PRACTICAL ACTION
Technology challenging poverty

ETHANOL AS A HOUSEHOLD FUEL IN MADAGASCAR

technical brief

Introduction

In Madagascar, like many developing countries, the majority of the population use traditional biomass sources to meet their energy requirements; approximately 50% of all households and 90% of rural households worldwide still utilise solid fuels for cooking and heating (WHO, 2004). In Madagascar, it is estimated that 95% of households rely on woody biomass and charcoal for household energy, with annual national consumption figures of approximately 9 million m^3 of firewood and 8.6 million m^3 of charcoal.

Overreliance of a community or population on woody biomass can often be linked to two major impacts:

- Ill-health & respiratory problems
- Deforestation

The combustion of biomass or coal emits substantial quantities of health-damaging pollutants, such as particulates, carbon monoxide and nitrogen oxides in smoke (Smith, 1987); leading to an estimated 1.4 million annual premature deaths worldwide. In Madagascar, nearly 12,000 deaths are attributed to respiratory infections caused by household air pollution (HAP) each year, over 80% of which are children under 5 years old.

In addition, the Malagasy forests have been in steady decline for several decades due, primarily to 'slash n' burn' agricultural techniques, but also a heavy reliance on wood for fuel (5-20%). Over 80% of the country's forests have been lost, with another 200,000 hectares lost annually. It is expected that annual direct consumption of woody products will increase to more than 23 million m^3 by 2025, and that all of the island's forests will be lost within 40 years at this rate.

Project background

This brief details a project conducted by a partnership between Practical Action Consulting, Project Gaia, Berkely Air, the University of Liverpool (UoL) and the World Health Organization (WHO). The aim was to study the viability of ethanol as a commercial household fuel in Madagascar, and it was initiated to help achieve the goals set out by the Madagascar Action Plan (MAP), of:

- the promotion of alternative sources of energy to relieve the pressure on forest resources
- the reduction of childhood mortality rates

The MAP was developed by the Madagascan Government as an overall framework of policies and plans in response to the issues of health and deforestation described above. The programmes include the Forestry Sector Development Plan and the National Environmental Action Plan. A key feature of these plans has been the conservation of the natural environment, and has led to the establishment of the National Environmental Office and the Madagascar National Parks (MNP).

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Ethanol as a household fuel

Ethanol as a fuel has been implemented on a large-scale in several countries, although Brazil is so far the only developing country to have done so. The development of ethanol as a national energy supply in Brazil has reduced oil imports, improved energy security and created an estimated 700,000 jobs (APEC, 2010). However, a centralised system primarily benefits the transport sector, and is generally not suited to a rural supply scenario with limited transport access. Additionally, economic benefits tend not to reach lower income groups in a centralised system.

Whilst small- and micro-scale production of ethanol is well documented in several developed countries such as the USA, there is limited, and only recent, formal international experience of its use as a commercial household fuel in development scenarios. In Africa, the ethanol base is less well developed, but several countries are beginning to increase production, and there are a few examples of ethanol stoves being used in energy delivery programmes.

- Sudan currently produces roughly 60 million litres of ethanol per year. It exports 60% of this to Europe, but the remainder is successfully supporting a domestic household fuel industry.
- Ethiopia is currently providing refuge for people displaced by fighting in Somalia; a project implemented by the Gaia Association supplied ethanol stoves to nearly 1800 households in the Kebribeyah refugee camp, reducing the time the families spend collecting firewood and improving conditions within shelters. Although the refugees didn't pay for the stoves or ethanol, the model has highlighted the potential for widespread uptake (Ashden, 2008).
- In both Malawi and Ethiopia, the Governments are producing ethanol from molasses, and recognising the large markets for household energy. Ethiopia already has a domestic market of 100 million litres a year, whilst Malawi has been an early adopter of the fuel and produces approximately 18 million litres per year. Most of the current production in exported to East African countries, although UNDP and GTZ backed projects are helping to commercialise ethanol stoves to utilise the surplus.

Project

The project described in this brief was commissioned to analyse the cost efficiency and economic viability of an ethanol programme at reducing disease and protecting the forests in Madagascar. It identified three key areas:

1) Health benefits
2) Financial and economic assessment
3) African lessons for scaling-up a program of support for ethanol as a household fuel

Project partners

The project was conducted under the following management structure:

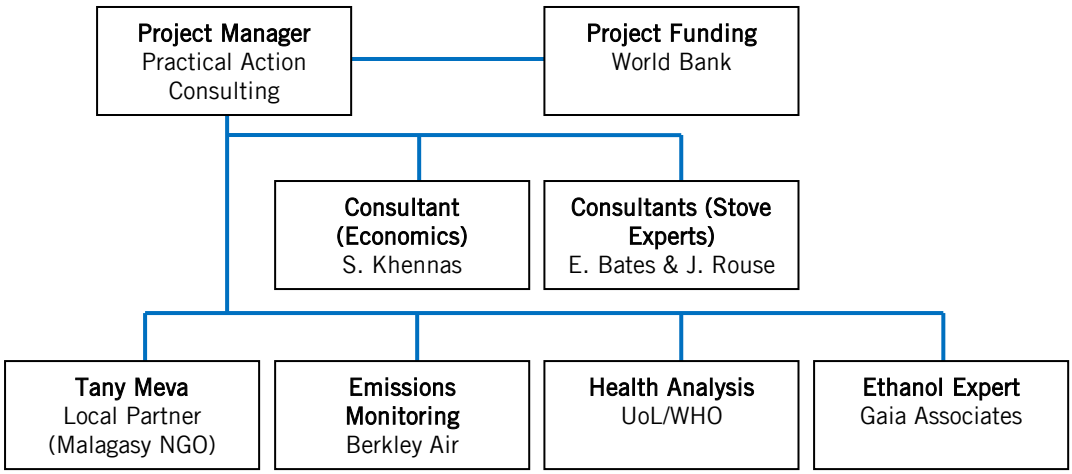

Figure 1: Structure of project partners.

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Health assessment

Methodology

In order to evaluate the potential health benefits from using ethanol stoves, the project conducted HAP analyses in a study group of households at two different locations; Ambositra in the central highlands, and Vatomandry on the Eastern coast. Households in each area were selected on the following criteria:

- Have a child under 4 years
- Currently use charcoal or wood as main fuel
- Purchase at least half of their fuel
- Have an enclosed kitchen
- Have "Mother" as main cook
- Be interested in having an improved stove

Ambositra

- Central highland location (1300m alt.)
- Cool in dry season
- Predominantly brick houses
- Main fuels are predominantly charcoal and wood
- 144 household study group

Vatomandry

- Coastal location
- Warm climate
- Predominantly wooden houses, more open
- Main fuels are predominantly charcoal and wood
- 180 household study group

Figures 2: Typical house structure in Ambrosita Photos: Practical Action.

Figure 3: Typical house structure in Vatomandry.

In order to compare the effects of both raising awareness of health issues and replacing traditional fuel supplies with alternative solutions, each study group was split into five (or four) samples, each to receive a different level of intervention:

Group	Intervention	Ambositra	Vatomandry
1	No intervention (control group)	36	36
2	Awareness raising only	36	36
3	Awareness raising + improved biomass stove	0	36
4	Awareness raising + improved charcoal stove	36	36
5	Awareness raising + ethanol stove (Cleancook)	36	36
	Totals	144	180

Table 1: Sampling groups for health study

To gauge the population's awareness, health status, economic status and energy use, a simple questionnaire was administered at interviews by trained field staff. Questions related to the participants' health were used to provide an indication of the prevalence of chronic respiratory symptoms and eye irritation in the study population. Information on another common symptom, headache, was also collected to investigate the relationship between reported frequency/severity of headaches and women's exposure to CO. At the time of the questionnaire, an initial sampling of emissions of CO and $PM_{2.5}$ in the households' kitchens was undertaken as a baseline with which to compare later results.

The following figure describes the project process:

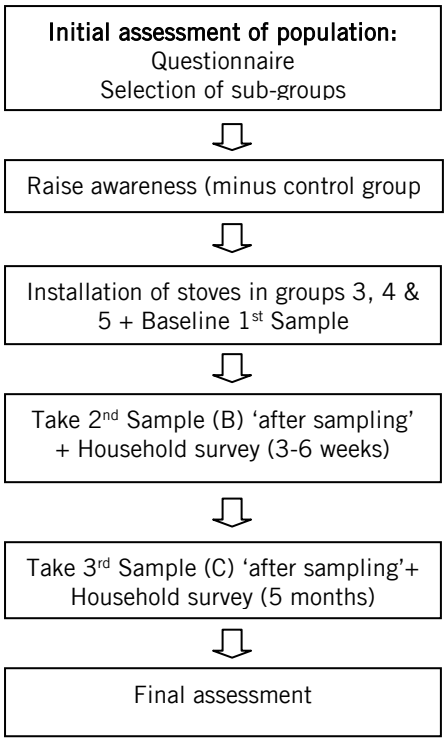

Figure 7: Project process

Figure 4: Improved biomass (wood) stove

Figure 5: Improved charcoal stove

Figure 6: Cleancook ethanol stove

Emissions monitoring

Each household in the study was equipped with a particulate matter (PM) monitor and carbon monoxide (CO) monitor, to measure levels over a 24 hour period at each sampling stage. Personal exposure to CO was also measured using a CO tube on each individual mother and child, the results of which were used to estimate personal exposure to PM, as measuring PM for adults and children is inconvenient.

Both monitors were set close together at a fixed distance from the stove.

The initial questionnaire was used to gauge levels of health and incidences of acute lower respiratory illness (ALRI), whilst emissions results could be used to project benefits and potential reductions in illness through reduced household pollution levels.

Figure 8: HAP monitoring equipment in kitchen

Figure 9: Individual CO tube

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Results

The overall results of HAP measurement showed a marked decrease in levels of PM and CO for the group using ethanol stoves, in comparison to both the control group and the charcoal and biomass stove groups. Table 2 shows the average emissions reductions for the ethanol group compared against the baseline measurements for the biomass and charcoal groups over the 3 sample periods.

	Ambositra		Vatomandry	
Emission	Ethanol (vs. biomass baseline)	Ethanol (vs. charcoal baseline)	Ethanol (vs. biomass baseline)	Ethanol (vs. charcoal baseline)
CO	N/A	-79%	-93%	-93%
$PM_{2.5}$ (predicted)	N/A	-57%	-85%	-72%

Table 2: Average emissions reductions of ethanol group against baseline measurements from biomass and charcoal groups

- The improved biomass (wood) stove that was used only in Vatomandry achieved reductions of 66% (PM) and 63% (CO) compared to its baseline measurements. The improved charcoal stove was not effective in reducing HAP levels.
- The 'awareness only' groups saw little effect on HAP levels in Ambositra, although amongst households in Vatomandry, where use of woody biomass is common as a conventional fuel, significant reduction in PM levels was recorded.
- The control groups at both locations showed little change in HAP levels over the 3 sampling periods, suggesting conditions remained stable throughout the study.

The individual measurements taken with a CO tube attached to mothers and children showed a significant decrease for the ethanol group compared to the control group, as shown in Table 3.

	Ambositra		Vatomandry	
Emission	Adult exposure (mother)	Child exposure	Adult exposure (mother)	Child exposure
CO	-74%	-64%	-53%	-35%
$PM_{2.5}$ (predicted)	-62%	-63%	-44%	-47%

Table 3: Average reductions of HAP exposure levels for adults and children; ethanol group compared to control group

- Approximately 80% of households in the ethanol group also used a charcoal or wood stove for some of their cooking requirements and consequently results could be even lower if only ethanol was used.
- In Ambrosita, the charcoal and awareness groups showed little change in exposure levels between baseline and 2nd and 3rd samples.
- Levels of HAP exposure were much greater in Ambrosita than Vatomandry, predominantly due to the closed design of the house structures.
- In Vatomandry, all improved stove groups showed reductions in predicted PM exposure levels compared to the control group.
- Compliance among the population to use the CO tube was high, with 90% of adults and 91% of children found to be wearing the equipment when fieldworkers arrived on Day 2.

Analysis and potential health benefits

The post-study analysis by the project team developed the following conclusions regarding the HAP and health monitoring stage of the process:

- A comparison of the kitchen CO averages shows that the ethanol stove can significantly reduce kitchen CO levels below the 8-hr WHO guideline level of 8.7 ppm. Although the ethanol stove significantly reduced $PM_{2.5}$ concentrations in the kitchen, the Round 2 and 3 levels in Vatomandry were still about two to three times the annual WHO Interim Target 1 for PM2.5 of 35 µg/m3, while in Ambositra they were approximately four times this target.

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- Despite a number of challenges, allocation to groups, follow-up, and the rate of dropouts was satisfactory.
- Use of other stove types by the ethanol group compromised the HAP and exposure reductions (which may have been even greater without this secondary stove use), it also emphasises that – at the time of the project – the stove technology and arrangements for obtaining fuel were not meeting all needs.
- On average, the use of ethanol stoves reduced the amount of time a stove was alight in each household by 2.5 hours.
- In comparison with the control group, the ethanol stove led to substantial and highly significant reductions in headaches, eye irritation and burns among women in Ambositra. In Vatomandry, there were large and highly significant reductions in the women's reported headache and eye irritation for the charcoal, wood and ethanol intervention groups. The ethanol group reported substantially less burns in women and the wood stove group showed marginally significant reductions. Only the improved wood stove group showed significant reductions in burns in children.
- In Ambositra the most positive post-study assessments were seen for the ethanol group with around two-thirds saying that the child's health was better, and 10% that it was worse (compared with 11% and 26% respectively for the control group), with some evidence of benefits in the charcoal intervention group.
- In Vatomandry the ethanol group showed the clearest evidence of perceived benefits to family health, with 61% saying the child's health was better and only 3% that it was worse (compared with 0% and 6% respectively for the control group).

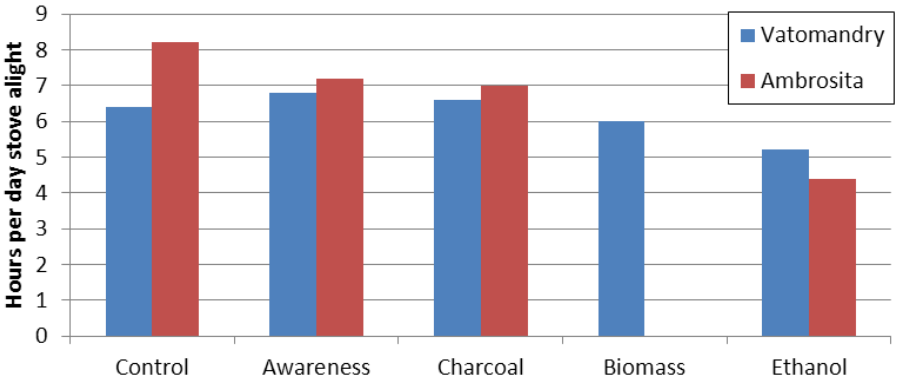

Figure 10: Average hours per day stoves were alight for different groups. Source: Practical Action Consulting.

Additionally, the project has put forward two possible adoption scenarios and the potential health benefits these will bring, based on the findings from HAP measurements:

- **Scenario 1:** The rate of adoption required to meet Universal Clean Energy Access Goal as supported by UN: Universal access to clean, modern household energy by 2030
  - Prevention of around 17% of total national deaths and DALY's for child Acute Lower Respiratory Infection (ALRI)
  - Prevention of around 16% of total national deaths and DALY's for adult Chronic Obstructive Pulmonary Disease (COPD)
  - Prevention of around 5% of total national deaths and DALY's for adult Ischemic Heart Disease
- **Scenario 2:** 17% adoption at 10 years; based on ethanol price 35 cents/litre; 20-year adoption period
  - Prevention of around 3% of total national deaths and DALY's for child ALRI
  - Prevention of around 2.5% of total national deaths and DALY's from adult COPD
  - Prevention of around 1% of total national deaths and DALY's from adult IHD

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Financial and economic assessment

The project analysed the potential economic impacts of ethanol as a household fuel; considering both the impacts on individual households and also focusing on the wider impacts of the production of ethanol using sugarcane micro-distilleries with the sale of by-products, over a 30-year period to full market penetration.

The following is a summary of the main conclusions from the project assessment:

Household analysis

Ethanol is a clean-burning fuel to compete with LPG, but since the majority of the current Malagasy population uses firewood or charcoal, ethanol will have to attract a significant proportion of this population to have a large impact; currently only 1.6% of the country's population in urban areas can afford an annual supply of LPG at US$300. Figure 10 shows the relationship between annual fuel cost and the proportion of the population that can afford the fuel:

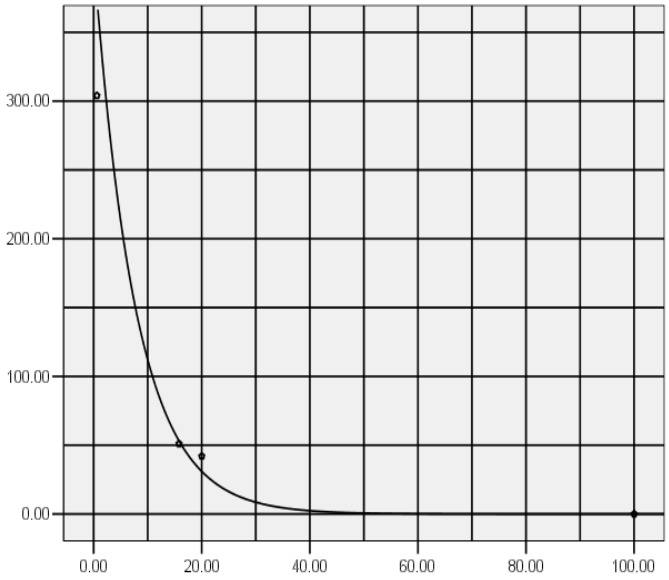

Figure 11: Relationship between annual cost of fuel (Y) and percentage of population that can afford it (X)

Stove	Total Cost (US$)	Life (years)	Annual Cost (US$)
Wood	25	5	5
Charcoal	2.4	0.5	4.8
LPG	50	5	10
Ethanol	50	10	5

Table 3: Total and annual expected costs of different stove types.

- Households may be using a less desirable fuel even if they would be willing to pay somewhat more for a more convenient fuel, as they cannot afford the next price step.
- Additionally, the upfront cost of purchasing a stove may be prohibitive for much of the population.
- Based on the household surveys conducted in Ambositra and Vatomandry, on average households save approximately 1.8 hours each day in cooking and cleaning time through the use of an ethanol stove. This estimate was based on an average of two variables; the difference in time that the stove was alight during the 24-hour monitoring periods at baseline and Round 3, and the cook's perceived reduction in time spent cooking and on cooking-related cleaning since the start of the project. The estimated time saved is valued based on a rural average wage rate of US$1.92 per day

The study was unable to gain sufficient data to make conclusions regarding the economic impact of the potential health benefits.

Micro-distilleries

If ethanol production is to be scaled up in Madagascar, then micro-distilleries can be constructed in rural settings close to the feedstock sources, and can produce high-grade household fuel ethanol to supply local markets. Single micro-distilleries operating as discreet business units can compete in a local or regional stove fuel market if the system is closely tied to a feedstock source that is competitive and if the processing unit is efficient. The benefit of the micro-distillery is that it enables ethanol production to be carried out on the same scale in which most other biomass energy is procured.

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A set of scenarios were developed to test a financial model for a 120 litre per day capacity micro-distillery, based on currently operating plants in Brazil and USA, and using feedstock costs for both molasses and waste products from fruit and vegetables. A range of prices for ethanol were calculated, based on whether only ethanol was sold, or the more likely option, where ethanol and a set of valuable by-products were sold.

For most of these analyses, the price of feedstock was taken as US$15/tonne for raw sugar cane or US$4/tonne for agricultural waste, based on estimates from other countries such as Ethiopia and quoted FAO values. However, since the price of ethanol, and thus the adoption rate of ethanol as a household fuel, is highly dependent on the price of the raw feedstocks, a range of prices (from $4 per tonne to $100 per tonne) was considered, for 330 days per annum production of ethanol in all cases.

	Price of feedstock (US$ per tonne)>	4	15	25	50	100
With sale of by-products	Price of ethanol US$/litre	0.19	0.33	0.48	0.73	0.86
	Annual household cost (US$)	74	125	180	271	319
	Urban adoption (%)	61	31	15	4	2
	Rural adoption (%)	13	9	6	3	2
Without sale of by-products	Price of ethanol US$/litre	0.40	0.55	0.70	0.94	1/07
	Annual household cost	151	206	261	348	396
	Urban adoption (%)	22	10	5	2	1
	Rural adoption (%)	8	5	3	1	0

Table 5: Expected impact of feedstock price on ethanol production cost and household adoption.

As Table 5 indicates, at a feedstock price of US$15 for sugarcane, with the sale of by-products, ethanol could be produced in micro-distilleries at approximately 35 US cents per litre. At this price, some 31% of urban households and 9% of rural households might be expected to adopt ethanol as a household fuel.

Adoption of a new fuel on this scale would take some time; with a price of 35 US cents per litre and a 30-year period, it was estimated that availability of ethanol in the price range of 20 - 35 US cents per litre could lead to its adoption as a fuel by 1.3 million to 2.6 million Malagasy households, requiring the eventual production of 485 million - 970 million litres of ethanol annually. This resulted in estimates based on the following assumed rates of adaptation:

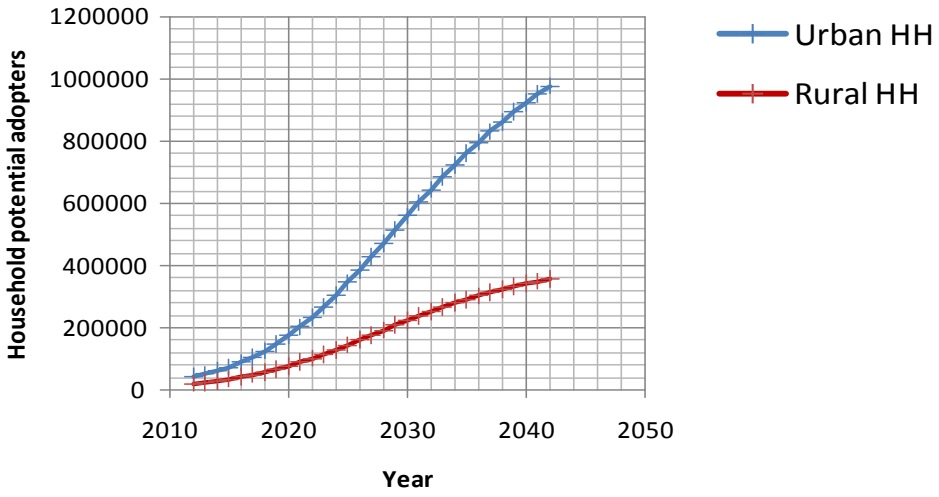

Figure 12: Assumed adoption rate of ethanol as a household fuel over 30-year period.

A financial analysis was conducted for an ethanol micro-distillery plant, producing 120 litres per day, using the four production scenarios detailed below. An ethanol price of 35 US cents per litre would provide a positive return for micro-distilleries in each of the scenarios, except for those using sugarcane as a feedstock without the sale of by-products.

Scenario	Price of ethanol (US$)	Payback period
Low-cost feedstock w/ by-products	0.14	10 years
Sugarcane w/ by-products	0.26	11 years
Low-cost feedstock only	0.34	10 years
Sugarcane only	0.46	10 years

Table 6: Break-even price of micro-distilleries operating with different feedstock/product scenarios

Deforestation

If ethanol replaced the use of wood and charcoal for household cooking on a large scale, this would have a significant impact on the forests of Madagascar. Currently it is estimated that 90% of wood for household cooking (either as wood or by conversion to charcoal) is from unmanaged sources, resulting in forest degradation. The value of avoided deforestation was calculated by taking the equivalent amount of charcoal that would be required to produce the same energy as that provided by ethanol stoves, assuming that a traditional charcoal stove consumes 513 kg of charcoal per household per year, which worked out in total at 1.4 million hectares of forest (FAO, 2005).

Using a factor of 418 tons/ha carbon sequestration capacity of natural forests, an emissions reduction of 585 million tonnes of carbon was calculated, equating to US$324 million.

Employment and reduced household labour

A large scale ethanol household fuel program could have significant poverty reduction benefits if managed correctly, mainly through the decentralisation of energy production and the increased use of a very clean household cooking fuel. Combining the labour required to produce the sugarcane feedstock and the labour required to produce the ethanol and transport it to market (analysis of other micro-distilleries from Brasil and the US allow an estimation of 4.5 full-time staff required per micro-distillery) gives an estimate of 0.05 days labour per litre of ethanol.

The increase in labour employed in producing ethanol will be offset in part by the reduction in employment in the charcoal industry, estimated at 10.6 man days per tonne of charcoal. Based on the projected rate of adoption of ethanol as a household fuel, this yields a net increase in employment of 571,000 additional jobs over the 30 year period, predominantly in rural areas.

Overall summary

Calculating the net present value (NPV) of all the economic categories, using an ethanol price of 35 US cents per litre, over a 30 year penetration period, discounted at 10% over a 30 year operating period, Table 7 reports the total economic benefits over 30 years using a sugarcane plant selling by-products, and includes increased fuel and stove costs to households and returns on investment to distillery operators (including the production costs of ethanol, as well as the sales of ethanol and related co-products).

Note: disability-adjusted life years (DALYs) was estimated at 0.03 per household per year, for a household switching from charcoal to ethanol as the household fuel, result in a total of 442,000 DALYs saved over the 30-year period, equivalent to a total discounted value of US$34 million.

Economic benefit	NPV of benefits over 30 years (US$ million)
Increased costs to households of fuel and stoves	-175
Return on investment to micro-distillery operators	74
Avoided deforestation (dependent on valuation approach	87.5-324
Avoided DALYs	34
Time savings	368

Table 7: Overall NPV for economic factors over 30 year period

Promoting ethanol as a household fuel

The project examined lessons from African experience with improved stove and fuel programmes, looking at previous Initiatives to deliver household cooking interventions. They have included switching to alternative fuels with associated new stoves, improving the efficiency of stoves, technologies to extract harmful smoke, approaches to change the behaviour of cooks regarding the manner or location of cooking, and replenishing stocks of woodfuel through re-afforestation.

The assessment was completed in order to provide the following institutional and policy recommendations for a program to promote the development of a commercial market for ethanol as a household fuel in both Madagascar and on a wider scale:

Fuel options

- LPG and electricity are currently the cleanest fuels in the kitchen widely available globally. Neither of these fuels appears to be viable for widespread dissemination in Madagascar at the present time because of their high capital and running costs.
- Woodfuel is the most widely used fuel worldwide, and cooks quickly, but is highly polluting, and reduces the quality of life for many users.
- Charcoal is cleaner than woodfuel, but is a highly inefficient process.

Stove options

- For stoves to be adopted on a fully commercial basis, it is essential that people like the stoves and will want to use them, and replace them when necessary. To be used, stoves must have the product attributes desired by cooks; the stove quality must be good, and the fuel consistent. There must be a reliable fuel supply chain or people will revert to their previous practices.
- Semi-commercial opportunities exist within a limited time frame where the stoves are either given away, or sold below cost, but nevertheless have the support of NGOs, or governments. This arrangement can be very successful, and appears to be a useful interim step to complete commercialisation, distribution and long-term sustainability.
- A well-proven NGO structure is used by the NGO Vita EnterpriseWorks for the Gyapa stoves. These stoves are sold by independent businesses, but the NGO provides support to the new businesses with training and promotion. The Ugastove benefits from carbon finance to subsidise its cost and make it affordable.

Role of government & private sector

- The Government has an essential role to play in the development of a biofuel strategy and policy conducive to the use of such fuels in household energy provision, including the establishment of standards for ethanol fuel quality, as well as stove safety and efficiency. In the case of ethanol, Government support to overcome initial barriers to adoption, including through support for demonstration pilots and access to credit.
- A further role for Government is in facilitating partnerships between government bodies, the private sector and NGOs. Governments can create an enabling environment for private sector investment through addressing major barriers such as a lack of clarity of regulations and legislation, lack of security of investments, prohibitive investment costs and duties.
- The private sector has an essential role to play in applying commercial and marketing approaches to the various social, environmental and public health issues implicit in household energy and clean fuels.
- Products need to be thoroughly tested and reviewed by a representative sample of consumers, feedback obtained in a structured way, and issues identified, addressed and re-piloted, until a desirable product is developed.
- The majority of household energy programs have involved NGO participation at their inception. NGOs can play a key role in undertaking pilot programs and demonstration projects. They can work with other actors in facilitation, supporting services, sector co-ordination, advocacy, piloting, linkage with community groups, and demonstrating safe practices.

- Rather than subsidies, government should focus on assisting the new fuel market by avoiding injecting cost into it while it is young and fragile. Ethanol as a fuel must be differentiated from ethanol for other uses, and if possible, taxes should be removed or reduced on ethanol fuel to assist it in getting into the market

International experience with both improved household cooking approaches as well as ethanol production is significant and growing. The recently launched Global Alliance for Clean Cookstoves, involving engagement by national and international organisations at the highest levels, was launched in late 2010, reflecting the growing awareness of the issue of HAP, and its connection with health and the environment. World production of ethanol is rising, with its growth linked with high oil prices, international awareness of global warming and concerns about energy security.

Although Africa's ethanol base is less developed than those in Latin and North America, several countries are increasing production and there is significant potential for the African biofuels industry to expand. Despite recent growth however, the global market for biofuels is still in its relative infancy. The dominant current consumption of ethanol is for transport fuel-blending; however, in developing country contexts, household energy often accounts for 75-90% of total energy demand. Ethanol has been shown to have potential as a cleaner and healthier household fuel in several countries, and development of a stable domestic ethanol household fuel market is considered to have potential to offer substantial economic, health and environmental benefits at local, national and international levels.

The realisation of such benefits in Madagascar would involve a substantial shift in current patterns of production and consumption, and the overcoming of a series of barriers. Although ethanol is produced in Madagascar, production levels are currently low in the large-scale formal sector which has experienced declines in output and productivity in recent years. Small-scale artisanal production of alcohol from sugarcane continues, but at fuel concentration and price levels not suitable for use as a household fuel.

Woodfuel and charcoal are available at low prices externalising their environmental damage, and their use is accompanied by a low awareness of the dangers of HAP. Furthermore, a series of barriers to the expansion of ethanol as a household fuel has been encountered in previous programmes internationally. These have included promotion of inefficient or unpopular ethanol stoves, fuel blending mandates pulling affordable supply away from households, quality issues with ethanol strength and impurities, policy variability, and competing fuel price fluctuations. If Madagascar is to develop a successful ethanol household fuel programme at scale, it would be the first country to do so.

References and further reading

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