Project Gaia: converting biomass to a clean liquid fuel for domestic use

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The best way to avoid the many problems associated with burning wood as a household fuel is to stop burning wood. Instead, wood, and biomass generally, including waste biomass, may be used to make methanol, which is the simplest alcohol and the ideal clean-burning liquid fuel. This offers a cleaner and more efficient way to use biomass as the primary source for household energy wherever adequate quantities of biomass can be grown on a sustainable basis.

This opportunity exists because there is a proven stove that operates safely and effectively with methanol – the Dometic Origo® stove. Currently used in special applications where safety and air quality are all-important, this stove is being adapted for use in developing countries. The Dometic Corporation is building a sturdy, functional and inexpensive stove for use in the simplest household. Methanol is manufactured all over the world from natural gas and is shipped in large quantities. It is the most widely available alcohol. It is also the most easily and cheaply produced from biomass. The authors discuss technologies available to gasify biomass for methanol synthesis and, likewise, a technology to manufacture methanol from synthesis gas on a small scale.

The authors argue that methanol from natural gas is the ideal bridge between the current day and the day when biomass can be manufactured from plantation and renewably harvested biomass on a scale large enough to achieve economies and serve significant populations. This is referred to as the "hard green" approach, in contrast to the "soft green" approach that seeks to find more efficient ways to continue to burn wood directly.

The opportunities for developing countries that implement a methanol-based energy economy are discussed. Introduction of the stove and its fuel would result in savings per family of 5 tonnes of CO_2 per year. If carbon credits are sold, this could return money to the family to offset the cost of stove and fuel. Labour savings from not having to gather fuel-wood could mean additional hours each day for gainful employment. Local manufacture and distribution of the stove and fuel represent potential wealth-producing industries.

The authors note that the use of methanol will not be limited to cooking. Other appliances are under development for refrigeration and lighting. Engines and small direct methanol fuel cells will generate household electricity. Because of the close link between household energy and local enterprise, the availability of adequate energy supplies and the technology to use them will create the opportunity for many wealth-producing activities.

1. Introduction

The solutions to major problems are often far from the most obvious ones on which we tend to concentrate initially. Our natural tendency is to try to improve on existing practices, which may be already obsolete. It would seem, for example, that the way to improve on the use of wood as a domestic fuel is to make a more efficient stove and then pipe the decreased but still very significant smoke and fumes out of the house or the courtyard. But this is not the best solution. The best solution is to depart completely from tradition just as the inventor of the self-cleaning stove oven did. Who would ever have thought that the way to clean an oven was to set it on fire? Yet, that is what he did. He closed the oven with a safety lock and then heated it to the ignition temperature of grease and carbon and held it just above ignition temperature – not too hot – so the grease and carbon would oxidize away in a couple of hours to a little bit of white ash that could be wiped off with a damp rag. Now such ovens are installed on stoves all around the world.

It is not obvious that the quickest and best way to solve the wood-burning problem is to stop burning wood. Instead, make wood into a clean liquid fuel and burn that. Our paper could end here because we have given the

Figure 1. A one-burner Origo methanol stove

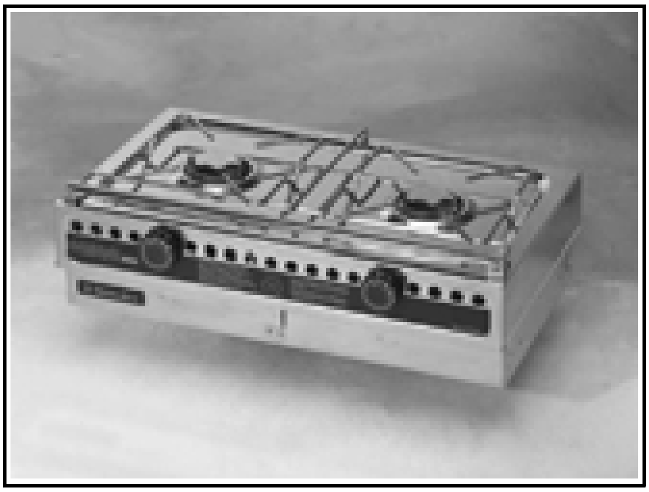

Figure 2. A two-burner Origo methanol stove

answer. However, the reader will want an explanation of not only how to accomplish this but also how to bridge the time gap between now and the day when we can actually make biomass into a clean liquid fuel for use in the home.

2. "Hard" and "soft" green approaches

By way of background, let us look at some interesting history. Travelling in the British Isles, one is struck by the lack of forests in a once heavily forested country. Even Iceland, where there is scarcely a tree today, was once well forested. Where did the trees go? They went to heat homes, to cook with, and to make charcoal for the manufacture of iron, as well as to other manufacturing purposes. Had England not discovered coal and how to use it, the population of the entire UK today would perhaps be 5 or 10 million people subsisting on agriculture and cooking with biomass. Now in the British Isles there is a respectable degree of reforestation occurring in the Lake Country and other places. In quite a few developed countries, forest cover is increasing and has been increasing for years, as in the US for example. The reason is always the same: other fuels taken from below the ground have replaced wood.

Similarly, the answer to the use of biomass for domestic fuel is to stop using trees as fuel. Instead, substitute a clean fuel derived from a fossil source as the way to bridge the gap between now and the day when we can regrow our forests. This must be done on a very large scale. When we again have an adequate forest resource, we must learn to harvest and convert it efficiently, to make the same fuel we have used in the meantime. In this way, we will have bought the time needed to get away from using trees directly. This might be called the "hard green"[1] approach, as opposed to the "soft green" approach that merely advocates continuing to burn biomass, but a little bit more efficiently. It is the "hard green" approach that has allowed the developed countries to reclaim their forests. The managed forests that are being constantly regrown and harvested in countries with well-organized forestry programs rely on the extensive use of fossil fuels for their planting, maintenance and harvesting. However, the energy for conversion of trees into lumber and pulp is increasingly derived from the wastes from these processes. If we follow the hard green approach for domestic fuel, the fossil-derived "bridging" fuel we have chosen can eventually not only be made from the trees but also can be used as the fuel to operate the machinery used to thin, harvest, transport and chip the plantation trees. Thus, in the long run, we can finally get back to a "soft green" approach, i.e., all of the domestic fuel being derived from renewable biomass, which also uses the same fuel in its production. But we cannot get there rapidly. There must be a bridging fuel, derived from a suitable fossil resource. The fossil fuel is natural gas, and the bridging fuel is methanol from natural gas.

3. Methanol as a bridging fuel, and the Origo® stove

Why is methanol the appropriate bridging fuel? The simple answer is that it is also the ultimate fuel for domestic use, a fuel that can be made from fossil fuels or from biomass, and a fuel that burns very cleanly. Its use will eliminate smoke and soot from wood, and reduce household CO_2 production by about 5/6 compared to using non-replaced forests for fuel.

The use of methanol as a domestic fuel is not only possible but also desirable for at least three compelling reasons. First, methanol, the simplest alcohol and the one we know how to make most efficiently and economically, can readily be made from wood. Indeed, it entered commerce over 100 years ago from this source, albeit as a minor by-product of making chemicals and charcoal from wood, using a very non-selective and inefficient process. Today we can make methanol from any type of biomass far more cheaply and efficiently than we can make ethanol from corn. Second, methanol is absolutely incapable of forming soot when it burns because its one carbon atom is firmly anchored to one of the two oxygen atoms needed to burn it. Thank Mother Nature for this. Third, methanol is a splendid cooking fuel, and there has been in use for over a decade a very efficient stove in which to burn it. Designed for ethanol, this stove performs better with methanol. It is not pressurized; it is safe, controllable, convenient and, when produced and distributed on a large scale, it will be quite inexpensive. This stove, known as the Origo® stove, which was developed and is produced by the Dometic Corporation of Sweden, is pictured in Figures 1, 2, 3, 4 and 5. These pictures show the stove in its present one- and two-burner models, as well as in its form for low-cost mass production, and a model in use in a South African home. Also shown is its fuel canister. The fuel canister is packed with a highly porous refractory mass. The methanol is contained within this mass and cannot spill or run out except by the intended capillary action when the surface methanol is burned off.

Methanol, when very pure, has only a faint, pleasant odour. Its boiling-point is similar to that of the premium liquid hydrocarbon fuels widely used in boat and camp pressure stoves and lanterns. A methanol flame is easily extinguished by water because methanol is soluble in water in all proportions. Water tends to spread a hydrocarbon flame but in the case of methanol it cools and extinguishes the flame. Methanol is handled as a liquid in non-pressure containers just as for a century or more we have handled kerosene and the gasoline-range hydrocarbon stove and lantern fuels. Indeed, methanol, early in its existence, was often used in upscale restaurants to heat chafing dishes and warming tables in the dining-room amidst the guests. It burned cleanly without odours or smoke. It was easy to handle. Then came the invention of Sterno®, which was ethanol denatured by methanol and gelled by an aluminum compound so it was, in effect, a solid fuel. This made it even more convenient for waiters and safer for the guests. Sterno stoves have become a stand-by stove for households all over the world as well as a boon to campers and picnickers. The fuel and stoves are still available. The can of gelled fuel is not refillable. The fuel is used up and the can is thrown away.

The invention of the Origo stove, by one of the authors of this paper, went several steps farther. The inventor put the fuel in a reusable canister containing a permanent, porous, refractory mass that absorbs and holds the liquid methanol so well that it will not spill out of the canister, even when it is inverted. In essence, the Origo stove provides for storing the fuel as though it were solidified, but in a manner that permits convenient fuel replenishment. This novel, patented method makes for a degree of safety and convenience not hitherto seen in a liquid fuel stove, and does so without sacrifice of efficiency or heating rate. The inventor then designed a safe, all-stainless-steel stove body to contain the canister, and a burner extremely effective in primary and secondary air mixing. Methanol performs best of any alcohol in this burner because of its higher volatility and better inherent burning characteristics. As the burner heats, the methanol evaporates from the fuel canister into the burner. This causes the burner to perform like a gas burner, even though the methanol is not under pressure. The burner is fitted with a regulator that controls the surface area from which the methanol is being volatilized. This allows the burner to be regulated like that of a gas stove. The burner must be extinguished before the stove body can be opened to refill the fuel canister(s), a valuable safety feature. An electric element was placed in some stove models for dual use and other models were designed with an oven. The inventor has now redesigned the stove for mass production at relatively low cost.

Figure 3. Fuel canister used in the Origo stove

Figure 4. Origo stove with large pot, in South African home. The stove is being redesigned to be larger, sturdier, and more stable, able to handle large pots.

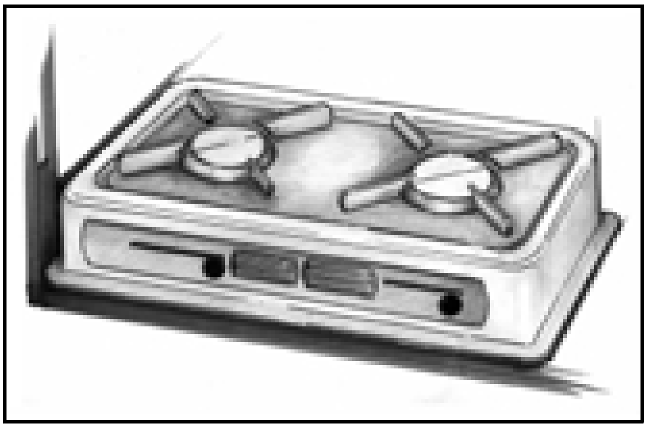

Figure 5. Low-cost Origo stove for developing countries

Now we have the stove, but what about the fuel? The answer is that methanol is made all over the world from natural gas and in a few places from coal, oil, or from miscellaneous wastes, including municipal wastes. But

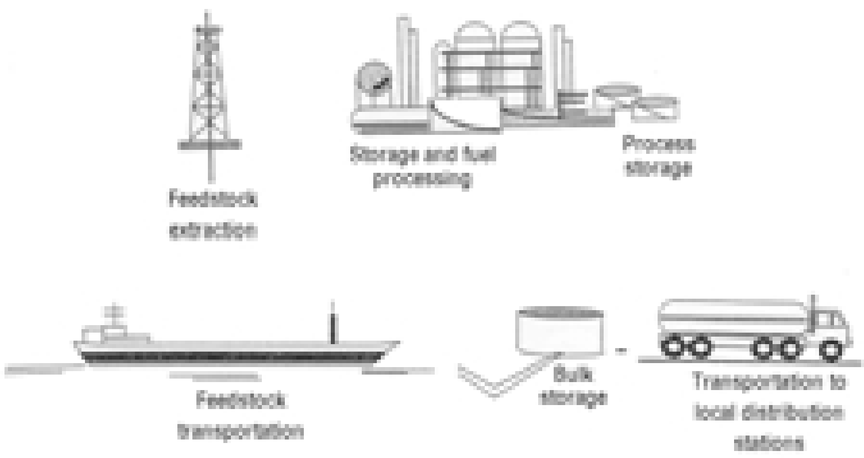

Figure 6. How methanol reaches the market today

today virtually all of it is made from natural gas. It can readily be made from biogas and there are several projects that propose to do this in the US from biogas recovered at landfills. Methanol is recovered as a by-product from a coal-to-synthetic-fuel plant in South Africa. It is also made directly from coal in South Africa. Similarly, it is made from coal in the US today. It can be made from any carbonaceous material: wood, bagasse, grasses, agricultural waste, lignite, semi-bituminous coal, bituminous coal or anthracite. Heavy petroleum residues can be used, including the very heavy bitumens from Venezuela and Canada, to name only two sources of this very plentiful material. Several plants have been built to make methanol from heavy oils of this general character.

For at least the next 50 years, however, we have plenty of low-cost natural gas, already discovered, to make the methanol we will need for the many fuel uses to which it will be put, including cooking. There is enough flared gas in a country such as Nigeria to supply every family in West Africa with methanol for cooking fuel. All over the world, methanol is produced from natural gas and transported to the market at very low transportation cost, as depicted in Figure 6. This is of course the same transportation system used with petroleum and its products. Considering the efficiencies obtained in its use, methanol can be delivered on average at a cost comparable to or cheaper than purchased wood, kerosene or propane when all are priced on a free-market basis. If the household gathers its 5-10 kg of wood for daily cooking, it will use 2 to 6 hours of labour. Even at a labour value of only 25 US¢/hour, about one hour's labour will buy the daily methanol needed. The other 1 to 5 hours can then be sold into the marketplace for agriculture or manufacturing, if such opportunities are available.

4. The methanol economy

Methanol is traded worldwide as a commodity like fuels refined from petroleum. As with any commodity, its price can vary with supply and demand. On average, its real price has been declining for the 75 years since it entered the market as a synthetic product. As the market expands, ever larger plants, already engineered, using well-proven components, will be built, lowering costs. Already it is transported in ships as large as the largest tanker used to transport gasoline. Its price delivered to seaports all over the world will average about US$ 130 ± 30 per tonne (t) with rare excursions above $ 160/t but with an increasing tendency to sell at a lower average price, perhaps as low as $ 110 to $ 120/t. With crude oil at $ 30 (per barrel, or 0.147 t), a price reached in 2000 for a number of months, gasoline sells ex-refinery for as high as $ 367/t, which is comparable on a heating value basis to methanol at $ 190/t. With crude oil at $ 22 to $ 28, the now widely expected future range, or an average of $ 25, the methanol equivalent would be $ 160/t. These figures are given to put the cost of methanol in perspective. The consumer cost, as with gasoline, will be higher due to delivery to local distributors and their mark-up. When methanol is eventually made locally, these distribution costs will be much lower and all costs will become wealth created in the local economy, the result we all desire to accomplish eventually.

If one looks at the CO_2 effect of burning non-replaced wood compared to life-cycle emissions for methanol, one finds that CO_2 emissions from methanol are about one-sixth as much as from burning wood. The reduction or elimination of other greenhouse gases by burning methanol in place of wood is equally, if not more, dramatic. A wood-burning stove produces, in addition to carbon dioxide, methane, carbon, carbon monoxide, polyaromatic hydrocarbons and nitrous oxide. A methanol stove produces carbon dioxide and water vapor. The beneficial effect of reducing the production of greenhouse gases is obvious.

What will it take to get started using methanol to replace fuel-wood? In any given market area, the use of a new stove and a new fuel will need to be encouraged with a demonstration or pilot program of perhaps up to 1,000 stoves placed in households in selected communities to allow people to become familiar with them. This phase will have to be subsidized at a cost on the order of tens of thousands to several hundred thousands of dollars, depending on how large the program is, for a year-long pilot program. Credits for the sale of stoves and fuel at subsidized prices (representative of commercial prices after scale-up, when full economies of scale can be achieved) would offset or reduce these costs. The next step would be to assist local entrepreneurs to collaborate with the stove manufacturer and fuel importer to distribute both stove and fuel. The distribution of fuel can and should be in local hands. Fuel distributors could be community cooperatives.

Because methanol is toxic and must not be ingested, the methanol fuel must be clearly marked on its container as toxic and should be coloured with a dye to promote easy identification. A standardized colour should be selected for this purpose. Highly effective dyes exist that will colour methanol at a thousandth of a percent by volume. The methanol should also be denatured, preferably with both a smelling and a tasting agent, to render it unpalatable. A standard tasting agent in wide use for just this purpose is Bitrex™ (Denatonium Benzoate NF). This tasting agent is extremely bitter and is very effective in parts per million. Not only will it render a liquid bad tasting, but also it will make it physically intolerable to hold in the mouth. It is in wide use in household products, such as cleaning fluids. A feasible smelling agent is methylamine, which will give an unpleasant smell to the liquid methanol, but when the methanol burns, the methylamine will burn cleanly without smell. It also has the added advantage of adding some orange colour to methanol's blue flame.

Methanol will come by ship to ocean-side terminals. Railroad tank cars or tank trucks will take it inland, depending upon distance and the availability of railroads and roads relative to the market. Local dealers will receive the methanol, denature it, and sell it to their clients who will transport it themselves from dealer to home in easily carried 5-litre plastic containers weighing, full, about 4 kg. This is, of course, similar to the way in which kerosene is distributed. Historically, a great benefit of kerosene has always been that it can be transported by donkey, by ox-cart or in the same fashion that fuel-wood is transported. This is not so with LPG or any pressurized or gaseous fuel. In time, 100- to 200-litre methanol tanks could be placed in homes or villages. These tanks would be supplied by a local tank truck service. As methanol supplants the use of kerosene in a given area, it would simply take over the kerosene distribution infrastructure or recreate it.

Kerosene was produced initially in central refineries rather than delivered to terminals. Crude oil was delivered to the refinery and refined into kerosene, LPG and other products within tank car- or tank truck-range of the market. In the case of methanol, the plants to make the fuel will be at the gas source. In countries with an oil or gas resource, such as Bangladesh or Nigeria, small package methanol plants using cheap natural gas can be installed as soon as the stove fuel market develops. Consequently, the whole fuel system from oil- or gas-well to user will produce wealth within the country, associated gas can be "monetized", and gas-flaring could be avoided. The need for hard currency to buy imports would be reduced or eliminated.

In other countries, without fossil fuel resources but with ample biomass, including plantation biomass or biomass grown "on purpose", local biomass-to-methanol plants could be built soon. Critical to building such plants is the development of an adequately-sized methanol stove fuel market that can produce revenues sufficient to justify the financing of such plants. The component parts of a biomass-to-methanol plant already exist and are produced in modular, highly transportable form. Therefore, these plants could be placed far inland or wherever local biomass resources sufficient in size and reliable in their yield exist. A concentration of biomass waste (such as piles of sawdust and lumber-mill tailings) can supplement the plantation biomass. It is important to stress that such plants will not be built on a purely speculative market. Therefore, the market must be developed first using methanol brought in from natural gas sources outside of the country, when those resources do not exist in country.

5. Developing the methanol industry

We are not dealing with unproven technologies. Use of the Origo stove and alcohol fuels is well known. Small-scale methanol plants have been built and are offered commercially today with guarantees by HydroChem Linde AG, which is part of a world-class integrated chemical and industrial gas company. In the US there is a proven Department of Energy (DOE)-sponsored technology operating to make raw synthesis gas from wood with the gas being burned for power production. This is the Battelle dual fluid bed pyrolyser-reformer. The technology is now owned and offered by FERCO, of Atlanta, Georgia. The supplier of the small methanol plant, HydroChem, can readily adapt its plant to this gas, which is already partially reformed to synthesis gas.

The cost of methanol from biomass is, however, another matter. It is a capital-intensive process and conditions have to be just right to justify a plant. These conditions are, first, a local supply of waste biomass at very low cost, and, second, a proven, freight-sheltered (protected from tariffs, etc.) domestic fuel market for the methanol. In time, niche projects will be found and built, but only if the market is first proven using methanol from existing sources.

If there were a local market for methanol and local biomass available at low cost, engineering contractors and entrepreneurs could be found to build commercial plants right now. If the plant needs to be a large one, for example 1000 t/day or larger, the commercial technologies of Winkler (Krupp Uhde) and Kellogg are available to gasify wood or other biomass.

In the longer range, 20 to 30 years or so from now, when the growing and harvesting of biomass for energy is better known and cheaper relative to the then cost of fossil fuels, production of methanol from biomass can be undertaken on a larger scale without niche economic conditions or subsidies.

An important point to note about the high-temperature processing of biomass to methanol synthesis gas is that it can be done without by-products other than wood ash. If such a plant is operated to make methanol and power and to recover low-temperature heat, its overall thermal efficiency can approach 70 %, which is about the maximum that can be reached by natural-gas-based methanol technology (or any co-generation technology for that matter).

The other interesting technology that can be used is production of biogas (two-thirds methane and one-third carbon dioxide) by anaerobic digestion of almost any kind of biomass with, of course, by-products. This biogas can readily be made into methanol, and part of the CO_2 is also converted to methanol by:

$$3H_2 + CO_2 = \underset{\text{(methanol)}}{CH_3OH} + H_2O$$

The hydrogen is the excess from methane reforming after the CO made in reforming the methane is converted to methanol.

6. Opportunities for developing countries

One can ask, is all this worthwhile just to replace wood for cooking fuel? To answer, we have only to look at the need to stop forest depletion, on the one hand, and to lower CO_2 emissions on the other. It is hard to put an exact monetary value today on either, especially on the value of arresting forest depletion. But if CO_2 credits were worth \$ 30/t (\$ 110/t of carbon) as some expect them to be, then the yearly CO_2 credits for a family's use of methanol in place of wood would buy a stove and its methanol supply for an entire year, with some money left over. The second year, more money would be left over, which could be granted to the family for other uses.

Further, if the labour in gathering wood is valued at 25 ¢ an hour and is needed for local enterprises or agriculture, and 6 hours daily are required to gather wood, the family could have its methanol supply paid for and \$ 1.25 per day of cash income to spend on food, medicine, and wealth-generating activities.

A single family would save about 5 t of CO_2 a year. Since upwards of 400 million families still cook with wood, the possible CO_2 reduction from a 20 % market penetration is enormous, on the order of a half a billion t/year.

But methanol's use need not stop with cooking. Today, refrigerators are produced and sold that run on kerosene and propane. These refrigerators have been thoroughly tested on methanol, a fuel they can readily use. New cooling technology, best described as heat-operated refrigeration using adsorption technology, has been developed by Dometic, powered by methanol, which will be affordable for and adaptable to the developing world. Methanol can fuel a suitable lantern, the heat from which can be recovered for cooking or water-heating. Small generator engines can run on methanol and, in time, small direct methanol fuel cells will be used to generate household electrical energy. Heat can be recovered from engines or fuel cells for the family's hot water. By introducing methanol as a domestic fuel, we are laying the groundwork for a total energy system for the household.

There is an extremely close relationship between household energy and local enterprise. In addition to having more time for work outside the home, the availability of adequate and affordable energy supplies and the right technology to use that energy in the home create the opportunity for commercial activities based on cooking, cooling and the processing and preserving of food. Other activities such as crafts (sewing, metal-working, etc.) can flourish when there is light to see by and energy to power simple machines. Any gain that can be achieved in the household energy sector will also bring gain to the local economy.

Thus, it can be seen how a carefully selected, clean-burning fossil fuel, ultimately to be sourced from biomass, can help to lift low-income people to a much improved standard of living with significant family health benefits together with local as well as global environmental benefits. We must add to this the opportunity to create, in time, a local, self-sustaining industry based directly upon the new fuel, particularly when it is produced from biomass. Both fuel and stove, and the other appliances designed to run on methanol, will become the basis for industry built, run and sustained in the country where they are used.

The less fortunate people of the world do not benefit proportionally from the world's resources. For example, natural gas cannot reach 2 to 3 billion people today because pipelines cannot be built to them. Mother Nature and modern technology allow us to "package" and transport natural gas as methanol, so the extensive benefits of natural gas can be distributed far and wide, not just to the more well-off people in cities and towns in the developed countries. The benefits can begin by creating opportunities for people in developing countries to replace inefficiently burned wood gathered at great labour from fast depleting forests. These benefits can grow into what will eventually be a complete household energy system used for cooking, cooling, heating, lighting and producing electrical energy. In the end, the revegetated forests, as well as plantation biomass, can become once again the primary fuel source for people all over the world, but this time by means of efficient conversion to a clean liquid fuel, not by direct burning. Perhaps then, the widely sought after goal of energy sustainability can be achieved, at least for communities or nations whose energy requirements do not outstrip their ability to grow, harvest and process biomass.

It is for this reason that we call our Project *"Gaia"*, out of respect for Nature, which will allow us to return to her for our energy when we build the right bridges to get there. If we do not build such bridges, we will very possibly run out of energy choices, including the choice to return to Mother Nature for sustainable energy from biomass. ■

Note

1. We are indebted to Peter Huber, author of the book *Hard Green*, published by Basic Books, 1999, for this term and for the term "soft green".