is not necessarily a net benefit to a country if the local resources used for domestic energy production could have earned more foreign exchange through alternative uses or energy product export.[44] While this case rarely applies to waste use, it may be important in deciding the opportunity cost of using forestry and agricultural products for the domestic energy rather than the export market. More research on both export possibilities and actual foreign exchange cash flows is needed for any conclusive statement to be made.

Byproduct credits and environmental externalities

Another economic advantage often cited to promote biofuel systems is that they can provide additional byproduct markets. For example, biogas plants provide a fertilizer from the effluence that otherwise might present a health cost to society.[45] Unpriced sanitation benefits are being obtained by the users in addition to their fertilizer replacement costs. Other examples of biofuel systems with beneficial byproducts are rice residue conversion systems where the highly valuable export ash sales provide possibly 50% of the net benefits, integrated fuelwood-cropping schemes, and tree plantations with land stabilization/watershed management enhancement.[46] The dilemma for the country is how to capture the value of such benefits. While some of these byproducts increase the net financial returns to the energy producer (as in rice or wood byproducts), many economic benefits go unpriced by the private market or simply enter the informal sector.

All biofuel systems do not produce positive externalities. Smoke production from wood stoves in India is a major health concern for energy users.[47] Likewise, large wood-fired direct combustion systems require adequate air pollution control devices and waste treatment facilities in order to dispose of the air pollutants and ash. Given the rather tentative nature of most developing countries' environmental protection regulations and even the developed world's general inability to agree on actual values, such environmental costs cannot be assumed to be internalized by the energy producer or user.

In contrast, the byproduct benefits of fossil fuel production are more often valued (in monetary terms) by the private sector and captured by the feedstock producer. However, environmental diseconomies from these fuels at the energy production stage generally include far more serious and higher levels of air pollutants, such as sulphur dioxide, nitrous oxide, and carbon dioxide. These diseconomies simply are not fully internalized by the market in both the developed and developing world. For instance, the environmental costs in terms of coal-burning plants are certainly higher than for similar-scale wood-fired direct combustion plants. With low fossil fuel prices, the negative externality of the greenhouse effect from fossil fuel burning may be the most disastrous long-term global impact that is being overlooked in the comparison of biofuel *v* fossil fuel use.

[44] Rask (1984) *op cit*, Ref 19; Moo-Young *et al*, *op cit*, Ref 19.

[45] World Bank, *op cit*, Ref 39; Michael T. Santerre and Kirk R. Smith, 'Measures of appropriateness: the resource requirements of anaerobic digestion (biogas) systems', *World Development*, Vol 10, No 3, 1983, pp 239–261.

[46] Amin-Arsala *et al*, *op cit*, Ref 9.

[47] Kirk R. Smith and Jamuna Ramakrishna, *Biomass Fuels and Health*, ERG Monograph No 98, International Development Research Center and United Nations University, Ottawa, Canada, 1986.

The residential sector

In contrast to the industrial and transport sectors, where high-quality fuels are needed, the residential sector in most developing countries depends on a combination of high- and low-quality fuels. In fact, the demand by the residential sector for high-quality energy, such as electricity, usually far outstrips expansion potential in many developing countries.[48] In terms of human impacts, the low-quality fuel issue claims higher priority in most countries than generally received. The increasing scarcity of low-quality fuels such as wood and, until recently, the high costs of alternative fossil fuels, affect the broadest segment of the population in these countries.

Where serious biofuel scarcity problems exist, such as Africa and South Asia, the lack of cooking or home-industry fuels is generally the critical issue for the residential sector. Even more than in the other sectors, the divergence of pricing factors affecting the economics of these fuels makes broad generalizations impossible. First, the wide disparity across countries between fuel subsidization policies – until the early 1970s usually favouring fossil fuels – and biofuel scarcity problems drastically changes the comparative advantages of biofuel *v* fossil fuels between countries. Second, reported market prices for biomass cooking fuels can be extremely misleading. For instance, fuelwood prices reported in many studies often use averages of highly variable urban prices. On the other hand, most rural and urban-poor biofuels such as twigs, branches, crop residues and dung are not marketed, so they must be valued at their associated opportunity costs. Such values are also rarely calculated.[49]

A comparison of average cooking fuel costs attempts to show some key relationships between biofuels and fossil fuels in selected developing countries (Table 5). Since comparing costs across countries is misleading due to varying foreign exchange distortions, it is useful to compare relative prices within a country. Except where fossil fuels are heavily subsidized or acute biofuel shortages exist, as in Ethiopia, fuelwood is generally cheaper than fossil fuels. The addition of capital costs for cooking stoves tends to further enhance these fuel cost patterns.

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[48] Leach and Gowen, *op cit*, Ref 8.
[49] *Ibid*; Moulik, *op cit*, Ref 24.

Table 5. Cooking fuel prices in various developing countries.[a]

	Fuelwood		Charcoal		Kerosene		LPG		Electricity	
Country	Fuel price ($/kg)	Cost per utilized energy (¢/MJ)	Fuel price ($/kg)	Cost per utilized energy (¢/MJ)	Fuel price ($/l)	Cost per utilized energy (¢/MJ)	Fuel price ($/kg)	Cost per utilized energy (¢/MJ)	Fuel price (¢/kWh)	Cost per utilized energy (¢/MJ)
Africa										
Ethiopia (1983)	0.04–0.09	2.3–4.6	0.19–0.48	3.0–7.4	0.37–0.45	2.9–3.5	0.33	1.6	7.0–8.0	3.2–3.7
Kenya (1981)	0.01	0.8	0.06	0.9	–	–	–	–	22.0	10.2
Liberia (1984)	0.05–0.13	2.3–6.2	0.14–0.22	2.2–3.5	0.1–0.61	2.3–4.8	–	–	15.0	7.0
Madagascar (1984)	0.04–0.05	2.3–3.0	0.09–0.17	1.3–2.5	–	–	–	–	2.0	0.9
Morocco (1983)	0.02–0.06	0.8–3.1	–	–	–	–	0.41	2.2	0.9	4.2
Niger (1982)	0.06	3.1	0.15	2.2	0.5	3.9	0.98	4.9	17.0–19.0	7.9–8.8
Asia/Pacific										
Thailand (1984)	0.02–0.04	0.8–2.3	0.09–0.21	1.3–3.0	0.27	2.0	0.42	2.2	6.0	2.8
Latin America										
Peru (1983)	0.02–0.06	0.8–3.1	0.38	5.7	0.46–1.09	3.5–4.8	0.27	1.3	4.0	1.8

[a] Assumes wood high heating value of 20 MJ/kg (oven dried), 15% moisture content wet basis (mcwb) at burning, and woodstove system efficiency of 15%; charcoal net heating value of 29 MJ/kg at 5% mcwb and improved charcoal stove efficiency of 23%; kerosene net heating value of 35 MJ/l and stove efficiency of 45%; LPG net heating value of 45.5 MJ/kg and stove efficiency of 55%; and electricity net heating value of 3.6 MJ/kWh and stove efficiency of 60%.

Sources: UNDP/World Bank Energy Sector Assessment Reports.

With low oil prices, such relationships may change for some countries with access to cheap oil products. The solutions to a biofuel crisis in the cooking sector are probably different for various income groups and regions. For the urban and rural poor who are dependent on 'free' biofuels, these oil price changes may relieve the demand pressure from low- or middle-income users, which has bid up the price of biofuels. If lower crude oil prices are passing along into lower kerosene prices, then the historic energy transition pattern for middle-income people away from biofuels to petroleum or other fossil fuels may again resume. Since cash expenditure is the major constraint for the poor, subsidizing kerosene prices may not alleviate their problem.[50] As noted above, non-cash users with access to 'free' biofuels can be expected to use them unless the social opportunity cost of kerosene is less than the opportunity cost of the biofuels.

Conclusions

This comparison of the financial and, to a more limited extent, economic impacts of biofuel and fossil fuel use suggests a substitution potential for biofuels that is highly dependent on the level and quality of demand, and national energy priorities. Given recent oil prices and the chequered success of advanced biofuel systems, biofuel use certainly will not meet earlier expectations for significant displacement of high-quality fossil fuel use in most countries in the 1990s. On the other hand, neither will it rapidly be displaced by fossil fuels in many of its current residential or rural industrial uses without greater price or user-profile changes.

As shown in this paper, the specific cost structures, scale economies, and macroeconomic impacts exhibited by biofuel systems often contrast significantly with those associated with fossil fuel systems. On a financial basis, given the plateau in oil prices and greater perceived risks of biofuels, particularly with larger biofuel systems, most developing countries can be expected to rely on fossil fuels rather than biofuels for meeting their largest industrial and transport fuel demands. This view is clearly a function not only of the limited, if not negative, net financial benefits for some large biofuel systems, but also to a great extent of the higher financial risks and administrative and operational complexity associated with such systems.

The major exceptions are competitive biofuel systems that rely on wastes. In fact, competitive, efficient biofuel waste systems should be encouraged by national and international agencies, particularly in the rural industrial sector in which the savings to the country from the promotion of these industries are significant. Future analyses should look closely at those firms or private entrepreneurs who can and are making money on biofuel use rather than potential users with no experience in deriving profits from biofuels.

Whereas at present biofuel provides limited, but important, economic potential in the industrial and transport sectors, biofuel systems are still the least-cost and primary option on a financial and economic basis in the residential cooking sector for most developing countries. In fact, the greatest global potential for biofuel programmes could be from energy conservation through improved technological innovation in this sector. As Smith hypothesizes, a modern biofuel transition is needed whereby modern efficient systems replace traditional ones.[51] Thus, current

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[50] Evidence suggests that such subsidies may be no help to the poor; see Bhatia, *op cit*, Ref 7.

[51] Smith, *op cit*, Ref 1.

support of such biofuel programmes needs to be strengthened.

The lack of macro-level analyses of biofuel systems raises the need for greater study of employment generation, internal market stimulation, and net foreign exchange effects. Besides the oil security issues, biofuels may have other economic benefits such as taking advantage of existing indigenous resources, stimulating more efficient commodity production systems, absorbing excess rural labour, and increasing rural incomes. These factors need to be seriously compared and coupled with private market incentives. The impact on financial viability and system reliability of the seasonal nature of biofuel supplies, as contrasted with most fossil fuels whose use can be delayed or suspended for future use, is a critical research issue that has been ignored. This factor has important risk implications on long-term biofuel use. It is clear from the Philippines' experience that if some countries choose a biofuel strategy because they place a premium on diversifying their energy base and stimulating internal markets, they must ensure adequate biofuel supplies will exist at reasonable costs to the consumer. Poor market development, or conversely competitive product markets for biofuels, are often key reasons for private and public biofuels schemes' failures or successes.

Despite the marked relative price changes for biofuels *v* fossil fuels at present, it is important that volatile crude oil prices do not lead to a general apathy in energy planning in areas where biofuels or other fuels such as hydro or solar are appropriate. For instance, falling crude prices have only slightly affected rural diesel oil or kerosene prices in some countries with high import duties or taxes. However, it is obvious that setting aside their economics, the organizational barriers to implementing biofuel strategies are extremely high. Historically, biofuel programmes have required more institutional coordination and cooperation at the regional, national and international agency levels than is often possible. Thus, costly fossil fuel or hydro projects have been more attractive, and in practice more feasible, to the public sector than many small or medium-scale biofuel projects.

Since these recommendations are based on limited field data, both financial and economic, it is important to highlight the tentative nature of these findings. Reliable financial cost data from operational systems is limited and often quite aggregated. The macro-level impacts that might favour biofuel use, such as income generation, market development and balance of payments effects, are even more uncertain and still require serious analysis. These studies are essential since many benefits from biofuel use are not reflected in a financial analysis.

Given the high profile biofuels have received over the past decade, this lack of data is troubling. Yet the limited amount of actual biofuel substitution for fossil fuels in most developing countries suggests serious economic as well as non-economic barriers must exist. At a minimum, greater evaluations of past projects by these countries and international agencies should occur to identify more definitively the full private and social comparative advantages of various fuels. While much technical progress has been made, at present the current research focus should be on appropriate systems, either fossil fuel or biofuel, with the greatest economic and social promise. The breadth of biofuel substitution certainly is less than originally envisioned. While traditional biofuel use has long been with us, the future challenge is to focus on environmentally sound, and economically justifiable, advanced biofuel systems.