Ethanol as a Household Fuel in Madagascar

Health Benefits, Economic Assessment, and Review of African Lessons for Scaling-up

Volume I - Summary Report

Separately available:

Volume II - Analysis of Household Air Pollution Interventions in Madagascar

Volume III - Economic Assessment of the Ethanol Household Fuel Program

Volume IV - Review of Sub-Saharan Africa Experience in Scaling-up Household Energy Interventions

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ACRONYMS AND ABBREVIATIONS

ALRI	Acute Lower Respiratory Infection
MNP	Madagascar National Parks
CBA	Cost Benefit Analysis
CO	Carbon Monoxide
COPD	Chronic Obstructive Pulmonary Disease
CRA	Comparative Risk Assessment
DALY	Disability-Adjusted Life Years
EHF	Ethanol Household Fuel
EU	European Union
GDP	Gross Domestic Product
GNI	Gross National Income
HAP	Household Air Pollution
IHD	Ischemic Heart Disease
KCJ	Kenya Ceramic Jiko
LPG	Liquid Petroleum Gas
MAP	Madagascar Action Plan
$PM_{2.5}$	Particulate Matter less than 2.5 microns
UN	United Nations
UNDP	United Nations Development Programme
USAID	United States Agency for International Development
WHO	World Health Organization
WWF	World Wildlife Fund

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EXECUTIVE SUMMARY

The Challenge: Forest Degradation and Household Air Pollution in Madagascar

i. In Madagascar forests are at the nexus of development and environmental concerns. The forestry sector represents 5% of GDP and 17% of the primary sector, while of the total average annual household agricultural income of US$240, over US$110 comes from forest products, including non-timber products. Forest-related activities provide the primary source of cash income in rural areas, primarily through employment, with over 16 million work days per year paid in cash. However, Malagasy forest resources have, for several decades, been in a state of decline. The principle causes of deforestation are land clearance for agriculture, fuelwood for household energy and wild fires. Underlying trends driving these factors include population growth, the continuation of the *Tavy* (slash and burn) agriculture method, household dependence on wood fuel for energy, and institutional and regulatory problems relating to forestry governance and land rights. Forest cover constitutes less than 25% of the total land area of Madagascar; 80% of its natural forested areas have been lost, and an estimated 200,000 hectares more is lost annually. Recent studies indicate that if the rate of forest reduction remains at the current level, all of Madagascar's forests will be lost within 40 years.

ii. It is estimated that 95% of households in Madagascar depend on woody biomass, primarily fuelwood and charcoal, for their household energy, with annual national consumption of about 9 million cubic metres of firewood and 8.6 million cubic metres of wood as charcoal. Fuelwood is the predominant fuel for the poorest, poorer and middle income quintiles, whilst charcoal predominates for the richer and richest quintiles. Electricity, natural gas and kerosene provide cooking fuel for only a very small minority, with LPG accounting for 11% in the main cities, but a negligible share elsewhere.

iii. In addition to impacting on forests, this reliance on traditional biomass for cooking imposes a critical toll on public health. Nearly 12,000 deaths per year in Madagascar are attributed to respiratory infections caused by inhalation of Household Air Pollution (HAP) from traditional cooking with biomass, of which over 10,000 are children under 5 years. Some 20% of all deaths of children under 5 years are due to Acute Lower Respiratory Infections (ALRI), and 370,000 Disability-Adjusted Life Years (DALYs) are estimated to be lost each year due to HAP.

Objectives of the Study

iv. In the context of these two linked and pressing problems, a variety of initiatives are proposed for the development of alternative sources of clean household energy. Among other documents such as the Forestry Sector Development Plan, the Madagascar Action Plan (MAP) sets out the agenda for this transformation, citing specifically *the promotion of alternative sources of energy to relieve the pressure on forest resources*, and *the reduction of childhood mortality*. The same issues connect with a range of other sectoral priority areas including energy security, environmental health and agricultural reform. In this context the Government of Madagascar requested the World Bank to provide analytical support on the potential for scale-up of ethanol produced from sugarcane or sugarcane molasses as an improved cooking fuel.

v. This study was commissioned to analyse the cost efficiency and economic viability of an ethanol programme at reducing disease and protecting the forests in Madagascar. This information is also expected to be of interest regionally and internationally, given that the WHO estimates that there are nearly two million deaths per annum globally due to HAP, representing 2.7% of the global burden of disease. Of these nearly 400,000 deaths per annum due to HAP are in Sub-Saharan Africa. With only 20% of the world's population, Africa suffers a disproportionate share of around half of all deaths from pneumonia for children under five years, for which HAP is a major risk factor.

vi. This study investigates the potential of ethanol as a household fuel in Madagascar focusing on three main components: (i) health benefits, (ii) financial and economic assessment, and (iii) African lessons for scaling-up a program of support for ethanol as a household fuel.

Ethanol as a Household Fuel – Limited Production Experience

vii. 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 and, by 2007, had reached around 50 billion gallons produced per annum, 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, whilst 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 multiplier benefits at local, national and international levels.

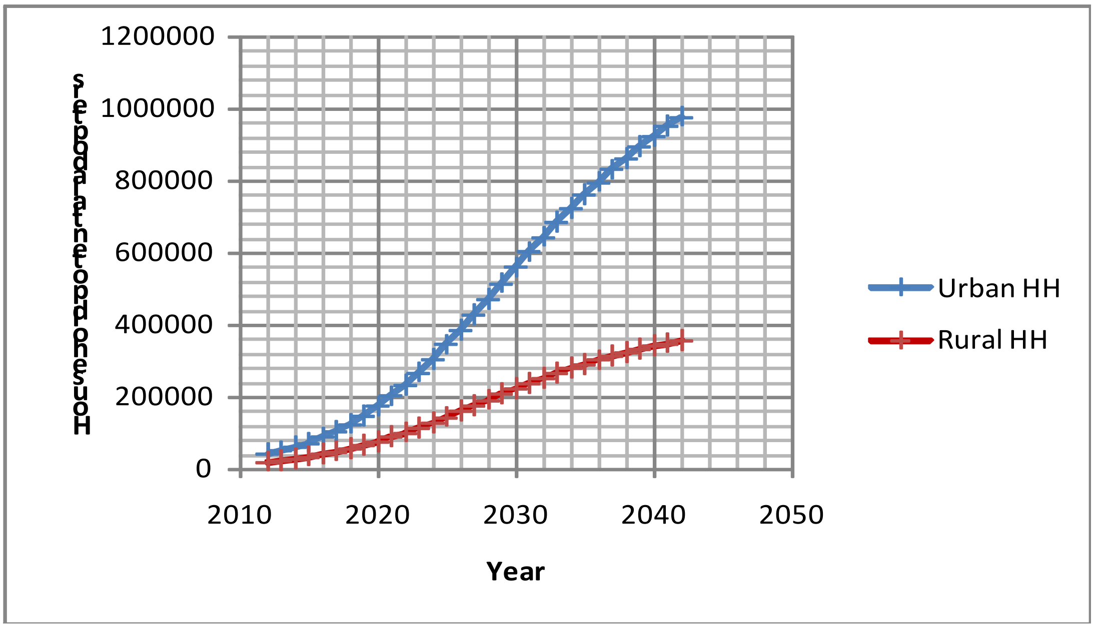
viii. The realization of such benefits in Madagascar would involve a substantial shift in current patterns of production and consumption, and the overcoming of a series of barriers. Although ethanol production is practiced in Madagascar, production levels are currently low in the large-scale formal sector 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. Dominant household fuels based on woody biomass 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. It should be noted that if Madagascar is to develop a successful ethanol household fuel programme at scale, it would be the first country to do so.

Potential Market for Ethanol as a Household Fuel in Madagascar

ix. An initial estimate of the potential market for ethanol for household cooking, with a conservative current price of 35 US cents per litre based on micro-distillery production costs, based on available consumer preference information from household surveys and analysis of the purchasing capacity of households, indicates that over a 30 year timeframe over one million households could be expected to substitute their current primary cooking fuels with ethanol. This would equate to over five million people in total, approximately 16% of the 2042 Malagasy population. The projected rate of market penetration would follow an S-curve as shown in Figure I below.

x. These households would predominantly be those that, while unable to afford LPG as a household fuel, are willing to pay a premium above the cost of charcoal for the benefits of ethanol as a household fuel, which include time-savings, cleanliness, and improved health. A lower ethanol price would create an even larger market. The assumptions made in this analysis include population growth following a similar trend to that observed over the last ten years (currently 2.9% p.a. (WHO)), and that substantial efforts are made in the promotion of ethanol as a household fuel, providing access to credit to facilitate stove purchase over an extended period, and ensuring that supply chains for ethanol are as reliable and accessible as the fuels being replaced.

Figure I: Projected Rate of Adoption of Ethanol as Household Fuel at 35 US cents per litre



Health, Livelihood and Environmental Benefits of Ethanol as a Household Fuel in Madagascar

xi. Were such a level of uptake of ethanol to be achieved, then the impacts on health would be substantial. Modelling of impacts on Acute Lower Respiratory Infections (ALRI) in children, and Chronic Obstructive Pulmonary Disease (COPD) and Ischemic Heart Disease (IHD)in adults suggests that households switching from charcoal to ethanol as the primary household fuel could avoid the loss of 0.03 Disability-Adjusted Life Years (DALYs) per household per year. Valuing each DALY by the Gross National Income per capita, the adoption of ethanol as a household fuel as shown in Figure I above would lead to a total discounted value of $34 million in avoided health costs over a thirty year period.

xii. Even more significant than the health benefits, in economic terms, would be the livelihood benefits to households switching from charcoal or fuelwood to ethanol as the primary household fuel. These include time-savings which the cook could allocate to alternative productive activities, as well as time saved as a result of cleaner households. Appreciation of these benefits was widely expressed by the women using ethanol stoves as part of the household survey component of this study, which found that households save approximately 1.8 hours each day in cooking and cleaning time through the use of an ethanol stove rather than a charcoal or fuelwood stove. Valuing this time at the rural wage rate provides an estimate of $368 million in time savings discounted over thirty years, based on the adoption scenario shown in Figure I. It is this significant economic benefit that underlies the willingness of households to pay more for cleaner, more convenient fuels, although they may not be able to afford LPG.

xiii. In addition to the health and household livelihood benefits of an ethanol programme, there is also an important impact in terms of economic activity around agricultural production, distillation, distribution and also in the stove production and distribution system. Over the 30-year period, ethanol uptake would involve the creation of an estimated 814,000 jobs compared with the equivalent of some 242,000 jobs in charcoal. Approximately 25% of these jobs would be in the production of feedstock, and the remaining 75% in employment at micro-distilleries, predominantly in rural areas.

xiv. A large scale ethanol production scenario would have a significant impact on the forests of Madagascar through the reduced use of wood and charcoal for household cooking. 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 substituted by ethanol, and converting this into an estimate for reduction in loss of forests. If households switched to ethanol as shown in Figure I, it is estimated that 127 million

m^3 of wood obtained from all forests, 90% of which is from unmanaged forests, can be avoided, over a 30 year period. This equates to the avoided degradation of roughly 1.4 million hectares of unmanaged forests, equivalent to approximately 10% of Madagascar's forest area.

xv. For the purposes of assigning an economic value to the avoided deforestation, two alternative approaches were used. The first converted the reduction in degraded forests into avoided CO_2 emissions, which was valued using a market value for a ton of carbon. The scenario shown in Figure I would result in the reduction of 663 million tonnes of CO_2 equivalent as a result of avoided forest degradation, which discounted over 30 years equates to a total economic benefit of $324 million. An alternative approach to valuing the economic benefit of avoided deforestation is to apply the avoided reforestation costs. On this basis, the total value of avoided reforestation costs discounted over 30 years is estimated at $87.5 million. It should be noted that neither of these approaches provides a separate value for the globally important biodiversity that would be protected through reduced deforestation in Madagascar.

xvi. For all biofuels, land use for feedstock production is a significant concern. If the level of uptake shown in Figure I was achieved, the associated annual requirements for household ethanol fuel would be 18 million litres by 2012, reaching nearly 400 million litres by 2041. Such an expansion of ethanol production at distillation efficiency rates within international norms and sugar cane yields currently achieved in Madagascar would require 99,570 hectares of sugar plantations by 2040, equivalent to 3.5% of the current arable land area of Madagascar. This level of household ethanol consumption would displace 127 million m^3 of firewood, equivalent to about 1.6 million hectares of managed and unmanaged forest that would otherwise be used by those consumers switching to ethanol. The net effect of the switch from unsustainable wood fuel to sugar plantations would mean that over the course of the 30 year projection the land area required to produce household fuel would be reduced by 1.5 million hectares compared with the business as usual scenario.

xvii. At the national level, and including the valuation of benefits in terms of time saving, avoided health costs, and environmental services, the net present value of the proposed programme is shown to be in the range of US$450 million for a scenario using sugarcane feedstock micro-distilleries without the sale of by-products, to over US$700 million for a scenario with low cost feedstock micro-distilleries with the sale of by-products. Table I below reports the breakdown of economic benefits under a scenario using sugarcane as a feedstock with plants selling by-products. As this Table shows, households face a financial cost in the price of the ethanol stove itself, as well as the higher cost of the fuel. This financial investment is offset however by the economic returns to households through time savings, improved health and avoided medical costs. In addition, the switch from charcoal to ethanol brings the economic benefits of reduced deforestation described above.

Table I: Breakdown of Economic Benefits of an Ethanol Programme in Madagascar

Economic Benefit	Net Present Value of Net 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 (the range depends on the valuation approach)	87.5 - 324
Avoided DALYs	34
Time Savings	368

Promotion of Ethanol as a Household Fuel – African Lessons for Madagascar

xviii. African experience with the promotion of improved stoves and alternative fuels provides a variety of lessons for the successful launch and commercial sustainability of any initiative to promote ethanol as a household fuel in Madagascar, which will demand the effective participation of the Government, private sector and civil society. Safety and quality issues should be paramount, with rigorous testing of stoves –

particularly for new designs – to ensure that they are fit and safe to use. The establishment of quality standards by the Government will reduce accidents, promoting both consumer confidence in the stoves, and access to carbon finance by requiring a minimum product life. Quality standards for ethanol fuel will also be important, as will the Government's determination to differentiate taxation between ethanol fuel and beverage alcohol.

xix. Private sector involvement will support promotion of ethanol stoves by focusing on attributes that are considered most important to the cook (e.g. cleanliness, attractive design, and speed of cooking) whilst helping ensure the efficacy and affordability of the product through on-going development of technologies in response to customer feedback and competition. NGOs can play a key role in support to entrepreneurs through community-based approaches designed to raise awareness of the benefits of ethanol as a household fuel, and by providing training in stove manufacture and micro-distillery installation.

xx. The economic benefits of ethanol as a household fuel provide justification for public investment to help overcome barriers to adoption, through support for demonstration projects and access to credit for both the purchase of stoves and investment in micro-distilleries. Carbon finance could provide an additional source of finance for the program, helping make ethanol stoves and fuel affordable to poor households otherwise lacking the financial means to invest in the health, livelihood and environmental benefits of switching from smoky, unsustainable woodfuel and charcoal.

xxi. Madagascar has the opportunity to learn from African experience, including early set-backs and mis-steps in developing ethanol as a household fuel. This study indicates that ethanol has the potential to take an important place in the household energy mix in Madagascar if the latest available technologies and practices appropriate to the Malagasy setting are applied in terms of agricultural production, distillation and stove appliances.

xxii. Based on assessment of international best practice, the principles for the production approach most likely to lead to the successful establishment of a household ethanol fuel program in Madagascar would be:

- Support for the introduction of modern micro-distilleries, processing sugarcane and low-cost feedstocks in decentralized locations for the sale of ethanol in nearby urban markets, together with the sale of by-products;
- Facilitated import of leading internationally-available ethanol stoves, at the same time as encouraging the local manufacture of these stoves to the greatest possible extent;
- Taxation should distinguish between beverage alcohol and ethanol fuel, but ethanol fuel should not be directly subsidized;
- Artisanal (household) scale distillation should not be included in the fuel program as appropriate strength, quality and conversion efficiency cannot be achieved.

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Chapter 1: THE CHALLENGE – FOREST DEGRADATION AND HOUSEHOLD AIR POLLUTION IN MADAGASCAR

I. Deforestation and Forest Degradation in Madagascar

1. In Madagascar the forestry sector represents 5% of GDP and 17% of the primary sector. Recent surveys conducted by PAGE (a US-funded program) showing that out of the total average annual household agricultural income of US$240, over US$110 comes from forests products, including non-timber products. Forest-related activities provide a major source of cash income in rural areas, primarily through employment, with over 16 million work days per year paid in cash[1].

2. Despite this, Malagasy forest resources have, for several decades, been dwindling. The principle causes of deforestation are land clearance for agriculture, wild fires, and for fuelwood for household energy. The indirect causes are population growth, particularly in rural areas, expansion of the *Tavy* agricultural system (a form of slash and burn), the use of wood for construction, as well as institutional problems relating to forestry governance and an ambiguous framework of land rights[2]. Forest cover constitutes less than 25% of the total land area of Madagascar[3].

3. According to the World Wide Fund for Nature (WWF), most of Madagascar's dry forests have been cleared for slash-and-burn agriculture, pasture, and firewood collection, or for construction material. This land is now largely covered by secondary grasslands[4]. Madagascar has already lost 80% of its natural areas of forest, and continues to lose an estimated 200,000 hectares annually to deforestation. Recent studies by the Centre for Applied Biodiversity Science at Conservation International indicate that if the rate of forest reduction remains at current levels, all of Madagascar's forests will be lost within 40 years[5].

Sources of Deforestation

4. Only 4% of the land in Madagascar is cultivated, and more than 77% of the population depends on agriculture for their livelihoods. The population of Madagascar has more than tripled since 1950[6] and continues to grow at nearly 3% per year[7]. Thus the demand for cultivable land is set to increase, and with it, the threat to its forests. Although the majority of deforestation can be attributed to agricultural clearing, it is estimated that direct consumption of forest products accounts for between 5% and 20% of all deforestation[8]. The Jarialy programme estimated consumption of woody forest products (fuelwood, charcoal, poles and lumber) would grow from 21.7 million cubic metres per year in 2005 (Table 1.1) to more than 23 million cubic metres per year by 2025.

Table 1.1: Estimation of annual consumption of various wood products (Jarialy, 2005)

Type of wood	Rural (m^3/person)	Urban (m^3/person)	Total (millions m^3)
Fuelwood	0.686	0.134	9.026
Charcoal	0	1.75	8.575
Construction	0.24	0.22	4.127
Total	0.93	1.97	21.728

5. The same report estimates that in the immediate future, the total amount of available forest product (wood) will be 18.5 million cubic metres, of which 7.9 million will be available for charcoal production and 5.7 million for construction and services. Importantly, the report points out that 20% of the total productivity for charcoal will be provided by eucalyptus plantations. Total sustainable production is predicted to decrease

[1] World Bank PID, 2003
[2] IRG Jarialy, 2005
[3] FOSA 2000
[4] http://www.worldwildlife.org
[5] http://www.worldwildlife.org
[6] UN 2001
[7] UNDP 2003
[8] (Jarialy, 2005)

by 100,000 cubic metres per year in the coming years. Given that consumption of forest products is set to increase, this publication predicts that by 2025, forest production will no longer be able to meet demand.

Forest Regulation

6. The Forestry Sector Development Plan draws on the Madagascar Action Plan (MAP), which is based on a stakeholder consultation process and the UN Millennium Development Goals. Commitment to the conservation of the natural environment is a key feature of the MAP, and forest protection has been recognized by the Government as central to this aim. In Durban, 2003, Madagascar Officials reaffirmed the country's commitment by announcing plans to expand national conservation areas from 1.7 million hectares in 2003 to 6 million hectares by 2008[9]. In 2004 an intra-ministerial decree was promulgated to minimise conflicts between the mining and forest sectors during the time required to identify sites for protection and implement the required legislation. Under this decree, the granting of mining and forest licenses was suspended in the zones reserved as 'conservation sites'.

7. Madagascar is currently implementing the third phase of its 15-year National Environmental Action Plan, with the support of a consortium of development assistance agencies, through a well coordinated Environmental Program. Over the past 10 years, significant progress has been achieved in establishing a National Environmental Office, and in restructuring the institutional framework for the management of Madagascar's national parks and protected areas[10]. The network of parks and protected areas has greatly expanded, under management of Madagascar National Parks (MNP). The size and number of these current areas are highlighted in Table 1.2.

Table 1.2: Forest Cover by Type

Type of Forest Cover	Existing Protected Areas	New Protected Areas	Forest outside Protected Areas	Total
Dense Humid Forest	736 116	2 358 396	1 516 304	4 610 816
Dense Dry Forest	319 532	674 353	1 388 214	2 382 099
Woodland	47 302	1 270 859	807 671	2 125 832
Mangroves	4 403	72 984	111 838	189 225
Pine Plantations	-	-	113 611	113 611
Eucalyptus Plantations	-	-	156 130	156 130
Total	**1 107 353**	**4 376 592**	**4 093 768**	**9 577 713**

Source: MEF 2008

Problems of Governance

8. All natural forests and some large scale plantations (Fanalamanga (80,000ha) and Matsiatra (30,000ha)) are the property of the State, and all extraction from forest areas, whether for commercial or subsistence purposes, even from private properties, requires a permit[11]. MNP exerts direct control over access to biodiversity resources within protected areas. In terms of regulating access to forest resources, the capacity of the forests administration is limited and is mostly restricted to issuing permits to commercial loggers at the regional level[12]. At the local level, permits are usually only issued for subsistence users if the forest administration is located nearby. Moreover, fire clearing permits are often issued without any field verification or monitoring for compliance and in very remote areas where forests are abundant and the authorities are not present, access to forests is often not controlled.

[9] (Jarialy, 2005)
[10] (USAID, 2005).
[11] (World Bank, rural sector review, 2003)
[12] (World Bank, rural sector review, 2003)

9. In more densely populated areas, there is typically some sort of local regulation of forest access, usually connected to traditional land tenure rights and/or local taboos (cultural beliefs)[13]. In areas where the State is also present, problems may arise when permits are issued for logging on land that is informally administered by the community[14].

10. Generally, governance within the forestry sector is weak and is characterized by a high frequency of illegal logging and exploitation of protected species, and failure in law enforcement. It has been observed that the majority of forest products which arrive at the market originate from illicit exploitation[15].

Land and Habitat Degradation

11. Land degradation is one of the most serious and widespread problems for the agricultural sector in Madagascar. The degradation dynamics in the uplands and lowlands are often linked, reinforcing each other. With the stagnation of yields in the irrigated lowland areas and demographic growth, farmers extend their agricultural activities to the hillsides. Upper watershed land use is often based on extensive and unsustainable management practices, the most important being lack of erosion control and lack of improved soil fertility management on agricultural plots, slash-and-burn agriculture (or *Tavy*), and the frequent burning of pastures. Land degradation is also caused by deforestation for agricultural purposes, with the consequence of increased carbon emissions, biodiversity loss and diminishing ecological services. These practices not only contribute to the degradation and low productivity of uplands but also significantly impact on lowland agriculture. Upland soil erosion and water surface run-off causes sedimentation of downstream infrastructure, contributing to the reduction of cultivated area under irrigation, local flooding of rice paddies in the rainy season and water shortages in the dry season[16]. The principle threats to Madagascar's biodiversity come from the small-scale but widespread clearance of habitats, primarily for firewood and charcoal production. Other threats include subsistence agriculture, overfishing and the effects of climate change on marine ecosystems.

II. Household Air Pollution in Madagascar

12. Indoor smoke from burning solid fuels comprises a variety of health-damaging pollutants, such as particulates (tiny particles that enter deep into the lungs), carbon monoxide, polyaromatic hydrocarbons (carcinogens), irritants (aldehydes), nitrogen oxides and (especially with coal) sulphur oxides.

13. The World Health Organisation (WHO) states that there is consistent evidence linking exposure to Household Air Pollution (HAP) with increases in the risk of several life-threatening illnesses, including pneumonia and other acute lower respiratory infections (ALRI) among children under 5 years, chronic obstructive pulmonary disease (COPD) among adults 30 years and older, and where coal is the fuel, lung cancer in adults 30 years and older (a strong link between biomass and lung cancer has not yet been established). A recent systematic review has provided quite strong evidence that HAP exposure increases the risk of low birth weight and still birth. According to WHO there is also tentative evidence linking HAP from solid fuels with a number of other disease conditions, including asthma, cataracts, tuberculosis, and nasopharyngeal and laryngeal cancers. The very strong evidence for outdoor air pollution and second-hand smoke causing ischemic heart disease has also now been accepted as indicating that HAP will almost certainly also increase the risk of this disease.[17]

14. WHO has assessed that HAP is responsible for nearly 2 million premature deaths and 2.7% of the global disease burden, based on 2004 exposure and health data (WHO 2009), and indicates that[18]:

- Pneumonia is the single most important cause of death of children under the age of 5. Exposure to HAP more than doubles the risk of this disease and is responsible for almost 900,000 of the 1.8 million annual deaths from pneumonia and other acute respiratory infections (ALRI);

[13] (World Bank, rural sector review, 2003)
[14] (World Bank, rural sector review, 2003)
[15] (Jarialy, 2005)
[16] (World Bank, Project Information Document, Watershed Management Project, 2006)
[17] (Wilkinson et al, Lancet 2010).
[18] *http://www.who.int/indoorair/info/briefing2.pdf*

- Women exposed to HAP are three times more likely to suffer from Chronic Obstructive Pulmonary Disease (COPD) than women who cook with electricity, gas and other cleaner fuels. As a result, HAP is responsible for approximately one million out of the three million global deaths due to COPD.

With more than 95% of the population of Madagascar using solid fuel for domestic purposes, the burden of ill-health resulting from exposure to HAP stood at over 400,000 DALYs in 2004 and nearly 12,700 deaths, 11,300 due to ALRI in children under 5 years, about 20% of all deaths of children of this age.

Chapter 2: ETHANOL AS A HOUSEHOLD FUEL

I. International Experience

15. Experience with ethanol production around the world is still evolving. The drivers for sector development include the need to modernise the sugar industry on the supply side, and domestic fuel blending mandates on the demand side, particularly in relation to rising, and unpredictable, petroleum prices and climate change mitigation targets. In many countries there is direct state support for the sugar industry and/or for fuel blending, even when there is not an adopted biofuels policy. A key lesson for Madagascar is that while fuel blending may drive sector expansion and address petroleum import issues, if only blending is encouraged then the household fuel sector for ethanol may not develop. Consumers who cannot afford a clean fuel such as LPG may not be able to gain access to ethanol as a household fuel and will thus receive little benefit from such fuels unless through equitably arranged agricultural livelihoods strategies in fuel production (e.g. small-scale production and distributed supply and sales). Such challenges are likely to be exacerbated through explicitly export-oriented strategies, which may be a temptation if markets like the European Union (EU) continue to demand increasing amounts from international supply.

16. In terms of production scenarios, the focus for industrial ethanol fuel development in most countries has been towards large scale production. However, trends in this regard are changing as the industry matures and local development benefits are being sought more explicitly within biofuels policy in developing countries. Smaller scale efficient production and distillation technologies are becoming available (see Volume III) which offers a route for the Malagasy ethanol sector which may not have been available in previous years.

17. World production of ethanol is rising as high oil prices drive demand for alternative fuels, and as international awareness of global warming and concerns about energy security intensify. For producer countries, ethanol production offers a range of opportunities, both for domestic energy supply and for export. In Brazil, the only developing country to have so far gone to scale with ethanol production, ethanol appears to have delivered a reduction in oil importation, improved security of energy supply and created 700,000 jobs directly, with perhaps 3-4 time that number indirectly[19]. Africa's ethanol base is less developed than those in Latin and North America, but 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.

Ethanol Production – Lessons for Madagascar

18. Experience with small and micro scale ethanol production has been especially rich in Brazil, the United States, India, South Africa and a few other countries, and there are lessons to be learned and technology to share from these countries. The micro scale experience comes not only from the beverage industry (formal or informal) in these countries, but also from agriculture and the search by farmers both for cheaper fuels and value-added products.

19. It must be noted that while ethanol has been used on a limited basis for cooking, heating, and lighting in many cultures, the formal, international experience of ethanol as a commercial household fuel is limited and relatively recent. Programmes in other countries have struggled, usually for one or more of the following reasons:

- Inefficient or unpopular stoves being promoted which are then not taken up by households. Examples are gel-fuel stoves in southern Africa (South Africa, Malawi, Zimbabwe, Mozambique), which have suffered from being under-powered and requiring frequent refuelling.[20]

- Ethanol supply mandates to fuel blending programmes, pulling affordable domestic supply away from household markets. A recent example is Ethiopia where the government pulled ethanol from the

[19] (APEC, 2010).
[20] UNDP-Malawi GSB for Poverty Reduction Program Report, Feasibility Study for the Use of Ethanol as a Household Cooking Fuel in Malawi, prepared by Ethio Resource Group and Gaia Association, November 2007. See also: Lloyd, P and Visagie, E., The Testing of Gel Fuels and their Comparison to Alternative Cooking Fuels, Energy Research Centre, University of Cape Town, Cape Town, South Africa, April 2007.

operating ethanol stove program for a government-run fuel blending program when production shortfalls caused a supply constraint. This left over 3,000 stove users without ethanol.

- Quality (energy content and form) of the ethanol fuel not being suitable for widespread use. Where beverage and farm-scale stills operate, in most instances they produce only a low grade ethanol, in the range of 40 to 55% ABV. This is true for Brazil as for India and selected African countries.
- Lack of supportive policy on biofuels, undermining sector confidence in both the fuel and stoves, required to maintain consumer confidence despite supply interruptions. Fuel blending in both Kenya and Ethiopia suffered interruptions, as has the ethanol stove program in Ethiopia.
- Ethanol fuel pricing is very vulnerable to commodity prices of existing fuels, for example charcoal, fuelwood and fossil fuels, particularly kerosene. Ethanol for domestic fuel may have to compete with ethanol priced for export to developed economies. An example is Eastern Africa, which is developing a robust trade in ethanol to the EU, encouraged by European businesses that are looking to diversify from Brazil. Sudan exports much of its new 60 million litres of capacity to Europe, although the government is also successfully supporting the use of LPG as a household fuel.

20. If the Malagasy household ethanol programme is to overcome these challenges it must learn from the experiences described here and put in place consistent and substantial measures for overcoming them. Such a programme needs to be based on a sustainable domestic supply of ethanol. If it is able to do so at scale, it will be the first country to achieve this.

Scales of Ethanol Production

21. Ethanol can be produced from any biomass containing significant amounts of starch or sugar. Production scales can be categorised as: large scale, micro-distilleries and artisanal scale. Artisanal production is very accessible to low-income rural producers due to low capital costs and local-level distribution; however this process delivers low ethanol quality and strength through the use of poor conversion efficiencies. Large quantities of fuelwood are used per litre of ethanol, and further refining would lead to a higher cost product, making it non-viable for a widespread household ethanol programme. The close association of this type of production with alcohol drinking, the higher market price per litre for this application, and the difficulties of policing production at this scale preclude its serious consideration for the household ethanol market creation.

22. Large scale production is relatively well known internationally and is the typical scale of production in Brazil and other large ethanol producing economies, offering good efficiencies, quality, strength, low cost per litre, and the ability to be fuelled entirely by bagasse, even generating excess energy for sale to the grid. However centralised plants will not necessarily promote maximum benefit distribution along the supply chain, and high capital barriers exclude local people from direct participation, other than as waged labour or raw material suppliers. The structuring of agreements with out-grower sugar-cane suppliers can have a strong influence on inclusivity and development impacts. In addition, centralized production may not be best suited for the supply of ethanol as a household fuel to rural areas with limited transport access, as is the case for much of rural Madagascar. This scale of production is more suited to transport sector fuel-blending, a use which competes with the household energy sector.

23. Micro-distillation is a relatively new scale of production. International experience to date indicates that it offers many of the energy efficiency and ethanol quality benefits of large-scale production, but with increased levels of decentralisation of production and corresponding dispersal of opportunities and benefits. Although a detailed analysis of costs of production is needed for each new installation, available micro-distillation technologies internationally appear to be capital cost competitive per litre of ethanol produced compared with large scale installations, and share the potential to be fuelled entirely by bagasse. The lower total cost per installation allows production to be dispersed, centred closer to cane production and household ethanol consumers, reducing the capital barriers to market entry and reducing transport costs. This is especially significant in Madagascar, where large distances and poor infrastructure leads to high transport costs.

24. International experience shows ethanol markets to be strongly dependent on government policy. Particularly given the volatility of international fuel markets and the multiple potential applications of ethanol at different price points, stable and progressive government policies will be important if the ethanol household fuel market is to develop sustainably. In the initial stages, it may be necessary to ring-fence and prioritise sufficient ethanol fuel for the household energy market to ensure that a failure in the supply chain for ethanol (perhaps linked to international price fluctuations or a fuel blending mandate) does not destroy the burgeoning market for stoves which would also be created. This is particularly important for large-scale industrial manufacture. Ethanol adoption as a household fuel is very vulnerable to commodity prices of existing fuels, for example charcoal, fuelwood and fossil fuels. If the full benefits of ethanol to health, the environment, rural incomes and balance of payments are to be realised, then government policy must mediate price fluctuation to some extent, especially in the initial stages.

25. In order to succeed, the Malagasy household ethanol programme must learn from the international experiences described above, put in place measures to overcome challenges encountered elsewhere, and replicate successes. Ethanol case studies from around the world, including a number of African countries, provide important policy lessons for Madagascar. In both Ethiopia and Malawi ethanol is produced from sugar-cane molasses, with priority given to blending ethanol with gasoline (E5 to E10), and in both countries ethanol is also promoted as a domestic cooking fuel. The main findings of studies conducted in these countries[21] indicate that the application of ethanol for domestic cooking is more attractive environmentally and socially than for gasoline blending for the following reasons:

- The household ethanol markets are larger than the blending mandates. In Ethiopia, at a maximum blend mandate of E10 only about 20 million litres of ethanol can be absorbed per year, while there already exists an annual domestic cooking market of 100 million litres;
- Using ethanol for domestic cooking entails few changes in the petroleum distribution infrastructure, and is therefore much easier to regulate;
- Application of ethanol for domestic cooking is socially more equitable because any gains in better energy access and reduced costs are more evenly distributed among different income groups; for gasoline blending on the other hand, gains tend to go to the highest 5% income group.

II. Experience in Madagascar

Ethanol Supply in Madagascar

26. Approximately one-half of Madagascar is potentially cultivable, but little more than 5% of the land is currently under crops. Taken together cropland and crop/natural vegetation mosaic accounts for 13% of land cover, with approximately 21% of the total land area covered by forests and 63% by shrub-land, grassland and savannah. The demand for cultivatable land is on the increase, and is not being matched with an increase in land allocated for agricultural use. Madagascar has problems of land ownership, land tenure, and land taxation; efforts to resolve these issues are likely to encourage increasing investment in small-scale sugar-cane production.

27. Madagascar has a recent history of land degradation and action needs to be taken to ensure that any expansion of sugar-cane production does not encroach on either sensitive ecosystems or on land required for food production. Sugar-cane production should not result in food price rises or decreased levels of food security. In general the agriculture system in Madagascar is underperforming, and requires significant investment in improved techniques and technologies to improve soil quality and production. The use of land for sugar-cane to produce both sugar and ethanol has great potential to reduce poverty if managed effectively, and with appropriate management could contribute to efforts to reduce soil erosion, but will require support to ensure high yields can be achieved sustainably. Producer cooperatives and associations might be an avenue for increasing productivity and ensuring that local farmers derive an equitable share of benefits. The extent to which foreign investment is sought to increase sugar-cane production needs to be carefully assessed to ensure that benefits to local farmers are maximised and the household ethanol fuel

[21] (UNDP/Malawi, 2007, UNDP/Ethiopia, 2006)

market is not ignored. The potential for sugar-cane production to increase ethanol supply will only be achieved if policy measures are integrated into national agricultural planning.

28. Currently Madagascar's sugar-cane productivity is low and there is significant potential to increase yields through improving efficiencies and technologies. Small-scale sugar-cane production is widespread, but generally with very low yields, and almost exclusively used to produce *Toaka Gasy*, the locally manufactured rum for human consumption. It has been suggested that artisanal *Toaka Gasy* production could be improved to fuel standard, but it is unlikely that ethanol of a high enough grade can be produced efficiently, sustainably and competitively from such scale of production. In response to international demand for ethanol to be blended as a transport fuel, and preferential access to EU markets for African producers, industrial production of ethanol in Madagascar is set to increase steadily over the next five years as additional distilleries come on stream, and action is taken to reinstate the sugar industry. The Government is giving some consideration to a requirement that a portion of this production should be sold domestically.

Potential Demand for Ethanol as a Household Fuel

29. It is estimated that 95% of households in Madagascar depend on woody biomass, primarily fuelwood and charcoal, for their household energy with annual consumption of some 9 million cubic meters of firewood and 8.575 million cubic metres of wood as charcoal[22]. Fuelwood is the predominant fuel for poorest, poorer and middle income quintiles, whilst charcoal predominates for the richer and richest quintiles. Electricity, natural gas and kerosene capture very little of the market even for the richest quintile. Most city households use charcoal rather than wood fuel, while the use of LPG is recorded as almost 11% in the main cities, but negligible in the small cities.

30. The household sector in Madagascar is expected to be heavily dependent on wood-based fuels for some time to come, with the FAO predicting an increase in household wood fuel consumption, and little substitution with electricity, kerosene or LPG due to the high costs of the fuels and appliances. Fuelwood may be extracted free of charge provided that it is not commercially traded, but an official permit must be obtained in order to sell wood. Illegal cutting is commonplace, however, particularly in areas where fuelwood is in short supply. As part of this study, user preferences for household fuels were investigated, and the major concerns were the speed of cooking, followed by convenience, cleanliness, and the price of fuel. Smoke, dirt, suffocation, bad health and inconvenience were some of the factors that made fuels disliked by the surveyed households and that create a potential market for competitively priced ethanol as a household fuel.

III. Policy Challenges

31. The following section highlights the sensitive policy context of ethanol as a household fuel in Madagascar. If measures are introduced to encourage foreign investment in large-scale sugar-cane and ethanol production for the transport sector and export, particular attention will be required to ensure that these same measures do not work to discourage small-holder sugar-cane cultivation and micro-distilleries producing ethanol for the local household fuel market.

Land Use, Ownership and Taxation

32. With current land use, ownership and taxation systems unclear or weak, any policy aimed at expanding sugarcane production for the ethanol market in Madagascar would require careful zoning and planning of agricultural encroachment into new areas (at any scale), and investment in the rehabilitation of abandoned sugar-cane plantations, to ensure that neither food production nor the delicate ecosystem are put in jeopardy.

33. Although some studies have shown that the private economic benefits of land titling would be minor and would not exceed the costs of taking this action[23], it is widely held that the absence of land titles for 90% of rural households is the main reason why most farmers tend not to invest in their land and

[22] Jariala, 2005

[23] (Jakoby & Minten, 2007)

diversify their production[24]. Without having the land title it is difficult for farmers to approach banks or credit unions for investment or harvest loans, thus land tenure policy may have considerable implications for small-scale sugar-cane production. Without security of land ownership, it could be argued that it would be highly risky for households not already involved in sugar-cane production to engage in out-grower schemes. While the complicated nature of the land tenure system could prove to be a major disincentive for investment in larger scale ethanol production, an additional source of cash income may enable small landholders to title their land and subsequently pay the annual land fee.

Fuel Crops, Food Security and Livelihoods

34. In order for economic and efficient yields to be achieved in sugarcane production it will be necessary to provide extension support to the agricultural sector to improve practices and address issues of security, liquidity and price-quality differentiation. This is likely to be the case for whichever scale of production is promoted. However, the predominance of small-holder farmers offers the potential for effective out-grower schemes if terms are agreed and producer co-operatives/associations are engaged or developed. Foreign investment in sugarcane production could become a dominant factor in the sector. Large-scale manufacture could present a significant challenge to the ethanol household fuel programme, as foreign investors would be more likely to target export markets than domestic household ones.

35. The crisis in agricultural productivity is already recognised across many agricultural sub-sectors in Madagascar. To ensure that a household ethanol fuel programme does not exacerbate food insecurity issues, productive land currently used for food production should not be turned over to fuel crops. The programme can play an important role in enhancing livelihoods by providing additional incomes for farmers in rural areas as an additional cash crop. Ensuring that these outcomes are achieved, rather than enhancing income disparities, must be a main focus of the design of the household ethanol fuel programme.

36. The household ethanol programme has the potential to create a very substantial new domestic market for one of the co-products of sugar cane, but if domestic production of sugar cane is to increase to meet this opportunity then efficiency and productivity improvements will be needed at all scales of the sugar cane industry. Production of sugarcane for ethanol, particularly as a household fuel, should be incorporated into national planning on agriculture and energy in order to avoid possible conflict between these two sectors.

Business Environment

37. Although the business environment in Madagascar is showing improvement, its ranking is still low, including for indicators such as access to credit and property registration. Complicated, expensive and time consuming procedures for titling land, constructing buildings and registering property could prove to be major disincentives for investment in ethanol production at any scale in Madagascar. Access to credit and difficulties securing land tenure could make it challenging for local farmers to become engaged in ethanol production without support measures.

IV. Financial Analysis

38. The USAID-funded IRG/Jariala report (2005) estimates that Malagasy families annually consume approximately 9 million cubic metres of wood as firewood and 8.6 million cubic metres as charcoal.[25] Table 2.1 indicates that a total of 72.4% of the Malagasy population currently uses firewood for household cooking while 25.2% uses charcoal, with only 2.4% of the population using other fuels such as electricity, LPG, kerosene and coal. As ethanol is a very clean burning fuel it will be able to compete with LPG, particularly if it is significantly cheaper, but due to the very low numbers of LPG users' ethanol will only have a significant impact if it can attract users of charcoal and wood that can afford to buy it.

[24] (African Economic Outlook, 2008)
[25] (IRG Jariala, 2005)

Table 2.1: Primary Cooking Fuel in Madagascar – Share of Households (%)

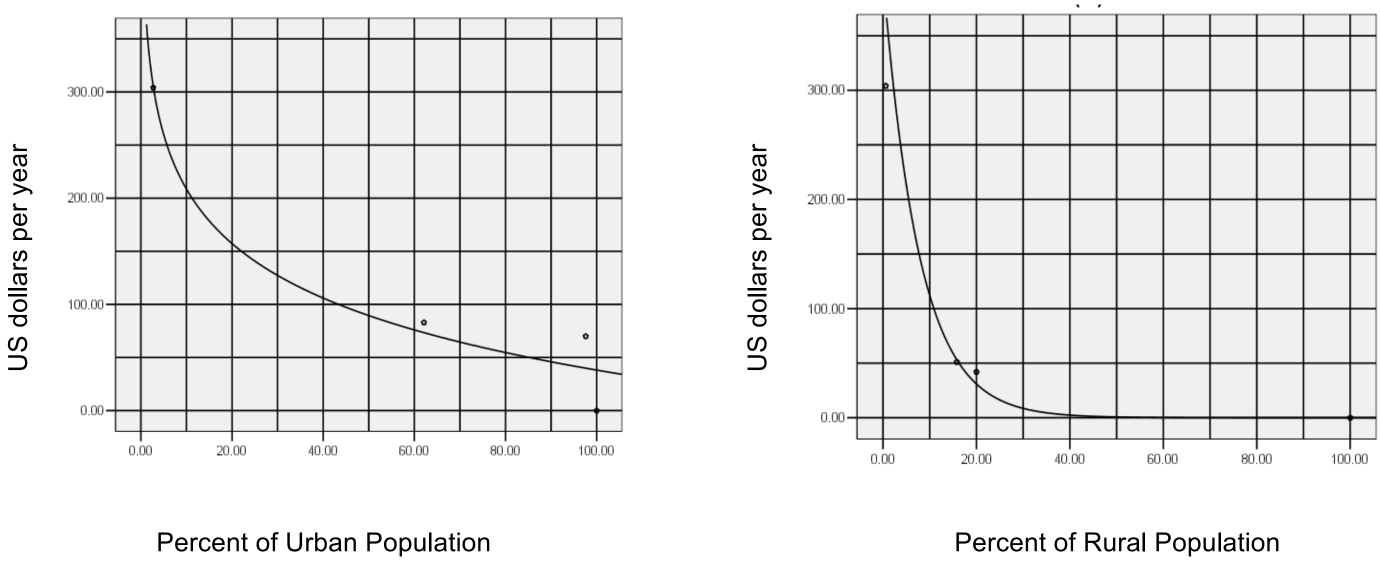
	Type of cooking fuel								
	Electricity	LPG, natural gas	Biogas	Kerosene	Coal, lignite	Charcoal	Firewood, straw	Dung	Other
Urban	0.9	2.7	0.3	0.2	0.7	59.4	35.5	0.1	0.1
Rural	0.1	0.6	0	0.1	0.2	15.2	83.3	0.3	0
Total	0.3	1.1	0.1	0.1	0.3	25.2	72.4	0.3	0

Cost of Household Cooking Fuels in Madagascar

39. The cost of household cooking fuels in Madagascar varies depending on where they are purchased, with prices in urban areas typically being higher due to the increased demand, fuel scarcity, and the greater transport costs from production to market. In rural areas wood is often collected, while wood is purchased in urban areas. Charcoal is always purchased but its cost is considerably higher in urban areas as it is further from its place of production. The cost of household fuels varies throughout the year with the price of biomass fuels rising in the wet season due to the lack of dry wood.

40. The graphs in Figure 2.1 are cumulative curves which describe the relationship between the cost of fuel (in dollars per annum, on the vertical axis) against the percentage of the Madagascan population who can afford to pay for a fuel. For example, in urban areas, for LPG (which costs around US$300 per annum), only 1.6% of the population are able to afford it, whilst for charcoal, the percentage includes the charcoal users and the LPG users – as both can afford charcoal. For woodfuel, the LPG, charcoal and purchased wood household percentages are included – and finally, the gathered fuelwood can be afforded by all. While the estimated demand curves are shown as smooth curves, in practice the limited choice of fuel options presents households with a series of price thresholds. As a result 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. This unmet demand is important for ethanol as a household fuel, which falls at a price point between charcoal and LPG.

Figure 2.1: Cooking Fuels in Urban and Rural Areas of Madagascar – estimated Willingness to Pay



41. Using these estimated demand curves, once the production cost of ethanol has been determined it is possible to estimate the percentage of Madagascan Households able to afford ethanol in both urban and rural areas, assuming that (i) at the same price, households will prefer to use ethanol rather than charcoal or wood for most (but not all) cooking purposes, due to its cleanliness and ease of use, and (ii) households will switch some (but not all) cooking from LPG to ethanol, if ethanol is cheaper.

Cost of Household Cook Stoves

42. Although the cost of purchasing a stove is relatively small over its lifetime, because households almost always have to pay the cost of the stove 'up-front' it constitutes a barrier for households wishing to change to using another fuel. Table 2.2 below summarises the annualized costs of household stoves in Madagascar.

Table 2.2: Cost of Household Stoves in Madagascar

Stoves	Total Cost (US$)	Stove life in years	Annual Cost (US$)
Woodstove*	25	5	**5**
Charcoal stove**	2.4	0.5	**4.8**
LPG stove	50[26]	5	**10**
Ethanol Stove	50	10	**5**

*The full price of an improved woodstove was not used in this analysis, as many households would be using a lower priced stove. A value of $5 per annum was used as a conservative estimate of the stove cost.
** A typical low-cost traditional charcoal stove burns through very quickly and this was valued at a low price, but with a life of six months.

Micro-Distillery Production of Ethanol

43. Micro-distilleries, such as the working models in Brazil and the USA, can produce ethanol of a high enough quality and strength to be used in ethanol stoves (over 92% ethanol), unlike the ethanol produced in artisanal (*Toaky Gasy*) stills, which produce ethanol at too low a concentration (only around 35-45% ethanol). A further advantage of advanced micro-distilleries is that they can be fuelled from the bagasse (residue) of the feedstock, and consequently do not require the large amounts of woodfuel used by artisanal stills, which are often obtained from unsustainable sources. Various levels of life cycle energy efficiency are reported for ethanol fuel from sugarcane and sweet sorghum ranging up to a nine-to-one energy gain for modern micro-distilleries burning feedstock bagasse.[27]

44. 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 - both energy efficient (economizing on fuel) and process efficient (possessing a distillation unit that efficiently separates ethanol from water). Feedstock represents the largest cost in making ethanol; after feedstock either labor or energy represent the next largest cost. If a micro distillery is able to exploit the opportunities offered by its small size to access locally available feedstock, labor and energy, which could not support a large plant, then the potential exists for the micro distillery to produce ethanol at a competitive price.

45. Small and geographically concentrated resources typify the kind of resource that is available for management and exploitation for biomass fuels in most African economies. In particular, charcoal is manufactured on a very small scale, and both farms and woodlots are generally small scale. In many if not most African settings, crops for bioethanol production can be produced on a small scale when they cannot be produced on a large scale. 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. Micro-distilleries may use simplified and inexpensive equipment which nevertheless produces ethanol efficiently. Potentially all of this equipment can be locally manufactured, allowing capital cost per unit output to compare favorably with industrial-scale plants. Further, as micro- distilleries serve a local market, there may be no need for a wholesaler in the fuel supply chain, which can be short and economical.

[26] Includes sundry items such as tubing, which needs to be replaced on a regular basis
[27] Blume David. 2007. Alcohol Can Be A Gas—fueling an Ethanol Revolution for the 21st Century. International Institute for Ecological Agriculture. See Appendix A: Ethanol and EROEI.
Macedo, Isaias Carvalho. 1996. Energy Balance of the Sugar Cane and Ethanol Production in the Cooperated Sugar Mills, CT Brasil, Ministério da Ciência e Tecnologia Brasil, UNFCCC.
Lorenz, David and Morris, David. 1995. How Much Energy Does It Take to Make a Gallon of Ethanol? Institute for Local Self Reliance.

46. Because micro-distilleries can be supplied with small feedstock streams, it can exploit feedstocks which might otherwise be considered to have no value. These include agricultural co-products and residues, market wastes and processing wastes. They may even include unusual feedstocks like poultry manure or wild, gathered feedstocks like prickly pear cactus and mesquite pods. Although ethanol can be produced from a wide range of feedstocks, this report focuses mainly on ethanol produced from sugarcane, molasses and agricultural waste products. It should be noted, however, that increasing the range of raw feedstocks can increase the number of days each year during which ethanol can be distilled, which has a substantial impact on the cost of ethanol production.

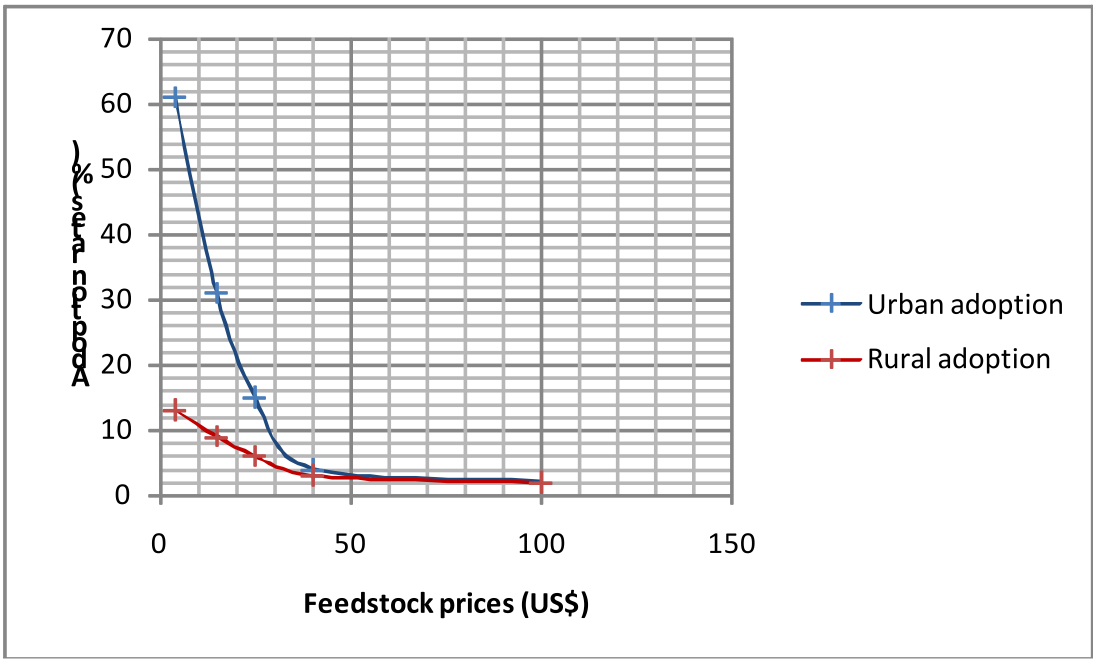
47. A set of scenarios were developed to test a financial model for a 120 litre per day capacity micro-distillery, based on currently operating plants in Brazil and USA, and using feedstock costs for both molasses and waste products from fruit and vegetables (however it must be noted that there are a wide range of other materials that are suitable for producing ethanol, which should be considered within a national ethanol production strategy). 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.

48. 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. The resulting ethanol prices (with and without the sale of by-products) were then combined with the demand estimates shown in Figure 2.1 to provide estimates of the uptake of ethanol as a household fuel, as shown in Figure 2.2 and summarized in Table 2.3.

49. It can be seen from Figure 2.2 and Table 2.3 that feedstock price has a significant impact on the cost of ethanol production and subsequent household uptake, falling from an adoption rate of 61% of urban households with a feedstock price of US$4/tonne, down to an adoption rate of 2% of urban households with a feedstock price of US$100/tonne.

Figure 2.2: Feedstock Price per Tonne and Adoption of Ethanol as a Household Fuel (% of Households)

a) With Sale of By-Products



b) Without Sale of By-Products

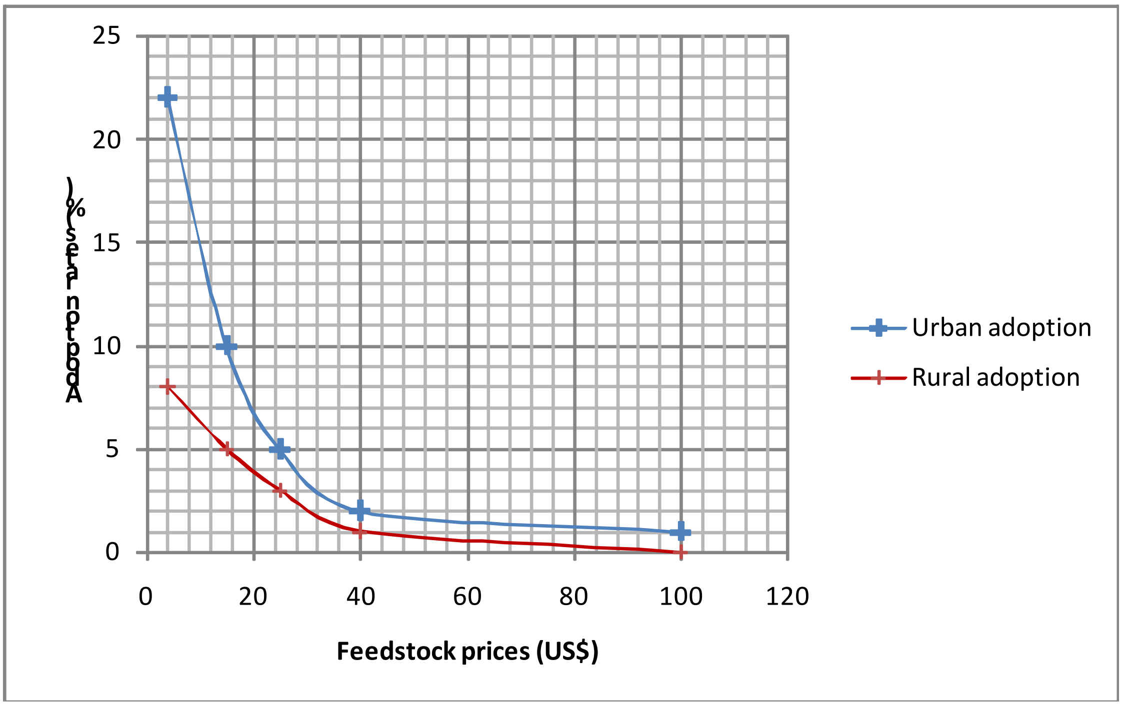


Table 2.3: Impact of Feedstock Prices on the Cost of Ethanol Production and Household Adoption

	Price of feedstock (US$ per tonne)	4	15	25	50	100
With sale of by-products	Price of ethanol (US$)/litre	0.19	0.33	0.48	0.73	0.86
	Cost to household per annum	74	125	180	271	319
	Urban adoption (%)	**61**	**31**	**15**	**4**	**2**
	Rural adoption (%)	**13**	**9**	**6**	**3**	**2**
Without sale of by-products	Price of ethanol (US$)/litre	0.40	0.55	0.70	0.94	1.07
	Cost to household per annum	151	206	261	348	396
	Urban adoption (%)	**22**	**10**	**5**	**2**	**1**
	Rural adoption (%)	**8**	**5**	**3**	**1**	**0**

Rates of Adoption of Ethanol as a Household Fuel

50. As Table 2.4 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, however, and this process was modelled as following an s-curve over a series of different periods. As shown in Figure 2.3 for a price of 35 US cents per

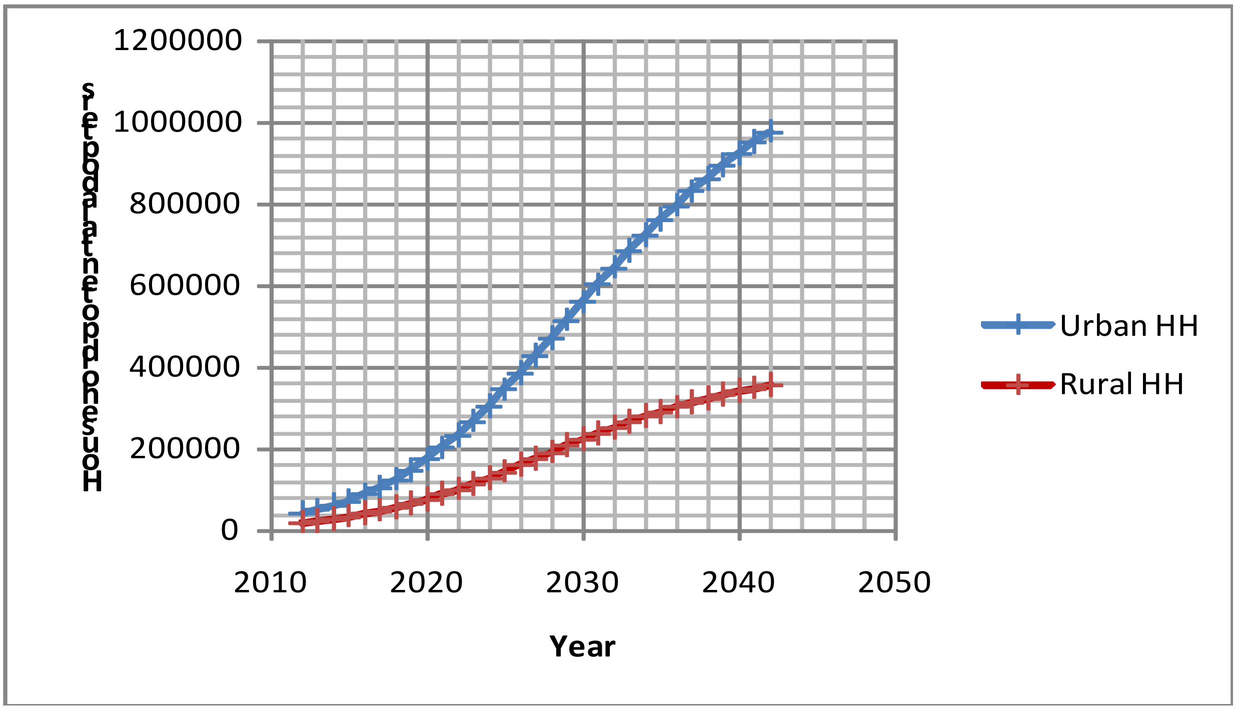
litre and a 30-year period, these adoption curves provide a means of determining the number of households adopting ethanol each year. Using this approach to model adoption over periods from 10 to 30 years, it was estimated that availability of ethanol in the price range of 20 - 35 US cents per litre 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. For the subsequent analysis, a 30 year adoption period was applied in order not to be over-optimistic about adoption rates. It should be noted that over this length of time other forms of energy may become more competitive (eg. second- generation biofuels), however the relative price of LPG is unlikely to fall because of limited global supply, and international experience shows that electricity is adopted late for cooking because of its high relative cost.

Financial Analysis of Ethanol Micro-Distilleries

51. In order for 120-litre per day micro-distilleries to meet the demand for ethanol shown in Figure 2.3, a total of almost 2,000 micro-distilleries would be required after 10 years, over 6,000 after 20 years, and over 10,000 micro-distilleries after 30 years. The total cost of constructing these micro-distilleries over a 30 year period, calculated on an average cost of $21,380, is approximately $215 million. A financial analysis was conducted for an ethanol micro-distillery plant, producing 120 litres per day, using the four production scenarios detailed below:

- Scenario 1: Low cost feedstock, with by-products
- Scenario 2: Sugarcane, with by-products
- Scenario 3: Low cost feedstock, without by-products
- Scenario 4: Sugarcane, without by-products

Figure 2.3: Households adopting Ethanol at 35 US cents per litre over 30 years



52. The by-products produced in ethanol production include feed for animals and fertilizer for high-value crops, which can be sold at approximately 10 US cents per litre of ethanol produced, creating an additional revenue stream for the micro-distilleries. Low cost feedstock assumes that crop waste is used in production of ethanol, which the model assumed is available at $4 per tonne, while sugarcane costs $15 per tonne (this is partially offset by the fact that sugarcane is a more efficient feedstock, providing more ethanol per unit than the low cost feedstock). Fermentation of many alternative feedstocks has to varying degrees been explored in the laboratory and tested in the field, but what is less well understood is the scalability of these feedstocks and how they would be managed and handled. Given these unknowns, while low cost

feedstocks are included in this analysis, subsequent sections of this report focus in more detail on ethanol production from sugarcane.

53. Where industrial sugar operations produce large amounts of molasses, this may be available cheaply for purchase and is an excellent feedstock for ethanol production. However, ethanol produced directly from sugarcane delivers a higher yield of ethanol per land area than ethanol from molasses – about ten times the ethanol can be manufactured per hectare by processing ethanol directly from sugarcane.[28] Although small scale sugar production is possible, this would require significant new investment and the establishment of new markets, supply chains and delivery channels, as the existing small scale cultivation of sugar cane in Madagascar is principally orientated towards the production of beverage alcohol.

54. The analysis was run for the four different scenarios to identify the price of ethanol at which micro-distilleries generate a positive Net Present Value (NPV). Discounting the production of ethanol and by-products at a rate of 10% over 30 years provided the break-even ethanol prices and payback periods summarized below. As Table 2.4 indicates, 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. At 35 US cents per litre, the three scenarios with a positive return generate internal rates of return (IRRs) of between 15% and 251%.

Table 2.4: Break-Even Price of Ethanol for Micro-Distilleries

Scenario	Price of Ethanol	Payback period
Low cost feedstock, with by-products	$0.14	10 years
Sugarcane, with by-products	$0.26	11 years
Low cost feedstock, without by-products	$0.34	10 years
Sugarcane, without by-products	$0.46	10 years

[28] Horta 2004 gives these equivalencies: One tonne of sugarcane will yield 6 liters of anhydrous ethanol (~7 liters hydrous) through the sugarcane to molasses to ethanol pathway (with sugar as the primary product). One tonne of sugarcane will yield 75 liters of ethanol through the direct sugarcane juice to ethanol pathway. The relationship is therefore about ten to one. (Horta, L.A., 2004, Aspectos Complementarios para la Definición de un Programa de Bioetanol en América Central. Proyecto de Uso Sustentable de Hidrocarburos. Convenio CEPAL/República Federal de Alemania. LC/MEX/R.857)

Chapter 3: REDUCING EXPOSURE TO HOUSEHOLD AIR POLLUTION IN MADAGASCAR

I. Addressing the Household Air Pollution Health Risk: International Experience

55. The WHO estimates that there were 1.96 million premature deaths and around 41 million Disability-Adjusted Life Years (DALYs) lost globally in 2004 due to Household Air Pollution (HAP)[29]. Of these deaths, some 550,000 were in the African region. Exposure to HAP from unprocessed solid fuels nearly doubles risk of pneumonia in children less than 5 years old. Although Africa accounts for only 20% of the world's population, it suffers around half of all deaths from pneumonia for children under five years. Evidence for these disease burden estimates comes from studies on childhood pneumonia and Chronic Obstructive Pulmonary Disease (COPD) and lung cancer from major research studies worldwide. HAP is also associated with low-birthweight and other adverse pregnancy outcomes (e.g. stillbirth), and there is also growing evidence of links with active tuberculosis, Ischaemic Heart Disease (IHD), asthma, and middle ear infection in children, nasopharyngeal and laryngeal cancer, and cataract in adults.

56. One of the most important components of solid fuel smoke, and a good indicator of the health damaging effects of this smoke, is small particles. Specifically, $PM_{2.5}$ is a measure of the levels of tiny particles (less than 2.5 microns in diameter) that get deep into the lungs causing ill-health, and which are commonly measured in studies and monitoring of air pollution. For this reason, $PM_{2.5}$ has been selected as the key measure of household air pollution in this study. Carbon Monoxide (CO) has also commonly been measured in studies of household air pollution, often as a proxy for exposure to small particles, as the latter are difficult and expensive to measure on people as they go about their daily activities, and almost impossible to measure in young children. More recently, evidence is emerging that it is not only acute exposure to high levels of CO that is dangerous to health: long-term exposure to moderate levels of CO also appear to be implicated in causing systemic changes, such as oxidative stress, which can affect the lungs and other organ systems.

57. As very few studies have been done looking directly at the health impacts of various energy interventions, it is necessary to compare the various interventions in terms of their capacity to reduce smoke, but this makes the assumption that people will have enough money to purchase them, and having purchased them, will use them. Nevertheless, studies suggest that chimneyless improved woodstoves reduce the levels of particles by around 40%-50% and CO by around 40%. A similar picture is found in other parts of the world that use large chimney stoves, where levels of CO are reported to be reduced by up to 90%, and $PM_{2.5}$ by around 60%[30].

58. Using LPG or ethanol stoves should, in theory, reduce the levels of $PM_{2.5}$ to virtually zero, but this seldom happens in practice as people use a mixture of stoves and fuels, when they are available. Reductions of around 64%-94% were reported for ethanol stoves in Ethiopia, whilst levels of CO in Ethiopia dropped by around 75%-80%, and by 72% in Kenya (where LPG was the fuel of choice for most study households).

59. Some studies, where personal exposure was measured, have found that personal exposure reduces proportionately less than area pollution. For example, within the Maasai community in Kenya, a 75% reduction in 24-hour mean kitchen $PM_{2.5}$ and CO was associated with a 35% reduction in women's mean 24-hour CO exposure. Similar proportionate reductions were found for women and children using wood stoves in Guatemala.

60. Switching from wood, dung or charcoal to more efficient modern fuels, such as kerosene, LPG, biogas and ethanol, brings about the largest reductions in HAP. In many poor rural communities access to these alternatives is limited and biomass remains the most practical fuel. Biomass improved stoves that are adequately designed, installed and maintained can reduce HAP considerably. Stove location, housing construction and better ventilation are partial remedies. Changing behaviours can contribute; drying wood improves combustion and lowers emissions, using pot lids cuts cooking time, and exposure of young children can be reduced by keeping them away from polluted kitchens (if this is safe).

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[29] Source: http://www.who.int/quantifying_ehimpacts/global/globalair2004/en/index.html

[30] Results from stoves with chimneys must be treated with caution, as households tend to maintain chimneys well during project periods, but long-term evidence from earlier programmes indicate that these levels of maintenance are not always maintained. Chimneys that are not cleaned block up rapidly.

61. Nevertheless, care should be taken in attributing specific reductions to specific stoves, as the same stove can perform very differently at different times, locations and with different users. Changes in HAP and personal exposure measurements are influenced by factors such as how long the stove was installed before monitoring, the availability of appropriate fuel, stove maintenance and user support, the time spent by the cook in the kitchen, and the need for space heating. Percentage reduction of pollutants is dependent on the baseline level, and this can vary significantly even from household to household. This means that even the same stove can give quite different estimates of performance when employing this frequently used measure.

II. Survey of a Household Ethanol Program in Ambositra and Vatomandry

62. To determine the health implications of a household ethanol program in Madagascar a HAP intervention was carried out in two Malagasy locations: (i) Ambositra in the central highlands, and (ii) Vatomandry on the coast. The intervention and survey consisted of four primary tasks:

- Sample selection
- Air quality and personal exposure monitoring
- Household survey
- Health overview

63. Using a 'before, after, after' study design, the effects of household ethanol use with raised awareness about kitchen smoke were evaluated in comparison to the effects of 'improved' stoves and increased awareness. Each study site also included a control group that received no intervention or exposure to the awareness raising campaign. The total baseline sample size was 180 households in Vatomandry and 144 for Ambositra. The fieldwork was led by two international consultants, assisted by two Malagasy health professionals and four local surveyors, recruited and trained at each site. The same team performed baseline monitoring, increasing consistency of methods and reducing training costs.

64. A series of stove performance and usability tests were conducted to determine whether the ethanol intervention stove would be safe and effective. Complimentary laboratory tests were also conducted at the Aprovecho Research Center in Oregon, USA. Testing results revealed that the stove originally selected for the intervention presented significant performance and safety risks. As a result the CleanCook stove (which already had several years of user experience in other African countries) was adopted.

Methodology

65. The following criteria were used to identify households within the target study group:

- 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

66. A structured questionnaire, administered at interview by trained field staff, was used to collect information from participants on their household energy use, health status, and economic status as well as baseline information required to evaluate health status for participant and child. These included some health and safety outcomes that could be assessed in the context of this relatively small, short-duration study.

67. Baseline household kitchen concentrations of $PM_{2.5}$ and CO were measured in every study household. The air samplers and real-time monitors were placed in the kitchen area over a 24-hour sampling period. Personal exposure to CO was also measured for the mother (primary cook) and a child under 4 over a 24-hour period as a proxy for PM exposure. Carbon monoxide was used for this purpose as monitoring $PM_{2.5}$ is cumbersome and inconvenient for adults, and impractical for young children, and the use of CO as a proxy has been shown to be effective in other studies. This same set of kitchen and personal monitoring was performed in the two post-intervention phases.

68. 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. As it was not feasible within the time-frame and resources available to measure ALRI incidence directly, this study used changes in exposure of children to estimate impacts on local ALRI rates using available evidence on the relationship between exposure levels and risk of ALRI.

69. A structured questionnaire was used to collect information from participants on their patterns of household energy use and cooking habits. The households that had received a project stove were asked about their initial experiences and perceptions of the stove. The results provided in this report are drawn from all three rounds of sampling: baseline, first 'after' round and second 'after' round. The full study data set allows reporting on the final results of the impacts of the various interventions on HAP, personal exposure and health. A thorough assessment of (and adjustment for) confounding factors has also been carried out.

70. HAP data were analyzed using both paired "difference in difference" tests as well as through statistical modelling using Generalized Estimating Equations. The Round 2 and Round 3 intervention groups were first compared to the baseline. Absolute HAP differences and percent differences were also determined, and tests of significance were performed for each comparison within each intervention groups (ethanol, improved charcoal, improved biomass, and awareness). Generalized Estimating Equations with robust standard errors and an exchangeable correlation structure ("xtgee") were used to assess the population level effect of each intervention on 24-hr average CO and $PM_{2.5}$ concentration. Each study site, Ambositra and Vatomandry, was analyzed separately due to the large differences in air pollution concentrations. The model accounted for differing starting fuels within each intervention group and adjusted for the location of the kitchen, which was found to be a significant covariate.

71. As $PM_{2.5}$ was not directly measured on women and children, regression analysis was used to predict values for each person, at each round, based on their measured CO values. The regression equations used to carry out this prediction were obtained from information on CO and $PM_{2.5}$ measured at the same location in the kitchens of a sub-sample of homes, in each round of the study. Data were collected on groups of homes representing wood, charcoal and ethanol users, as the relationship between CO and $PM_{2.5}$ differs between fuel types.

72. Analysis of personal exposure was carried out by testing differences in average exposure levels to CO and predicted $PM_{2.5}$, both between group (at each round) and within group (across rounds). In order to allow for baseline differences (in exposure and other potential confounding factors), and also changes in exposure determinants across rounds, a random effects multiple regression model was used incorporating both fixed variables (e.g. personal and household characteristics that would not change over time) and time-varying variables (for example season: wet/dry). A similar approach was used to assess the impact of the interventions on health outcomes (eye irritation, headaches and burns).

Household Allocation and Follow-Up

73. Households were allocated as close to a random schedule as possible, given the constraints imposed by homes having to use a fuel suitable to the intervention (for example wood users needing a biomass stove). Overall there was 13.2% (n=20) loss to follow-up in Ambositra and 14.4% (n=27) in Vatomandry between the baseline and the first "after' sampling. The reason for most of these losses was that the participant had moved away. Neither the extent of losses (13-14%), nor their characteristics, suggests very substantial bias. The higher rate of loss to follow-up among users of traditional charcoal stoves compared to wood stove users in Vatomandry should be kept in mind when interpreting results. Analysis showed no significant differences in key characteristics between the 17 new control group households and those lost to follow-up.

74. Loss to follow-up was much less significant between the two rounds of 'after' sampling, as these occurred within four months of each other. A further 3 households from Ambositra and 7 from Vatomandry, lost between the Round 2 data collection and the final round (Round 3), gave an overall loss to follow up of 14.9% (n=23) in Ambositra and 18.1% (n=34) in Vatomandry. The percent loss to follow-up allowed for in the sample size calculations was 20%.

III. Results of Household Surveys

Project Stove Use and Perceptions

75. All participants in the stove groups were asked about their perceptions of their stoves at Round 2 within a period of 3-6 weeks of receiving the stove, and again five months after receiving the stove. The collected data confirmed the positive responses and widespread adoption of the project stoves. In Round 2, despite the short time frame, at least 80% in each study group used the project stove as their main stove. These levels reflect a high rate of initial adoption, particularly adjusting to a new stove, and more significantly, a new fuel for the ethanol group. Round 3 data is a more representative reflection of how the project stoves met the households' cooking needs. After five months of use, at Round 3, 97% of the ethanol stove households in Ambositra reported that they used their ethanol stove as the main stove; this was lower in Vatomandry at 77%. The charcoal stove was used as the main stove at consistently high rates, with 100% of the charcoal group using it as the main stove at both study sites by Round 3. The improved biomass stove was being used as the main stove by 93% of the intervention group in Vatomandry.

76. At Round 2, many households expressed a need for a secondary stove. Use of a secondary stove was significantly different between study groups, with the ethanol stove households reporting a higher use of a secondary stove than the other groups in both study sites: (84.4% Round 2 and 80.6% by Round 3 in Ambositra and 75% at Round 2 increasing to 83.9% at Round 3 in Vatomandry). This may reflect the transitions in kitchen management needed to integrate a very different type of stove and fuel.

77. At Round 2, more than one third of households reported that the ethanol stove was not able to cook all of the food types they wanted but by Round 3 this decreased to 29.0% in Ambositra and 22.6% in Vatomandry. Cost may be another contributing factor, as at Round 3 a lack of access to fuel due to insufficient funds and inability to get to the store had stopped a small number of participants using their stove. A survey question which asked "Do you have any problems getting enough fuel for your needs?" revealed that in Ambositra the ethanol shop is often closed or the wait inside the store is sometime unacceptably long. There were fewer problems reported by the biomass and charcoal users at both sites. The majority of households that received a project stove (92.1% in Ambositra and 87.6% in Vatomandry) believed the new stove to be a bit or much better than their previous stove. The results were more favourable for the ethanol stoves.

78. Questions about robustness show that 6.5% of the charcoal stove users in Ambositra and 21.9% in Vatomandry reported that the liner within the stove broke within the short time since installation. There was no one particular problem experienced with the biomass stove, but 18.2% felt it was dangerous due to the chimney getting hot and potentially causing a house fire. These issues were raised again at Round 3 when the participants were asked if they would make any changes to the stove. Table 3.1 shows the number of participants who would make changes and examples of the changes they would make. The comments were similar from both sites.

Table 3.1: Study Households suggesting Stove Changes

Stove	% (N)	Suggested changes
Ethanol stove	27.4 (17)	Two burner stove and increase the size
Wood Stove	15.1 (5)	Increase number of pot stands. Reduce the overall size of the stove
Charcoal stove	29.0 (18)	Stove is too small. Needs a stronger liner. Needs a two pot capacity.

79. In terms of safety, a small number of households (7.9%) from both study sites) thought the charcoal stove was dangerous, citing general fire/ cooking safety reasons that were not particular to the study stove. The biomass stove clearly caused some concern to the households using it; 18.2% felt it was dangerous due to the chimney getting hot and potentially causing a house fire. This persisted at Round 3 with 12.1 % still fearful of house fires started by the stove. By Round 3, 11.3% households over both sites believed the ethanol stove to be 'a bit dangerous'. Fear that the pot might fall off the stove and that, on

occasions, flames would continue to burn when the stove was turned off were two examples of why the households thought the ethanol stove was more dangerous than their previous stove.

Air Pollution Monitoring

80. Key measures for monitoring indoor air pollution are $PM_{2.5}$, which measures the weight of tiny particles (less than 2.5 microns in diameter) in the air, and carbon monoxide (CO). The two pieces of equipment for monitoring these parameters are set close together at a fixed distance from the stove. A second CO monitor affixed to the cook measures the amount of CO she inhales; this is largely used as a proxy measurement for her inhalation of particles, although it is now understood that CO is a dangerous gas even at lower dosages than those that produce immediate health effects. The ethanol stove reduced kitchen $PM_{2.5}$ and CO levels in both locations by a significant level from the baseline, as highlighted in Table 3.2.

Table 3.2: Estimated Household CO and PM Changes from Baseline in Ambositra and Vatomandry

Estimated change from baseline in 24-hr average kitchen concentrations for CO (ppm) and $PM_{2.5}$ (ug/m^3) for ethanol treatment group in Ambositra and Vatomandry (p-values)				
	Ambositra		**Vatomandry**	
	Ethanol (wood baseline)	**Ethanol (charcoal baseline)**	**Ethanol (wood baseline)**	**Ethanol (charcoal baseline)**
CO	NA	-79% (<0.01)	-93% (0.01)	-93% (0.02)
$PM_{2.5}$	NA	-57% (<0.01)	-85% (<0.01)	-72% (<0.01)

81. 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 $PM_{2.5}$ of 35 µg/m3, while in Ambositra they were approximately four times this target. An increase between Round 2 and 3 in reported supplemental fuel mixing or primary fuel substitution was observed in the ethanol group and may explain the slight increase in CO and $PM_{2.5}$, to varying degrees, across both locations.

82. The improved wood stove (used only in Vatomandry) also showed an ability to reduce kitchen CO by approximately 63% and $PM_{2.5}$ by an estimated 66% at significant or near significant levels. The reductions were not as dramatic as with the ethanol stove, and the average $PM_{2.5}$ concentration was not close to the WHO Interim Target 1 in either round. The improved charcoal stove was not effective at reducing average kitchen CO or $PM_{2.5}$ concentrations in either Ambositra or Vatomandry

83. Awareness-raising had no effect on Round 2 and Round 3 kitchen $PM_{2.5}$ or kitchen CO in Ambositra compared to the baseline. In Vatomandry, where awareness-raising was conducted in both wood and charcoal-using households, a significant reduction in $PM_{2.5}$ was measured among wood users, but no effect was detected for charcoal users. No effect of awareness-raising on 24-hr average kitchen CO concentrations was measured in Vatomandry, regardless of fuel type.

84. Neither of the control groups at either location showed a significant change in kitchen concentrations for either pollutant between Rounds 1, 2, and 3, suggesting conditions remained generally constant over time and that there was little or no contamination of the control groups by any of the interventions.

Exposure Monitoring and Health Observations

85. In both study sites, compliance with the use of the CO diffusion tubes used for measurement was good overall, with around 90% or more of women and 91% of children found to be wearing the monitor

when the fieldworker arrived at the home on Day 2. These levels were maintained across both post-intervention rounds. The overall impacts of the ethanol intervention on personal exposure to CO and $PM_{2.5}$ (predicted) are shown in the Table 3.3. These are derived from the multiple regression analyses and allow for any baseline differences between groups, and for confounding factors. It should be noted that in both Ambositra and Vatomandry, at least 80% of the households in the ethanol intervention group also used a charcoal or wood stove for some of their cooking, so it can reasonably be assumed that exposure reductions would have been even greater if all households had used ethanol exclusively. There were insufficient numbers of 'pure' ethanol-using homes to study exposures in this group.

Table 3.3: Overall HAP Personal Exposure Impacts of the Ethanol Intervention

Percentage reductions in CO and $PM_{2.5}$ exposure compared to the control group for the ethanol user groups. All reductions, apart from CO (child) in Vatomandry, are statistically highly significant ($p<0.005$)

	Ambositra		Vatomandry	
	Mother	Child	Mother	Child
CO	-74%	-64%	-53%	-35%
$PM_{2.5}$	-62%	-63%	-44%	-47%

86. For adult exposure in Ambositra, only the ethanol group showed any substantial reductions, as measured by CO and predicted $PM_{2.5}$. Charcoal and awareness groups showed small, non-significant reductions compared to the control group. This pattern was reflected in a very similar set of results for child exposure (CO) in Ambositra, although there were marginally significant reductions in childhood exposure in the improved charcoal group.

87. Levels of CO exposure, and consequently predicted $PM_{2.5}$, were much lower in Vatomandry than Ambositra. For adult exposure, ethanol, improved charcoal and improved biomass stoves all showed significant reductions in predicted $PM_{2.5}$ in comparison with the control group (although only biomass and ethanol did so for CO). The largest reduction in predicted $PM_{2.5}$ was seen for the ethanol group. For child exposure in Vatomandry, a very similar pattern was seen, with both ethanol and improved biomass having similar impacts on predicted $PM_{2.5}$ exposure.

Outcomes of HAP Survey

88. Despite a number of challenges, allocation to groups, follow-up, and the rate of dropouts was satisfactory. Any differences in socio-economic characteristics between groups have been taken account of in the summary regression analyses. The data quality was good, and compliance with procedures including wearing of CO diffusion tubes was also at a level that should have avoided any major bias. Reductions in air pollution and personal exposure in Ambositra were only seen for ethanol. In Vatomandry, however, the improved wood stoves resulted in similar exposure reductions as ethanol, with lesser reductions for improved charcoal. The awareness group did not experience reductions in either site. While households generally liked the ethanol stoves, in practice around 80% continued to use either a charcoal or wood stove for some of their cooking tasks. Not only did this compromise the HAP and exposure reductions in this group (which may have been even greater without this secondary stove use), it also emphasises that – at present – the stove technology and arrangements for obtaining fuel are not meeting all needs.

Other Health Considerations

89. In the baseline survey, assessment was made of the frequency of respiratory and other symptoms, and of burns in cooks and children. For the women, the level of chronic respiratory symptoms (chronic cough and phlegm), reported by around 20% of wood users (Vatomandry only) was of concern. Headache

and eye irritation were common, and consistent with patterns of fuel use. Burns and scalds to cooks were also common, occurring repeatedly for many women. There is a very low prevalence of smoking among the women, and although other family members smoke at home in a substantial minority of homes, there was no strong evidence that this had influenced personal exposure levels of women or their children.

90. Due to the relatively small numbers in each intervention group, the study did not plan to assess respiratory symptoms at follow-up. Symptoms of headache, eye irritation and burns, being more common, were however monitored for the women during follow-up. For children, there was clear evidence of a problem with burns and scalds, with around one-quarter of parents reporting that their child under 5 years had been burned or scalded at least once in the prior 12 months. It was not possible from the data available to assess the true severity and longer-term consequences of these injuries, although between 10 and 15% of cases left a scar larger than a 10 Ariary coin.

91. The follow-up phase of the study examined the frequency of headaches, eye irritation and burns in women and frequency and severity of burns in children. Mothers were also asked about their level of anxiety regarding the risk of children being burnt in the kitchen. 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. There was also a non-significant reduction of burns in children. Of the other groups in Ambositra only the improved charcoal group showed benefits, which were seen for headache, eye irritation and burns in adults. However the reductions in risks were generally less than those seen for the ethanol groups. 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[31].

92. At end of the follow-up period the women respondents were asked about their impression of the overall impact of the intervention, and whether it had beneficial, neutral or negative effects on the health of the family. In Ambositra the most positive 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 again 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).

[31] The issue of ingestion of fuel was also considered, as it presents a potentially serious risk of lung injury particularly with kerosene. The risk of ingestion of ethanol is less well documented, although anecdotally we understand children are less likely to drink it. The fact that both of these liquid fuels are purchased and stored in soft drink bottles requires attention.

Chapter 4: ECONOMIC IMPACTS OF ETHANOL AS A HOUSEHOLD FUEL IN MADAGASCAR

93. The financial analysis presented in Chapter 2 assessed the competitiveness of ethanol as a household fuel, and potential returns to investment in micro-distilleries. This chapter expands on this analysis to look at the wider economic benefits of ethanol as a household fuel, including health benefits, avoided deforestation, and time savings.

94. This analysis focuses on the production of ethanol using sugarcane micro-distilleries with the sale of by-products, over a 30-year period to full market penetration. As shown in Table 2.7, the break-even price of ethanol for a sugarcane micro-distillery with the sale of by-products is estimated to be 26 US cents per litre. A higher price would be necessary to ensure a normal return on investment, and to allow for some variation in the sale price of by-products. Consequently, unless otherwise indicated, the following analysis assumes a price of 35 US cents per litre of ethanol, adopted as a household fuel at the rate shown in Figure 2.3, and applies a discount rate of 10% to the associated benefits over a 30-year period.

I. Valuing the Health Benefits of Ethanol as a Household Fuel

95. As the study could not, within the time-scale and resources available, study the direct impact on the major health outcomes associated with reduced exposure to HAP, these were modelled using methods of the Comparative Risk Assessment (CRA) of the Global burden of Disease[32], which provides estimates of reductions in childhood ALRI, as well as adult COPD and IHD based on a 90% reduction in exposure to HAP. This represents a more complete transition to clean fuel at the household and community level than observed during the household survey conducted for this study, but this may be more representative of a longer-term, larger-scale program to promote ethanol as a replacement for solid biomass household fuels. Using this approach, the avoided loss of 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. This figure was then scaled up by the estimated total number of households switching from charcoal to ethanol stoves each year, and multiplied by the Gross National Income per capita ($484 per year). These calculations result in a total of 442,000 DALYs saved over the 30-year period, equivalent to a total discounted value of US$34 million.

96. The analysis was not able to take account of avoided treatment costs associated with disease, due to lack of relevant data; however, a WHO global study on the economic benefits of alternative fuels found that, in the WHO sub-region for Madagascar, the health care savings as a proportion of overall economic benefits were very small (less than 1%).[33] Also not included in these estimates of deaths and DALYs averted are other health outcomes which have not yet been formally included in the CRA, but for which there is growing evidence of a link with HAP exposure. These outcomes include low birth weight, tuberculosis, cataract, and possibly also lung cancer.

97. Other health issues which were included in the study, notably burns/scalds, and symptoms of eye irritation and headache, are also not formally included in these calculations as suitable summary estimates of risk (in the case of burns) or impact on health (eye irritation, headache) are not available. The importance of these outcomes for health and quality of life should, however, be taken into consideration in assessing the benefits of ethanol as a household fuel.

98. While the improved wood stove used in the household interventions in Vatomandry also reduced exposure to HAP within households, this was achieved mainly by venting the smoke outside of the home. One important consequence of this is that we would not expect community outdoor levels of air pollution to be reduced, and consequently, reductions in personal exposures will never be as great as should be achievable with a low emission stove such as the ethanol stove.

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[32] Smith KR, Mehta S, Mäusezahl-Feuz M. Indoor air pollution from household use of solid fuels. In: Ezzati M et al., eds. Comparative Quantification of Health Risks: Global and Regional Burden of Disease Attribution to Selected Major Risk Factors. Geneva, World Health Organization, 2004:1435–93.

[33] Hutton, g. et al (2006). "Evaluation of the Costs and Benefits of Household Energy and Health Interventions at Global and Regional Levels." World Health Organization.

II. Avoided Deforestation

Valuation using avoided Carbon Emissions as a Proxy

99. 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. This estimate is based on a 2006 USAID reference that states that in 2006 there were 150,000 ha of plantations/managed forests with a productivity of 8 to 10 m^3/ha/yr. Based on this plantations in Madagascar only provide about 1.3-1.6% of all charcoal, with an estimation of a further 8% coming from forests managed by local farmers but not included in these national figures. This equates to approximately 10% of the supply of charcoal and wood coming from managed sources, the replacement of which would not deliver carbon benefits.

100. 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. The avoided charcoal consumption was then converted into its equivalent in wood, assuming a wood density of 0.70 tons/m^3, and operation losses of 15%. If ethanol is adopted as a household fuel at the rate shown in Figure 2.3, then it can be estimated that 127 million m^3 of wood obtained from forests, 90% of which is unmanaged, can be avoided over a 30 year period. This was then further converted into an estimate for reduction in loss of forest, using an average measure of standing wood volume of natural forests of 80 m^3/ha, saving roughly 1.4 million hectares of unmanaged forests, equivalent to approximately 10% of Madagascar's forest[34].

101. For the purposes of assigning an economic value to the avoided deforestation, the forest loss was converted into avoided greenhouse gas emissions using a factor of 418 tons/ha carbon sequestration capacity of natural forests[35], giving an emissions reduction of 585 million tonnes of carbon. This was valued at the market value for a ton of carbon (using a value of $3.39, the average price reflected by the voluntary carbon market) and discounted over the projected ethanol stove adoption period to give an estimated total economic benefit of US$324 million.

Alternative Valuation using Reforestation Costs as a Proxy

102. An alternative approach to valuing the economic benefit of avoided deforestation is to apply the avoided reforestation costs. Using an estimated reforestation cost for degraded land in Madagascar of US$350 per hectare, the total value of avoided reforestation over the 30 year period for adoption of ethanol stoves, discounted at 10%, is estimated at $87.5 million. It should be noted that neither of these approaches provides a separate value for the globally important biodiversity that would be protected through reduced deforestation in Madagascar.

III. Time Savings

103. Ethanol stoves require less time for cooking, cleaning, and fuel collection than when wood is being used as a fuel source; however, as this analysis assumes that ethanol is substituting for charcoal, the benefits of saved time associated with ethanol stoves are estimated for cooking and cleaning only. 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. Each variable provided an estimate that has limitations: the perceived time reductions are based on recall over 5 months and possibly under-estimate the actual amount of time saved; whereas the time with fire alight does not necessarily reflect the time actively cooking at the

[34] FAO 2005 gives forest area of 12.8m ha
[35] Moura Costa, P. (1996): Tropical forestry practices for carbon sequestration. In: SCHULTE, A. & SCHÖNE, D. (eds.): Dipterocarp forest ecosystems. World Scientific: Singapore: 308-334

stove, and may in fact over-estimate the time savings. The estimate presented takes into account these limitations by averaging each measure from each study site.

104. The estimated time saved is valued based on a rural average wage rate of US$1.92 per day. This value was held constant for the full 30 years of analysis, whereas wage rates will likely rise relative to other prices over that period, so the estimated value of the time saved may be an underestimate. Even if the household members who benefit from the time saving do not engage in income-earning activities, the rural wage rate provides a minimum estimate of the opportunity cost of this choice, whether the time is used for leisure or other non-paid activities. The estimated benefits from time savings total $368 million when discounted at 10% over the projected 30 year period for full market penetration of ethanol stoves.

IV. Poverty Reduction through Employment and Reduced Household Labour

105. 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.

106. 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[36]. 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. This is close to estimates of existing unemployment in Madagascar, and therefore must be viewed within the context of labour supply constraints. The economic value of job creation associated with ethanol production was not estimated for inclusion in the model presented here.

V. Availability of Land

107. Although a large scale ethanol household fuel program would have significant benefits the potential environmental damage must also be considered and mitigated. A large amount of land would be required to grow the feedstocks to produce the ethanol, as well as water resources, for irrigating the feedstock crops and for use within the micro-distilleries themselves. Each 120 litre/day micro-distillery requires around 1.5 tonnes of feedstock daily, equating to 495 tonnes of sugarcane feedstock per year (the figure is higher, 660 tonnes, in the case of low cost feedstock). In Madagascar current annual yield of sugar cane per hectare is about 50 tonnes (average in rural areas without intensification), meaning that each micro-distillery can be supplied through 10 hectares of land, assuming the land produces sugarcane annually. To ensure sustainably high yields land often has to be left fallow for some time before replanting, which means that more land might well be required.

108. For 2,000 micro-distilleries, this equates to a total land area of 20,000 hectares required for feedstock growth, for 6,000 micro-distilleries a total required land area of 60,000 hectares, and for 10,000 micro-distilleries a total required land area of 100,000 hectares. It should be noted that the current total arable land and permanent crop area in Madagascar is around 3.5 million hectares[37], so feedstock for household ethanol fuel production would require expansion of this area by about 3.5%. At the same time, this level of household ethanol consumption would displace 127 million m^3 of firewood, equivalent to about 1.6 million hectares of land, which would otherwise be used by those consumers switching to ethanol. The net effect of the switch from unsustainable wood fuel to sugar plantations would mean that over the course of the 30 year projection the total land area required to produce household fuel would be reduced by 1.5 million hectares compared with the business as usual scenario. It should also be noted that some of the land that has recently been deforested for charcoal production might well be suitable for growing suitable ethanol

[36] RWEDP, 1997
[37] FAO 2005

feedstocks and it is recommended that a full bioenergy mapping study be carried out to identify suitable land for feedstocks.

VI. Summary of the Economic Benefits of an Ethanol Household Fuel Programme

109. The findings of the economic analysis are positive across all scenarios (ethanol prices, plant scenarios, and market penetration periods). Using values for avoided deforestation based on avoided greenhouse gas emissions as described above, the total economic benefits range from US$454 million (using sugarcane feedstock without the sale of by-products, an ethanol price of 35 US cents per litre and over a penetration period of 30 years) to US$2.7 billion (using a low cost feedstock with the sale of by-products, an ethanol price of 20 US cents per litre and over a 10 year penetration period). Table 4.1 below presents the range of NPVs of the economic analysis, 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, for each of the four micro-distillery scenarios. The NPVs use avoided greenhouse gas emissions to value avoided deforestation.

Table 4.1: Summary of Economic Analysis NPVs

Scenario	NPV (US$)
Low Cost Feedstock with by-products	708 million
Sugarcane with by-products	625 million
Low Cost Feedstock without by-products	536 million
Sugarcane without by-products	454 million

110. Using this same scenario, the costs and benefits that contribute to the overall economic analysis, can be broken down by category, to give a sense of how they are contributing to the overall total. Table 4.2 reports the total economic benefits over 30 years, discounted at 10%, under a scenario 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).

Table 4.2: Breakdown of Economic Benefits of an Ethanol Programme in Madagascar

Economic Benefit	Net Present Value of Net 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 (the range depends on the valuation approach)	87.5-324
Avoided DALYs	34
Time Savings	368

111. As Table 4.2 shows, households face a financial cost in the price of the ethanol stove itself, as well as the higher cost of the fuel. For rural households, where charcoal costs approximately 10 US cents per kilogram, ethanol fuel prices need to be less than 21 US cents per litre in order for the investment in ethanol to be competitive with charcoal. In urban households, where charcoal is more expensive (17 US cents per kilogram), the ethanol stove is financially viable when the price of ethanol is 37 US cents per litre or less. This financial investment is offset however by the economic returns to households through time savings, improved health and avoided medical costs. Appreciation of these benefits was widely expressed by the women using ethanol stoves as part of the household survey component of this study. It is this significant economic benefit that underlies the willingness of households to pay more for cleaner, more convenient fuels, even if they cannot afford LPG.

Chapter 5: PROMOTING ETHANOL AS A HOUSEHOLD FUEL

112. Chapter 2 discussed the potential market for ethanol as a household fuel in Madagascar, as well as the potential return on investment in micro-distilleries, and Chapter 4 has considered the economic benefits that would be derived from a transition from charcoal to ethanol as the principal fuel for a significant share of Malagasy households. This Chapter examines lessons from African experience with improved stove and fuel programs, then provides institutional and policy recommendations for a program to promote the development of a commercial market for ethanol as a household fuel in Madagascar.

I. Lessons from African Experience with Improved Stove and Fuel Programs

113. Various factors have driven household cooking interventions over the years including health impacts of smoke inhalation, deforestation and desertification, the impact on greenhouse gas emissions from burning solid fuel, and the drudgery, time lost and danger for women collecting firewood and its contribution to maintaining poverty and vulnerability. Initiatives 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.

Fuel options

114. 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 has many advantages. It cooks quickly, is widely available, can be collected at no financial cost, and can be used in its raw state. Nevertheless, it is highly polluting, leading to around 1.6 million deaths per annum, it is responsible for frequent accidents through burns and scalds, and reduces the quality of life for millions of women who spend many hours each week gathering it, preventing them from being gainfully employed.

115. Charcoal is widely used in Madagascar by those in the two most affluent quintiles of Malagasy society, and is most widely used in urban areas. Although it is cleaner in use than woodfuel, it is generally made in rudimentary kilns, a highly inefficient process largely using wood from non-sustainable sources, releasing large quantities of carbon dioxide to the atmosphere. Ethanol, although used for several years in other settings[38], is a very new technology for household use in developing countries. Gelfuel (alcohol converted to a gel using additives), was promoted for some time but it is produces insufficient heat, and the additives generate additional pollutants in emissions.

Stove options

116. Annex1 lists some of the more successful improved stoves that are commercially available at the present time in developing countries. A more complete description is provided in Volume IV.

Fully commercial stoves

117. Of the stoves highlighted, only the KCJ (Kenya Ceramic Jiko), the Upesi (Maendeleo) stoves, and, in some circumstances, LPG sets, are fully commercial. In the case of the Upesi and KCJ stoves, the products benefited from well-supported projects that allowed the creation of a market by providing support to training in manufacture and business services. Economies of scale allowed the product price to become affordable to increasingly large numbers. Using local skills and materials to manufacture stoves can make the price more affordable, but if only locally-sourced stoves are promoted this can slow down the rate of change to cleaner, healthier, technologies for people who might wish to buy them.

118. The most important factor in achieving fully commercial stoves, is 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

[38] http://www.dometic.com/42ab8c84-8aee-4c39-9557-c6286ee461f1.fodoc

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. Overlooking this requirement has led to thousands of stoves being installed worldwide that only benefit those producing them.

Semi-commercial stoves

119. Between a completely commercial operation, and a project with a limited time frame where the stoves are either given away, or sold below cost, are commercial operations which nevertheless have the support of NGOs, or governments. This arrangement can be very successful, and appears to be a useful interim step to complete commercialization, distribution and long-term sustainability. It provides a good model for how to move from project to commercial business.

120. In the case study on LPG stoves in Sudan for example, a subsidy is still provided to support and train the women's organisations running the businesses that sell LPG sets, supply fuel and provide soft loans even though they are also sold through other outlets commercially to those on higher incomes. This provides a model that could be adopted for ethanol stoves and fuel. 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. A similar example is provided by the Vesto stove, manufactured by New Dawn engineering which brings in external finance and supports training, development and promotion.

121. The Ugastove benefits from carbon finance to subsidise its cost and make it affordable. Ethanol stoves are also well-placed to benefit from carbon finance as greenhouse gas emissions and pressure on forests is reduced, particularly where agri-wastes can be used as feedstock. Two stoves that work on similar principles – the StoveTec stove and the Envirofit stove - use 'rocket stove' principles. Although they use wood, a key factor with these stoves is the attractive 'modern' design which, along with heavy promotion in the case of the Envirofit, has led to widespread adoption. In Central America, two chimney stoves, the Onil and Ecostove stoves use a 'rocket principle' to increase energy output and reduce emissions. They require consistent and on-going support to consumers in the early days if they are to work efficiently. Regular visits by NGO staff ensure that they are being properly maintained.

Interventions that failed to achieve sustainability beyond the project life

122. Failure of some ethanol stoves can be attributed to several factors. The use of gelfuel, initially heralded as the fuel of the future, led to stoves, such as the SuperBlu, being promoted that were not appropriate to the target market. Putting additives into ethanol to make it gel produced a fuel that did not vaporise readily, slowing down the combustion process and preventing sufficient mixing of combustible vapour and air. This provided a slower, cooler flame that is less useful for cooking, although the fuel is still in use for occasional space heating. This stove also suffered some quality and safety issues. The CookSafe stove of South Africa performed well in tests in this study, but no longer appears to be in production as a household stove.

II. Roles of the Government, Private Sector, and Civil Society

123. 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, where broader economic benefits can be achieved (as demonstrated in Chapter 4), these provide a rationale for Government support to overcome initial barriers to adoption, including through support for demonstration pilots and access to credit.

124. A further role for Government is in facilitating partnerships between government bodies (environment, agriculture, forestry, energy, and trade and industry), 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. In terms of finance, governments should seek to provide information,

harmonize subsidies for all fuels to create a level playing field, and facilitate carbon finance acquisition[39]. Finally, generating demand for unfamiliar clean fuels can be a major barrier to private-sector involvement and to successful uptake. The Government has an important role to play in education and raising public awareness. Champions within key institutions can have a profound impact on the success of such initiatives.

125. 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. The private sector can provide choices of technology for households with different levels of income, while meeting national standards for fuel quality, as well as stove safety and efficiency, applying a commercial approach to scaling up, and leveraging finance, including carbon finance, for stove purchase. While a commercial approach is essential to the long-term success of any improved stove, most such initiatives have the support of NGOs in the early stages, particularly for training in business skills and financial management.

126. Products must perform well within the context of the household into which they are installed. The very best technology, if it is not acceptable to the cook, has zero effectiveness. There are countless examples of good technologies lying unused as they do not fulfil the needs of those for whom they were designed, for lack of consultation. Those living in poverty do not have the luxury of adopting goods or services which do not address their needs. 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. Similarly, the technology adopted for micro-distilleries should incorporate best international practice to ensure the efficiency and yields necessary to attract local investment, while at the same time minimizing environmental impact through the use of bagasse and agricultural waste as fuel, and the conversion of distillery waste into saleable by-products.

127. 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. Where projects are instigated by international organisations, local NGOs are vital in learning about problems or issues that beneficiaries might not wish to divulge to those outside the community. NGOs can act as 'honest brokers' who can act on behalf of a community, negotiating with banks, or local authorities on behalf of the community they serve.

III. Promoting Ethanol as a Household Fuel in Madagascar

128. 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.

129. The realization 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.

[39] The need for a well-researched and accepted set of baseline data for carbon finance in each country has been identified with some of the successful businesses mentioned in this report. This would reduce the amount of investment needed by each company and project setting up carbon finance. A government-led initiative to establish these data would facilitate obtaining carbon finance for the country involved.

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.

130. Nevertheless, as this study has shown, the development of ethanol as a household fuel in Madagascar appears financially viable and economically beneficial, in addition to being environmentally attractive and offering significant health benefits. The argument is further strengthened by the opportunity to revitalize the sugarcane industry. The final sections of this chapter discuss a series of design, policy and programming considerations that will be important to ensure the success of Malagasy efforts to promote ethanol as a household fuel.

Design Considerations: Producing and Delivering Ethanol for the Household Market

Scale of Production

131. There is significant investment interest in Madagascar for large-scale distilleries producing ethanol for export. Internationally-traded ethanol prices in 2011 were more than double the 35 US cents per liter estimated in Chapter 2 as a reasonable domestic price for micro-distillery ethanol sold as a household fuel. In the absence of government intervention, this price differential will deter the domestic sale of ethanol from large-scale distilleries. However, the regional commodity market requires bulk to compete advantageously, and consequently does not represent a realistic alternative market for micro-distilleries.

132. At the same time, micro-distilleries offer a number of real advantages for ethanol production for the local market. Micro-distilleries are not just scaled-down large plants; they are small plants engineered for simplicity, efficiency and size. The advantages of small-scale ethanol production, as demonstrated by the development of micro-distilleries in a number of countries (in particular Brazil[40]) include:

- Investment cost per liter of alcohol is approximately one third that of bigger conventional plants;[41]
- Considerable economy in fuel due to a reduction in the transport of both cane and alcohol;
- Simplicity of operation, avoiding the need for highly qualified personnel;
- Decentralization of job opportunities and a better spread of income, helping to settle labor in the rural areas;
- Energy security benefits from the decentralization of domestic fuel production points.

Supply Lines and Geographic Targeting

133. In any biofuel system, whether solid fuels like wood and charcoal or liquid such as ethanol, materials handling and delivery is a major part of the price build-up of the fuel and its life cycle energy efficiency. Producing fuel ethanol in place of *toaka gasy* and installing local integrated micro-distilleries to handle the production of many small farmers changes the way in which feedstock is handled and the product is marketed. Delivering cane from the fields to the distillery becomes a more extensive operation than for artisanal production of *toaka gasy*. Once cut, cane should be processed the same day to assure minimal loss of sugar in the stalk. Therefore, the area from which the distillery can receive feedstock is defined by the delivery times and cost to bring the cane to the distillery.

134. The location of micro-distilleries, at least in an initial phase, will need to strike a balance between proximity to feedstock and a market. It is probably most feasible to begin the commercialization of stoves and ethanol fuel in small urban markets which offer the advantages of more developed infrastructure, established supply chains, and consumer bases. Purchasing power and the comparative cost of other fuels will also be higher in urban settings, providing ethanol with more of a competitive advantage vis-à-vis other

[40] A recent example is a Brazilian study that used the Usinas Sociais Inteligentes (USI) micro distillery as the object of its study. See: Rosado Júnior Adriano Garcia, Coelho, Hilton Machado and Feil, Norton Ferreira. 2008. Análise da viabilidade econômica da produção de bio-etanol em microdestilarias. Universidade Federal do Rio Grande do Sul.

[41] For the same initial investment as that of one 120,000 litre per day conventional distillery, one hundred and forty-seven (147) micro-distilleries, producing a total of 352,000 litres per day, can be installed. Hulett, Deon. 1981 - The Development of a Micro Distillery for Fuel Alcohol in Brazil. Proceedings of the South African Sugar Technologists' Association, June 1981.

fuels. Further, cleanliness and convenience, efficiency and time savings are key advantages of the ethanol stove and fuel that are likely to motivate consumer decisions first in urban households. Given the need to also establish a micro-distillery near a good feedstock opportunity, initial locations are likely to be near rural market towns where population density is conducive to efficient delivery of the fuel. Under the right circumstances, fuel does not even have to be delivered - consumers can come to the distillery to purchase the ethanol from a metered pump located at the distillery.

Outfitting Distillers of Toaka Gasy *to Make Fuel Ethanol*

135. For farmers or artisans already running *toaka gasy* distilleries, two approaches seem possible: (i) they could sell their ethanol-water mix to a modern micro-distillery for further distillation, or (ii) they could upgrade their own equipment to produce fuel ethanol cost effectively. While the second option offers significant environmental gains, the former represents business-as-usual. Artisanal stills require a lot of energy, usually firewood, and the distillation is crude and inefficient. Creating a program to upgrade artisanal stills would offer advantages, both in fuel production and in the reduction in the use of fuelwood.[42] However, a substantial improvement over upgraded artisanal operations would be provided by installing integrated micro-distilleries sized to achieve some economy of scale.[43]

Establishing a Supportive Policy Framework

A Cautious Approach to Subsidies

136. National cooking fuel subsidy programs are enormously expensive, benefit the rich more than the poor, and eventually have to be abandoned. Development of a fully commercial ethanol fuel market from the outset will protect consumers from the eventual shock of government withdrawing its subsidy. If subsidies are to be added to a program to promote rapid uptake of ethanol fuel and the stoves necessary to burn it, then the subsidy should be applied to the stove rather than to the fuel for a number of reasons, including the following:

- A subsidy is paid once per stove, while the subsidy is paid on each increment of fuel. For a 10-year stove, a subsidy on fuel would be paid more than 3,600 times. If a $10 or $20 subsidy is paid on the stove, this makes a meaningful difference. If the same subsidy is applied to the fuel, it would not be meaningful. Stated another way, subsidizing the stove is much cheaper than subsidizing the fuel.
- For a clean fuel program to stand on its own and ultimately be sustainable, the cost of the fuel must be competitive with other fuels. Creating artificial fuel pricing is likely to be unsustainable. This is demonstrated by the fact that most African countries have of necessity deregulated their fuels.
- If a subsidy can enable the purchase of a high quality stove, this will produce gains in efficiency, durability, safety, and air quality. Conversely, "cheap" stoves end up costing more than higher quality ones, because they soon need to be replaced, creating dissatisfied consumers in the process.

137. A further reason to prefer a subsidy for stoves is that this could be privately financed through the sale of ethanol, just as the telephone handset is often subsidized by the sale of airtime. If ethanol fuel can be brought cheaply to the market, then it is possible that there will be enough economy in the fuel to provide a cross-subsidy for the stove. If a charge of 5 US cents per liter is placed in the fuel to pay for the stove, then the up-front cost of a $45 stove to the consumer would be $27 if the cross-subsidy is collected over one year, and $9 if collected over two years. The cost of the stove can "disappear" in the fuel, if there is enough economy in the fuel to permit this, and if the stove is of sufficient quality to be durable. A stove with a 6-month life can hardly be financed over 6 months, whereas a stove with a 6- or 10-year life can be financed over a year or 18 months.

Reducing Costs

138. 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

[42] The two most important improvements for artisanal distilleries would be a distillation column to replace the alembic or pot still and an improved furnace to fire the boiler. Instructions and training could be provided to operators on how to build a better furnace (a furnace with a grate and good air circulation could burn bagasse). An important improvement for the artisanal distiller would be to provide a hand operated cane crusher to improve juice extraction from cane, and further opportunities exist to increase productivity through training and seeds to produce hardier sugarcane and diversify to sweet sorghum where possible.
[43] The examples from Brazil (Usinas Sociais Inteligentes) and the U.S. (Blume Distillation) suggest better unit capital cost numbers beginning at 1,000 to 1,500 liters per day.

other uses, and if possible, taxes should be removed or reduced on ethanol fuel to assist it in getting into the market. Support could also be provided to micro-distillery technology and operations in the form of tax credits or holidays—especially for advanced technology coming in from outside the country. To import the stoves for this study, each stove incurred customs duties, VAT, Gasynet[44] fees, airport agency fees, and customs agency fees. This increased the cost of the stoves by 350%. Moreover, the process was staff-intensive and time consuming.

139. A barrier to the adoption of ethanol as a fuel that exists in many countries is the existence of local beverage markets and government uncertainty over how, or whether, to regulate for a fuel market and/or for a beverage market. Twice in US history nascent ethanol industries built on farm-scale distilleries was destroyed by beverage alcohol taxes[45], and significantly, Brazil used tax policy not only to build its ethanol industry, but also to select for large-scale over micro-scale plants, an outcome still argued in Brazil today.[46]

140. Currently in Madagascar ethanol is taxed as an alcohol beverage. There is no distinction for fuel or chemical ethanol although there is an exemption for alcohol used for pharmaceutical products. The seller of ethanol fuel currently must pay 20% VAT and approximately 58% excise tax. During the household survey conducted for this study, ethanol costing AR 1,200 per liter base price was sold to the project for AR 2,272. VAT is charged not only on the product itself but also on the excise tax levied against the product.[47] For ethanol to be competitive in the Malagasy fuel market, it must receive a tax treatment appropriate for fuel. A temporary holiday on both VAT and excise taxes would confer a strategic advantage, justifiable on the basis of the environmental and health benefits to be gained by substituting ethanol for charcoal as a household fuel, as demonstrated by this study.

Strengthening Forest Enforcement

141. Ethanol as a household fuel will compete primarily with charcoal. To the extent that charcoal is produced illegally, it receives an implicit subsidy reflecting the environmental costs that are not internalized in its price. Strengthened forest protection activities will constitute an important factor in the promotion of ethanol as a household fuel by limiting the supply of illegally harvested woodfuel, thereby raising the relative price of charcoal to a level that better reflects its true value. To reduce the social impact of enhanced forest protection, micro-distilleries could be part of a package that permits farmers to do more with their land, restoring degraded areas, and replacing charcoal-making with ethanol fuel distillation as a cash-earning activity. Strengthening the farm economy by giving farmers the know-how and tools to produce ethanol fuel could therefore form an element of the national strategy within the context of the existing NEAP and REDD programs.

Launching an Ethanol Household Fuel Program: Roles and Phasing

142. The successful launch and commercial sustainability of ethanol as a household fuel demands the effective participation of the Government, financial institutions, private sector and civil society. Safety and quality issues should be paramount, with rigorous testing of stoves – particularly for new designs – to ensure that they are fit and safe to use. Establishment of quality standards by the Government will reduce accidents, promoting both consumer confidence in the stoves, and access to carbon finance by requiring a minimum product life. Quality standards for ethanol fuel will also be important, as will the Government's determination to differentiate taxation between ethanol fuel and beverage alcohol. The economic benefits of ethanol as a household fuel provide justification for public investment to help overcome barriers to adoption, through support for demonstration projects and access to credit for both the purchase of stoves and investment in micro-distilleries. Carbon finance could provide an additional source of finance for the program, helping make ethanol stoves and fuel affordable to poor households otherwise lacking the financial means to invest in the health, livelihood and environmental benefits of switching from smoky, unsustainable woodfuel and charcoal.

143. Private sector involvement will support promotion of ethanol stoves by focusing on attributes that are considered most important to the cook (e.g. cleanliness, attractive design, speed of cooking) whilst

[44] All international trade to and from Madagascar must be registered on the Gasynet system which is a public-private partnership. This system is relatively new to Madagascar and is not yet working smoothly.
[45] Kovarik, Bill. 1998.
[46] Horta, et al. 2008.
[47] Summary of Tax System in Madagascar – Comparison of money bill 2007-2008. Available at www.impots.mg/uploadedfiles/documents/file_2_144.doc.

helping ensure the efficacy and affordability of the product through on-going development of technologies in response to customer feedback and competition. NGOs can play a key role in support to entrepreneurs through community-based approaches designed to raise awareness of the benefits of ethanol as a household fuel, and by providing training in stove manufacture and micro-distillery installation.

Phase 1: Initiation – Developing Local Capacity

144. Pilot study and measured scale-up will be essential to confirm the conditions under which small-scale distillation of ethanol for cooking is feasible. Much R&D has already been performed with ethanol stoves; for example, Project Gaia, Inc. considers the CleanCook stove used in this study to be fully commercial.[48] Other developers of ethanol stoves will surely test stoves in the Malagasy market and throughout Africa. It is likely that one commercially successful stove will lead to at least several in the market.

145. While micro-distilleries have been extensively tested, run and studied in Brazil, the U.S. and diverse other countries, they should be further tested and developed in Madagascar. This is not because the equipment and processes are mysterious, but because they need to be more fully understood by practitioners. In so doing, innovations and adaptations will emerge. Efficient running of these plants is a necessity, and can be repeatedly demonstrated to good effect. While there is considerable experience with ethanol production in Madagascar, it is recommended that experienced advanced micro-distillery suppliers be invited to the country to build prototype plants, which can then be studied and replicated by local developers.[49] Developers in Madagascar should also watch what develops elsewhere in Africa; for example, a USI distillery and 1,000 CleanCook stoves have recently been purchased in Nigeria for Oyo State[50], and the World Bank has funded the development of a micro distillery in Ethiopia under the Biomass Energy Initiative for Africa (BEIA) program.

146. A vital focus of the additional study needed on micro-distilleries in Africa concerns the production and supply of feedstocks. Growing, providing and preparing feedstock for the micro distillery is as important as fermentation and distillation of these products. Any micro-distillery project should have a strong agricultural component, preferably with the Ministry of Agriculture involved. For example, the International Institute of Tropical Agriculture in Ibadan, part of the CGIAR network, will be involved with the Oyo State project.

147. Another important focus during the initiation phase is government policy development. The Malagasy government should assist directly in technology transfer, knowledge sharing and reduction of barriers to commercialization. The PróAlcool in Brazil was developed over many years with the help of a comprehensive list of incentives. Development of ethanol fuel in Madagascar will be greatly speeded by the government's engagement on the policy and regulatory levels.[51]

Phase 2: Commercialization – Attracting Technology, Providing Finance, and Building Teams

148. The easiest pathway to commercialization is to start small and build incrementally. This is possible with a "micro distillery *plus* stoves" approach. If a commercial start-up begins with a scale of 1,000 liters per day, this is 4,200 tons of sugarcane consumed in one year, 1,000 stoves sold in one year, and 360,000 liters of fuel sold in one year. One sees the relative importance of the feedstock and the ethanol fuel to the stoves. For every stove sold, 4 tons of sugarcane are harvested and 360 liters of ethanol are sold per year.

149. Import duties will be a critical issue. Many countries provide incentives for importing machinery and equipment for value added processing or manufacturing either tax free or at greatly reduced rates. Madagascar does not have a clear program in this regard. Bringing in the best prototype equipment to start a small scale ethanol production industry is very important. Tax holidays on equipment and machinery can be justified for agricultural and industrial development reasons, for import substitution, and for the creation of a biofuels economy. Introducing high quality stoves offers the same benefits as introducing advanced micro

[48] Project Gaia, Inc. and Dometic Group.

[49] Several companies consulted in this study desire to build micro-distilleries in Africa and provide the technical support necessary to train local owners and operators in how to build, operate and maintain these plants. This includes Usinas Sociais Inteligentes (USI) of Brazil and Blume Distillation, LLC of the U.S.

[50] Facilitated by Project Gaia, Inc. This is the National Biotechnology Development Agency (NABDA) project.

[51] For a discussion on policies to promote biofuel development, see Horta Nogueira, Luiz Augusto, ed. 2008. Sugarcane-based Bioethanol – Energy for Sustainable Development, BNDES and CGEE, Chapter 8, Section 4.

distillery equipment. Getting high quality prototype equipment into local commerce will stimulate innovation and the development of "home grown" solutions.[52]

150. Providing financing opportunities for building and operating micro distilleries may be the most effective way to reduce financial impediments to creating an ethanol fuel market in Madagascar. If the micro distillery can be built locally, the equity required, at 20%, may be in the range of $5,000 to $10,000. To import and install one of the advanced systems from Brazil, the equity requirement would be quite a bit higher at $20,000 to $30,000. The return on investment on the more expensive, imported system is likely to be higher, however, because of its improved efficiency and productivity. The National Development Bank of Brazil has repeatedly stated its willingness to offer finance for these systems.

151. The ideal composition of a team to start a commercial project around ethanol stoves and fuel is a local investor with sufficient resources to provide project equity, a local bank willing to assist with loan capital at a preferred rate, and technical support from academic, non-profit and development organizations to provide advice and expertise on the technologies and project planning. Such facilitating organizations could also be the link to outside expertise on stoves, distilleries and agronomics, as the team will need to have access to a civil engineer, a process engineer or chemist familiar with fermentation and distillation, and to an agronomist familiar with the crops that will provide the feedstock for the ethanol manufacture.

152. Ways in which this team could be assisted to implement their first-of-a-kind business include:

- Funding and planning assistance to complete a business and financing plan (estimated cost is less than $10,000);
- Access to financing at preferred rates (estimated cost over 5 years is less than $30,000);
- Assistance with importing machinery and equipment (little or no cost);
- At least a temporary holiday on tariffs to promote technology transfer (estimated cost less than $35,000);
- At least a temporary holiday on VAT for the sale of stoves and fuel (estimated cost less than $10,000 for the first year of operation);
- Recognition in government of the cross-cutting nature of the enterprise, with engagement by the ministries of Revenue, Agriculture, Energy, Industry and Health (little or no cost).

The total cost of this package of incentives to start a commercial project built around ethanol micro-distilleries and stoves is $85,000, not all of which is borne by the same sponsor. Some combination of these incentives would help ensure the success of the first several start-ups.

[52] Dometic Group, the manufacturer of the CleanCook stove, has offered to the prospective local manufacturer the option of shipment of stove parts for local assembly. This approach would enable the local manufacturer to adapt the stove body and pot supports to local needs, while retaining the stove burner technology. The opportunity exists to build modular micro distilleries on an "assembly line" basis, and this in fact what both USI in Brazil and Blume Distillation LLC in the U.S. are planning to do.

Annex 1 - Stove Types, their Fuel, Distribution, Product Life and Approximate Cost

	Name of stove	Pollution reduction	Cost (US$)	Cost effectiveness	Fuel saving (%)	Approx life (yrs)	Notes
Ethanol & Gelfuel stoves	**Clean Cook**	Very good – virtually zero particles	~$55	Fair – very clean, high up-front costs but long life	n/a	~10yrs	Needs good supply chain for ethanol and people to be able to afford fuel and stove
Woodfuel stoves	**Upesi**	Inconclusive; faster cooking reduces cook exposure	Between $2 and $6	Low cost and long-lasting. Used all the time.	50%	~4yrs	Very well accepted, widely available.
	Onil stove	Very good	$100 often subsidised	Good where subsidy is available - Fuel can be gathered	60%-70%	5 – 10 years (estimate)	Used in Central America
	EcoStove	Very good	Not known	Fuel can be gathered	50%	5 – 10 years (estimate)	Promoted in Central America
	StoveTec	Very good	$12	Low cost stove with very good emission reductions.	40% (wood)	At least 2yrs - new	Stove body made in China - built into metal or ceramic casing. Charcoal version available
	Envirofit	Very good	$10-$40 subsidised	Very good at subsidised price as fuel can be gathered	60% wood	Not yet known	Charcoal version to be launched in Africa
Charcoal stoves	**KCJ**	Good	$2-$5	Cost effective in reducing levels of particles in the house, but leaving high levels of CO	30%-50%	5-10yrs	1.6million KCJ & various similar stoves. Traditional process produces substantial smoke.
	Gyapa	Reduced particulates	~$6	See KCJ	40%	At least 3 years	Very strong marketing campaign and carbon finance
	Ugastove	Reduced particulates	-	Carbon finance allows stove to be affordable	38% - 58%	At least three years	Carbon finance funded - voluntary market. Woodstove available

	Name of stove	Pollution reduction	Cost (US$)	Cost effectiveness	Fuel saving (%)	Approx life (yrs)	Notes
LPG stoves	**LPG sets**	Virtually 100%	~$50US	No smoke emission but often used only for rapid cooking, not main meals which use polluting fuels	n/a	5-10years	Used successfully in Kenya, in conjunction with fireless cooker as fuel costs are high. Need for savings for monthly purchase of fuel difficult for those on very low incomes.