



Strategy on Tree-based Energy

Clean and Sustainable Energy for Improving the Livelihoods of Poor People



The World Agroforestry Centre (ICRAF) is one of the 15 Centres of the CGIAR Consortium. ICRAF's headquarters are in Nairobi, Kenya, with eight regional and subregional offices located in China, India, Indonesia, Kenya, Malawi, Mali, Peru and Cameroon. We conduct research in 28 other countries in Africa, Asia and Latin America.

Our vision is a rural transformation in the developing world as smallholder households increase their use of trees in agricultural landscapes to improve food security, nutrition, income, health, shelter, social cohesion, energy resources and environmental sustainability.

The Centre's mission is to generate science-based knowledge about the diverse roles that trees play in agricultural landscapes, and to use its research to advance policies and practices, and their implementation that benefit the poor and the environment.

The World Agroforestry Centre is guided by the broad development challenges pursued by the CGIAR. These include poverty alleviation that entails enhanced food security and health, improved productivity with lower environmental and social costs, and resilience in the face of climate change and other external shocks.

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Main photo: A mother hauls firewood from Kereita Forest Reserve in Kenya. Photo © ICRAF/T Obara.

Insert: Pods of *Pongamia pinnata*, which has garnered worldwide attention for its oil rich seeds that produce a high quality biofuel. Before the Green Revolution, farmers purposefully cultivated this N-fixing pioneer tree species for the oil, which was used in lamps. Photo © ICRAF/C Watson.

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List of abbreviations and acronyms

BEST	Biomass Energy Strategy
CGIAR	Consultative Group for International Agricultural Research
CIFOR	Center for International Forestry Research
CRP	CGIAR Research Programme
DFID	Department for International Development
EIA	International Energy Agency
FAO	Food and Agriculture Organization of the United Nations
FTA	Forest, Trees and Agroforestry
ICRAF	World Agroforestry Centre
IDO	Intermediate Development Objective
IFES	Integrated Food- Energy System
IFPRI	International Food Policy Research Institute
LUC	Land Use Change
MDGs	Millennium Development Goals
MIT	Massachusetts Institute of Technology
ODI	Overseas Development Institute
OECD	Organisation for Economic Co-operation and Development
SD	Science Domain
SDGs	Sustainable Development Goals
SE4ALL	Sustainable Energy for All
SLO	System Level Objectives
TEA	Total Energy Access
TERI	The Energy and Resources Institute
UNDP	United Nations Development Programme
WEC	World Energy Council
WHO	World Health Organization

Executive summary

Energy is essential for individuals and populations to escape from poverty and move onto a path of greater well-being, security and prosperity. Families require energy to cook, stay warm, light their homes, and engage in productive activities that allow them to improve their livelihoods. Bereft of liquid fuels or electricity, for instance, farms are unable to mechanize, and communities become “stuck” without energy to increase the productivity of their enterprises and undertakings.

Although important global and national policies endorse providing the poor with greater access to a range of types of energy, about 2.7 billion people worldwide are almost wholly dependent upon solid fuel, mostly woody biomass, for cooking and heating. Woody biomass is one of the most renewable sources of energy; however, this reliance is currently neither healthful nor sustainable. Demand for woodfuel is growing and, in many regions, outstripping supply because of population growth as well as urbanization and increased incomes, the latter two of which lead to a rise in the use of charcoal for cooking. All of this comes at a great social and economic cost. Women and children spend many hours each day collecting firewood; human health is damaged by indoor air pollution; and charcoal production is degrading large areas of remaining dry forest as well as other forest types.

Bioenergy can be both healthful and sustainable. What are needed are bioenergy systems that, among other things, reduce drudgery and do not contribute to ill health or undermine the ecosystems upon which life depends. This document lays out an approach to developing various forms of bioenergy derived primarily from trees. It also recognises the role of trees on water

catchments in supporting other types of renewable energy such as hydropower.

The strategy's aim is first to promote pathways that address the provision of energy to meet basic needs, such as cooking, warmth and lighting. Its second aim is to promote pathways that provide more “modern” – in the sense of advanced and innovative – energy systems that use bioenergy, such as biodiesel from tree seed, to improve income generation and reduce poverty. These two aims are to be pursued in such a way that they support a third important aim – the improved management, protection and enhancement of ecosystems and productive landscapes. Greater use of sustainable and renewable bioenergy will help to mitigate climate change.

Among the approaches outlined in this strategy are: improving access to firewood; making charcoal production and use more sustainable and efficient; developing systems to generate electricity from woody biomass; and developing liquid biofuels. The focus of the last of these will be on sustainable production systems that integrate agroforestry and sustainable landscape management to ensure that biofuel production mitigates greenhouse gas emissions, improves land health and protects ecosystem services and does not compromise food production.

Poor people in developing countries will be at the centre of the programme proposed by this strategy, while strong policies and strengthened institutions will be the basis for change. The strategy employs a “research in development” approach that will require ICRAF to work closely with other CGIAR Centres, other research institutions and, crucially, with development partners.



Traditional charcoal burning in Mozambique. Such earth kilns -- which admit a copious amount of oxygen -- require 8-10 tonnes of wood to make one tonne of charcoal. Modern and more air tight kilns are more efficient, utilizing about 3.5 tonnes of wood to make one tonne of charcoal. Photo © ICRAF/Valter Ziantoni

Background and justification

Energy and poverty

Global energy production in 2013 stood at 13,634 Mtoe (million tonnes oil equivalent, or 570 EJ) (Riahi et al, 2012). However, most consumption takes place in developed countries where energy use has contributed to high standards of living. Energy consumption in developing countries is

very low. Moreover, countries with low Human Development Indices tend to have the lowest per capita energy consumption rates (Figure 1).

Large proportions of the populations of countries in sub-Saharan Africa and Southeast Asia live in energy poverty, defined as a lack of access to electricity or clean cooking facilities (Figure 2).

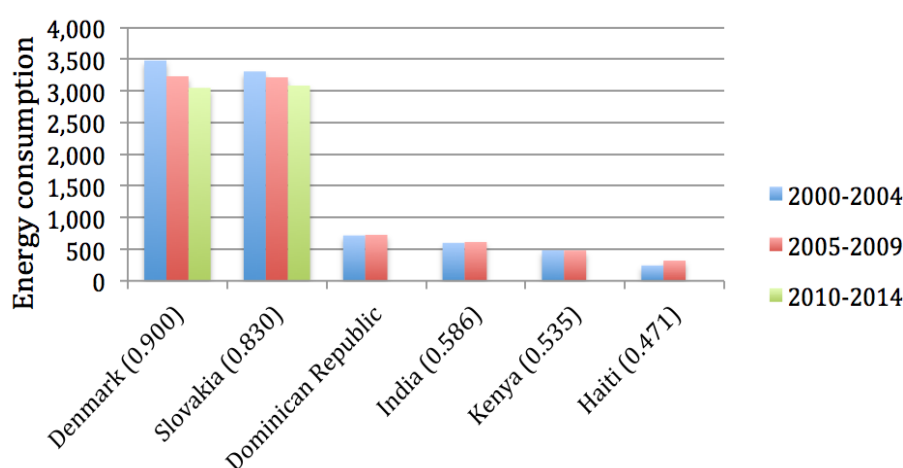


Figure 1. Energy consumption (ktoe) per capita in selected countries with different Human Development Indices – indicated in brackets (sources World Bank and UNDP)

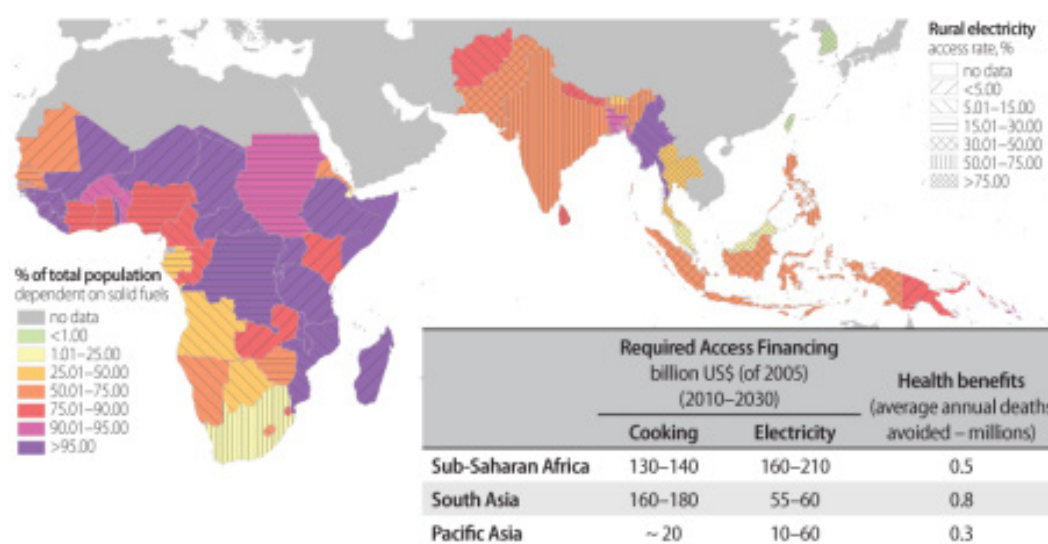


Figure 2. Populations without access to clean cooking fuels and electricity in sub-Saharan Africa and Southeast Asia. Note colours represent % of population dependent on solid fuels (Riahi et al, 2012).



Left: Women carry faggots on their heads. One ICRAF study found that 34 kg was the average load carried by women on their backs. Right: Charcoal from a private forest in Kenya, under conversion to grazing land. Photos © ICRAF

Lack of access to energy leaves people in severe poverty traps. The concept of Total Energy Access (TEA) has been used to set the lower acceptable limits for access to energy (Table 1).

The minimum standards set for energy access ensure only basic energy supplies for cooking, keeping warm, household lighting and access to information, while minimizing the effects of indoor air pollution. Much greater amounts of energy are needed to stimulate development. Enterprises

including agriculture, rural industries and modern businesses need energy for transportation, pumping, processing, manufacturing, and information and communications technology. Escaping poverty, improving livelihoods and improving incomes are all dependent upon sufficient access to sustainable energy. Unfortunately, globally, over 2.7 billion people have few prospects of having access to the energy they need (World Energy Outlook, 2011).

Table 1. Minimum Total Energy Access standards (Practical Action, 2012)

Energy service		Minimum standard
Lighting	1.1	300 lumens for a minimum of 4 hours per night at household level
Cooking and water heating	2.1	1 kg firewood or 0.3kg charcoal or 0.04kg LPG or 0.2 litres of kerosene per day
	2.2	Minimum efficiency of improved solid fuel stoves to be 40% greater than a three stone fire in terms of fuel use
	2.3	Annual mean concentrations of particulate matter (PM _{2.5}) < 10 µg/m ³
Space heating	3.1	Minimum daytime indoor temperature 18°C
Cooling	4.1	Households can extend the life of perishable products by a minimum of 50% over that allowed by ambient storage
	4.2	Maximum apparent indoor temperature 30°C
Information and communications	5.1	People can communicate electronic information from their households
	5.3	People can access electronic media relevant to their lives and livelihoods in their household

Sources of energy

The main sources of energy available globally are:

- Fossil fuels
 - ✓ Coal
 - ✓ Oil
 - ✓ Natural gas
 - ✓ Petroleum gas
- Nuclear energy
- Renewables
 - ✓ Wind power
 - ✓ Photovoltaics
 - ✓ Geothermal
 - ✓ Hydropower
 - ✓ Bioenergy
 - Biomass
 - Biofuel - ethanol
 - Biofuel - biodiesel
 - Second and third generation biofuels

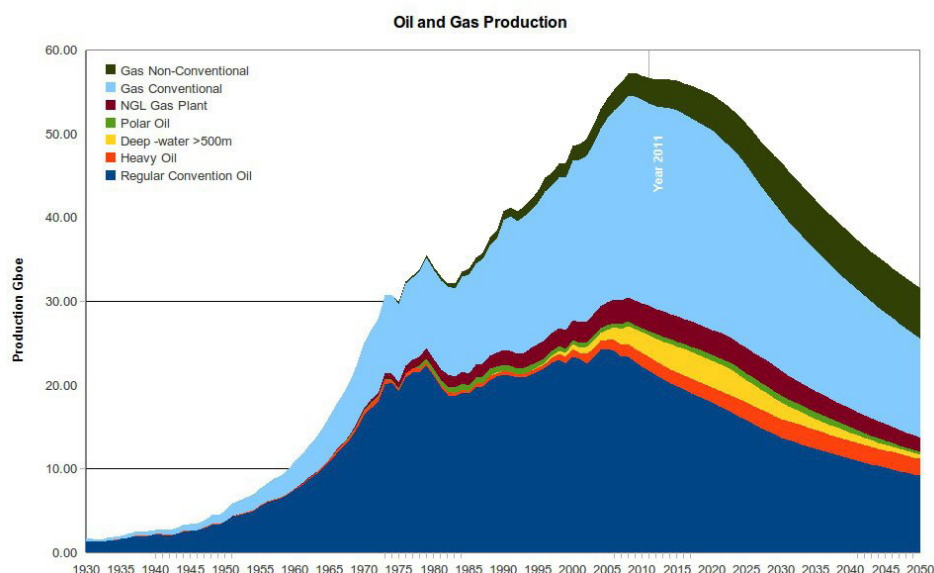
Fossil fuels

Fossil fuels are the largest contributors to climate change. Equally importantly, petroleum and gas will run out as they are non-renewable, finite and becoming more expensive to extract. An impending shortage of oil has led to further exploration and exploitation of areas where extraction was previously thought uneconomical. This has delayed “peak oil” (the time when access to oil stocks will start to decline), but only temporarily. Hydraulic fracturing (“fracking”) has provided a novel source of natural gas and oil that is increasingly being utilized. However, hydraulic fracturing will eventually be limited due

to difficulties in accessing gas-bearing rock and transport costs. Safety concerns may also limit fracking. “Peak Oil” (a web-based forum that explores the issue of hydrocarbon depletion) claims that peak production of hydrocarbons occurred in 2011 (Figure 1). The potential to shift from fossil fuels to renewables, including biofuels, will, to a certain extent, depend upon the differences in costs of different energy systems. Coal, oil and gas have been inexpensive for many decades, and, even though oil and gas are expected to become more expensive as their availability decreases and thus more expensive to extract, uncertainty remains about the future trajectory of prices and supply. Furthermore, there are pressing environmental reasons to shift to a low carbon economy.

[At the time of writing this strategy, the price of crude oil had crashed from over \$100 per barrel to below \$50. If maintained, this would make exploration for new sources of oil and gas unprofitable, but, in the short term, make investment in bioenergy less attractive as long as petrol, oil and gas remain inexpensive. Predictions for prices for the 12 months ahead varied greatly. Some analysts predicted that long-term prices would fall even more; others predicted that prices would recover to their former level. Mainstream predictions were that prices would stay low for some months and then rise to \$70-80 per barrel. If and when the international economy recovered fully, prices could rise even more].

Figure 3. Oil and gas production 1930-2050 (Exploring hydrocarbon, 2015).



There is an ample supply of coal, but, like oil and gas, it is increasingly believed to be too dirty and climate damaging to be used in large quantities, unless inexpensive methods of carbon capture can be developed (MIT, 2007). Given the undesirable effects of all fossil fuels on atmospheric warming, they will need to be phased out or reduced over the course of the coming decades if climate change and further environmental damage is to be avoided. The problem is what to replace them with.

Nuclear power

Nuclear power has the potential to provide abundant power without the emissions created during electricity generation. Full life-cycle cost analyses that take into account emissions during construction and decommissioning provide more realistic estimates of greenhouse gas emissions, which are nevertheless low over the long term. At present, fears about the safety of nuclear plants, in conjunction with the issues of storing nuclear waste, are militating against significant expansion of nuclear power. Additionally, there are significant costs associated with building the necessary infrastructure for nuclear energy and the subsidies needed. The International Energy Authority cut its predicted 2015 global nuclear capacity prediction by 10% compared to the previous year (World Energy Outlook, 2012). In light of this, there seems to be little chance that nuclear-sourced energy will be available to the energy-poor in the near or moderate future.

Renewables: solar, wind, geothermal and hydropower

A number of *renewable sources of energy* are being developed, used and improved. *Solar power* derived from photovoltaic panels is increasing in efficiency and reducing in cost. Solar panels have the obvious disadvantage that they only work during daylight and when there is plenty of sun. Additionally, solar panels do not deliver much energy per unit area, so their utility is limited. However, more efficient solar converters are under development (Sheng et al, 2014). Improvements in battery technology to store solar power will increase the usefulness of photovoltaics. *Wind* turbines are also improving

and becoming cheaper. They generate useful amounts of electricity, but only when it is windy, so cannot be relied upon as the only source of power. *Geothermal energy* is usually derived from hot water or rock under the earth's surface and might potentially supply substantial amounts of power but only at considerable cost. The Menegai geothermal project in Kenya will provide power to 500,000 households and 300,000 businesses and avoid 2 million t of greenhouse gas emissions a year - but at a start up cost of almost \$750m.

Hydropower could provide large amounts of energy without apparent harmful emissions. However, the construction of large-scale hydropower plants is expensive and generates significant emissions. The plants also significantly effect the environment around the dam as well as downstream. The future of hydropower is further limited by the fact that many of the locations with the greatest generating potential have been dammed already. Finally, hydropower depends upon careful management of the catchment. In Africa, landscapes increasingly denuded of vegetation are seeing water levels collapse in rivers, threatening electricity generation. Rwanda's Rugezi watershed supplies water to two power stations, which together generate 90% of the country's electricity. Drastic changes to the watershed led to a four metre drop in Lake Bulera, which triggered a severe energy crisis in 2004. Restoration efforts, including agroforestry interventions, allowed normal electricity production to resume in 2007 (UNPEI/REMA, 2014).



Trees deliberately integrated into the farming system on sloping land in Rwanda. Photo © ICRAF/M Iiyama

Bioenergy

Bioenergy is defined as a renewable energy that is made available from materials derived from biological sources. Currently, the most prevalent form of bioenergy is from biomass, or any organic material that has stored sunlight in the form of chemical energy. Tree-based biomass is a truly renewable energy source and accounts for most energy use in Africa and South Asia and in a considerable portion in other parts of the world. In Tanzania and Malawi, biomass accounts for 87% of total energy consumption. In Nigeria, biomass accounts for an estimated 97% of household energy demands (IEA, 2011). In a study in ten African countries, 99% of rural households surveyed reported firewood as their primary energy source. The average daily use per capita was 2.5 kg, primarily for cooking (Adkins et al., 2011). Firewood is preferred by the poor due to its inexpensiveness and accessibility (Wood-Based Biomass, 2011). Firewood is also used in industries, commercial enterprises (hotels, tea and tobacco drying and brickmaking), and institutions, such as prisons and schools.

Bioenergy has the potential to keep up with the growing demand for energy if the existing potentials continue to be explored. In 2008, bioenergy provided about 10% of the world's primary energy supply (Intergovernmental Panel, 2012). According to the International Energy Agency (IEA) "[Bioenergy] plays a crucial role in many developing countries, where it

provides basic energy for cooking and space heating, but often at the price of severe health and environmental impacts. The deployment of advanced biomass cook stoves, clean fuels and additional off-grid biomass electricity supply in developing countries are key measures to improve the current situation and achieve universal access to clean energy facilities by 2030" (Technology road map, 2011). In addition, the IEA predicts that biofuels could provide up to 27% of the world's transport fuel by 2050 (OECD/IEA, 2011). The World Energy Council predicts that world annual primary energy demand by 2050 will be in the range of 600 to 1000 EJ, and, based on reviews of studies carried out in 2008, estimates that global demand for bioenergy could be 250EJ/year (World Energy Council, 2013; Dornburg et al, 2008).

Bioenergy provides a range of options that reduce carbon emissions, and this will lead in turn to reductions in the impact of climate change. Producing trees for bioenergy in sustainably managed agroforestry systems and woodlots ensures increased carbon sequestration. Properly-managed tree-based systems result in other environmental improvements including the conservation of provisioning and regulating ecosystem services such as water storage, release and purification, soil fertility and ability to hold moisture, and biodiversity which helps to control pests and diseases. These ecosystem services contribute to improved agriculture. Therefore, bioenergy developed from integrated fuel-food systems is compatible with efforts to improve food security.

Firewood

Poor people around the world are dependent upon biomass energy, mainly derived from trees. Woodfuels provide more than 80% of primary energy in Sub-Saharan Africa, where the *per capita* consumption of wood for energy is almost 0.7 m³/person/year. In contrast, the global average is about 0.28 m³/person/year (Iiyama et al, 2014). Asia and Sub-Saharan Africa are the regions of the world that use most woodfuel overall (see Table 1).



Firewood is used for industry, in this case a bakery in Addis Ababa. Photo © ICRAF/M.Iiyama

Region	Sub-region	Woodfuel production (1,000 m ³)
Africa	Central Africa	110,621
	East Africa	200,699
	North Africa	47,792
	Southern Africa	58,469
	West Africa	171,091
	Total Africa	588,673
Latin America and Caribbean	Caribbean	5,120
	Central America	40,195
	South America	195,856
	Total Latin America and Caribbean	241,171
	East Asia	216,621
	South Asia	382,745
	South East Asia	185,903
	Oceania	12,838
	Total Asia and Pacific	794,104

Table 1. Woodfuel production by region (FAO, 2009).

Depending on location, greater or lesser proportions of the total woodfuel harvested will be used as firewood. The poorest people in the world, particularly the rural poor, are major users of firewood, usually in unimproved fireplaces.

There is great heterogeneity in the proportion of woodfuel that rural families obtain from their farms versus from off farm sources, including from forests. In Murang'a, Kenya, over 90% of households source woodfuel from trees on farm (Githiomi et al, 2012). In contrast, in Menagesha Suba in Ethiopia, 85% of households source the majority of their woodfuel from forests belonging to the state. Also in Menagesha Suba, as in much of rural Ethiopia, India and many other developing countries, families are heavily reliant on cow dung for cooking, utilizing between about 0.4 and 1t per year, depending on their proximity to the forest. In Menagesha Suba, an area typical of rural Ethiopia, the practice is becoming increasingly common and is a “strategy to fill the gap in firewood supply for energy production and now remains one of the major sources of energy” (Duguma et al, 2014). Using this form of biomass for energy deprives the soil of important nutrients and does not create a



A Rwandan hill cleared for timber, firewood and charcoal. Note the smoke from charcoal kilns. Photo © ICRAF/M Njenga

sustainable agricultural system.

However, using manure – often derived from fodder from trees – for biogas has strong benefits. In Embu, Kenya, a biogas system fed by two dairy cows was found to supply 30-40% of household energy needs, producing enough energy to prepare tea, rice, porridge for a family of four. In Tanzania, biogas from animal and human waste was found to reduce wood fuel use by up to 60% (Karanja and Kiruiro, 2003). The Uganda Domestic Biogas Program states that 25-38 kg of cow dung can produce biogas sufficient for 1.5 hours of cooking and four hours of lighting a day (Mugerwa, 2012). In addition to energy, biogas systems produce a nutrient-rich fertilizer called slurry.

Although major global initiatives are striving to ensure that poor people have access to “modern” energy systems (including the use of some renewables, but primarily focusing on kerosene, liquefied petroleum gas and other fossil fuels), woodfuels, in the form of firewood and charcoal, will remain important sources of fuel for the poor, especially in Sub-Saharan Africa and South Asia (see Figures 4 and 5).

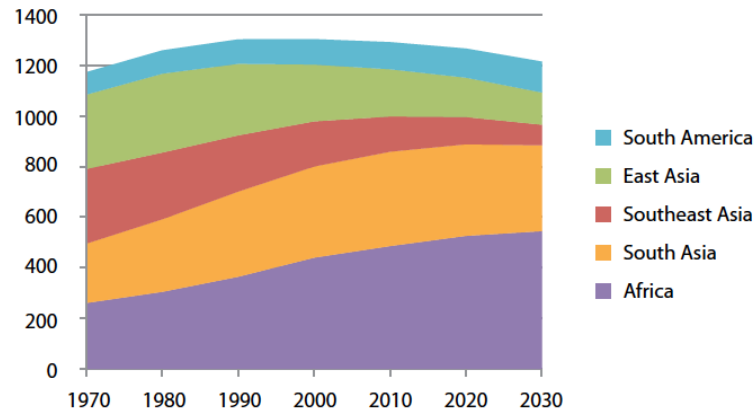


Figure 4. Projection of fuelwood consumption in developing regions (million m³) (Hofstad et al, 2009)

Charcoal

Also derived from trees, charcoal is another important form of bioenergy. It is used by an estimated 80% of urban households in Sub-Saharan Africa (Zulu et al, 2012). Even more than firewood, charcoal consumption is projected to increase rapidly in the coming decades. This is due, to a great extent, to expanding urban populations. In Dar es Salaam, a 1% increase in urbanization resulted in a 14% increase in charcoal consumption (Hosier et al, 1993). Rwanda's capital, Kigali, consumes 60% of the charcoal produced in the country (Drigo et al, 2013).

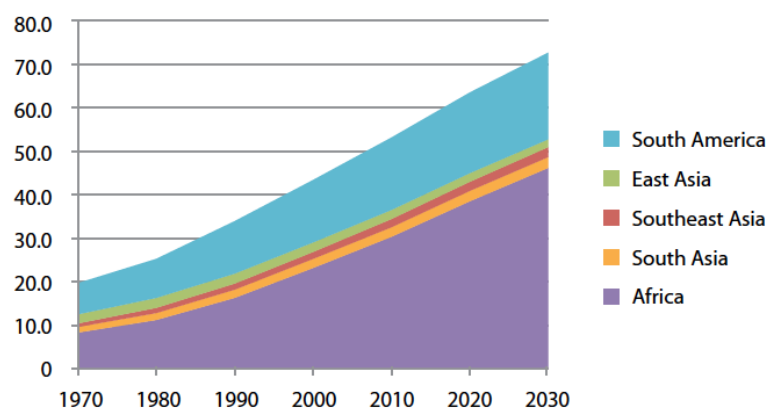
A study by Arnold et al (2006) found that firewood and charcoal consumption is generally on the rise in developing countries, with charcoal use projected to double by 2030 versus a 24% increase for firewood. Increasing demands for firewood and charcoal can open the door to ecosystem exploitation. As such, solutions are needed to provide an adequate and appropriately

sourced supply without damaging local ecosystems.

Trees can be purposefully planted for charcoal; Mampu, in the Democratic Republic of the Congo, is a longstanding agroforestry project producing 12,000t of charcoal, 10,000t of cassava, 1250t of maize and 7t of honey a year.

In addition, technologies abound to capture more of the energy of wood as it converts to charcoal. "Charcoal is the solid residue remaining when wood is 'carbonised' or 'pyrolysed' under controlled conditions in a closed space such as a charcoal kiln. Control is exercised over the entry of air...so that the wood does not merely burn away to ashes... but decomposes chemically to form charcoal." (FAO, 2014a) However, most charcoal making deploys earth mounds which admit air; the efficiencies of these traditional kilns are low, 10-20% by weight and 20-40% in energy terms (FAO, 2014b). Modernizing charcoal production to raise efficiency is urgent.

Figure 5. Projection of charcoal consumption in developing regions (million tonnes) ibid



Electricity generation

In addition to the important role of trees in the production of firewood and charcoal, trees also have the potential to contribute to more “modern” energy systems. In particular, woody biomass can be used to produce *electricity* at scales suitable for community use. The Energy and Resources Institute (TERI) in India has developed downdraft biomass gasifier generation systems in the range of 3.5-100 kWe (kilowatt of electricity) (Biomass

gasifier, 2011). A number of practical community-level applications of biomass power generation have been installed around the world, including India, Cambodia, Mali and several developed countries (Dimpl, 2010).

As shown in the photos below, in Sri Lanka, agroforestry systems, in which *Gliricidia sepium* is grown with coconuts, are being used to generate both electricity and fodder for livestock (Kulantunga, 2012).



Left: A farmer in Sri Lanka, contracted as an outgrower for *Gliricidia* feedstock, stands in front of his year-old *Gliricidia*. Centre: Wood harvested from rubber trees for use in an industrial-size biomass power plant. Right: A 3.5kw gasifier that uses biomass for powering a drip irrigation system Photos © ICRAF/S Mohan

Biofuels

Biofuels can be produced from biomass from annual as well as perennial plants. The first generation of large-scale bioenergy production was based on ethanol from sugarcane. Brazil was the pioneer country. By 2013, global ethanol production for fuel (from sugar cane, cereals and other sources) stood at over 88 billion litres per year, with 57% produced in the USA, 27% in Brazil, 6% in Europe, 3% in China, 2% in India and only 3% in the rest of the world (Renewable Fuels Association, 2015). Based on Brazil's success, there should be scope for increasing ethanol production in many developing countries.

Tree crops might be used to provide feedstock for the distillation of ethanol as a fuel. One potential tree is *Nypa fructans*, the Nipa Palm, which is widely distributed among mangrove forests of Southeast Asia and produces an abundant sap from which ethanol can be produced at a rate of

6,480-10,224 L/hectare/year. While this is less than can be produced from sugarcane, it is more than many other ethanol feedstocks. Furthermore, as Nipa grows well on saline soils, it could be used on soils unsuitable for agricultural production (Tsuji et al, 2011).

Biodiesel can be produced from a number of plants by extracting the liquid portion of fruits and seeds through cold pressing or use of solvents. Different biodiesel fuels lend themselves to either large-scale or small-sale processing. Processing begins with mechanical cold pressing or use of solvents to extract the oil, followed by filtration or sedimentation of suspended solids. Sometimes pre-preparation, such as roasting the seeds, is necessary. Where small-scale pressing is practised, the extracted oil can sometimes be used directly to drive diesel engines or as a fuel for cooking or lighting (Brittaine and Litaladio, 2011).

Alternatively, biodiesel can be processed on a

larger scale (with fruits or seeds sourced from either small-scale or large-scale producers) where oils are put through an industrial process of transesterification that produces a refined fuel and removes a number of undesirable contaminants (Rutz and Janssen, 2007).

A solid cake, typically representing 10% of the original fruit or seed, is left after processing. Depending on the toxicity and palatability of the original crop, this cake can be used for animal feed or returned to the soil as an ammendment (Paul and Kemnitz, 2006). In Karnataka (India), the seed cake by-product is much sought after by grape growers and other farmers.

Biodiesel can also be produced from animal fats, typically obtained from abattoir waste.

So-called second-generation biofuels are under development. They depend on thermal or biochemical treatment to break down the lignocellulosic components of plants into materials that can be fermented to produce ethanol. Third generation biofuels are still at the research stage. They are based on algae and have the potential to produce a range of liquid fuels.

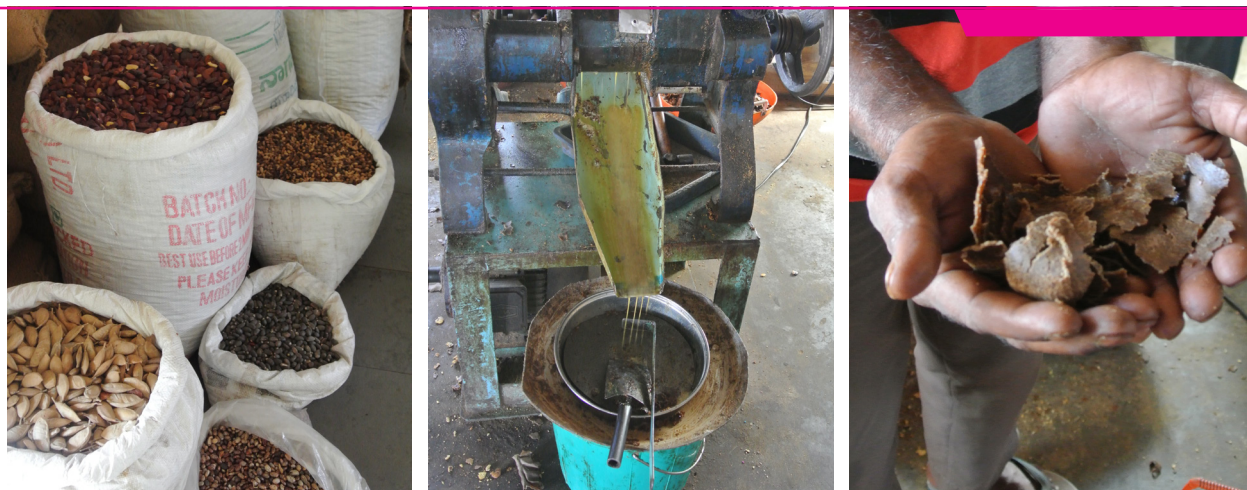
Valuable liquid biofuels can be obtained from tree species. Oil palm fruit, coconut fruit and *Jatropha curcas* can be used as raw materials for biodiesel synthesis or in blends to achieve the necessary oil profile for biofuels. Oil palm has a proven potential for transformation into a number of products and fuels, including biodiesel (Chew and Bhatia, 2008).

The original expected potential of *jatropha* has not been realized, mainly because while it grows on marginal land, it yields poorly and gives poor economic returns under smallholder management (Ilyama et al, 2013). However, industrial interest in *jatropha* as a biofuel crop remains high, but is based on improved cultivars and appropriate management rather than the use of wild varieties promoted as development opportunities for small-scale farmers.

Pongamia pinnata has been identified as a tree with potential for biodiesel production, but while commercial trials are under way, the crop is at an early stage of domestication (Bobade and Khyade, 2012). The by-products of *Pongamia* can be used as a valuable soil additive or in the manufacturing of animal feed, increasing the value of the commodity. Conversely, the by-products from *jatropha* are toxic.

Globally, there are many other trees with oilseed or other production potential for either biodiesel or ethanol. In India, an estimated 300 species of oil-bearing trees are available. Some of these species have been shown to be valuable feedstock for biofuel such as *Neem (Azadirachta indica)*, *Mahua (Madhuca indica /Madhuka logifolia)* and *Simarouba (Simarouba glauca)*.

In Africa, *Croton megalocarpus* is being harvested for biofuels, and the pulp left over from processing is used as a soil amendment material in local agriculture.



Left: Oil-rich seeds of half a dozen tree species await processing at the biofuel production unit in Hassan, Karnataka. Centre: tree seed oil pours from a press. Right: left over seed cake in the hands of the operator.

Photos © ICRAF/C Watson

The palm tree *Macauba (Acrocomia aculeata)*, with oil yields similar to oil palm but oil quality more suitable for biodiesel than oil palm, is a native of Central and South America. *Copiaifera langsdorfii*

(the diesel tree from South America), and *Xanthoceras sorbifolium* (from China) are among other trees with biofuel potential.

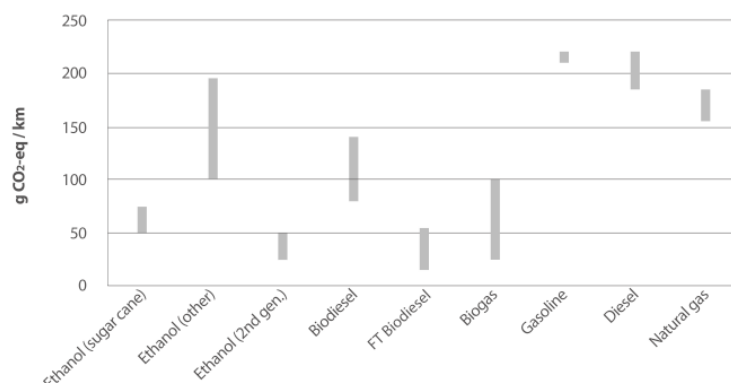


Figure 6. Ranges of greenhouse gas emissions for heat supply from different sources calculated using a life cycle approach (EIA Bioenergy, 2011).

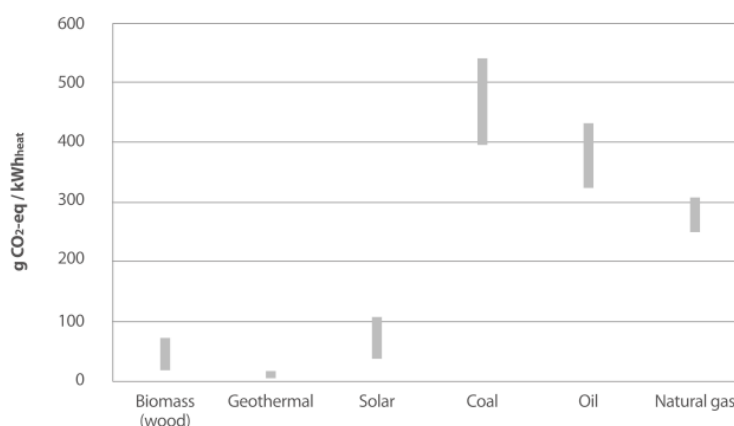


Figure 7. Ranges of greenhouse gas emissions for biofuels of different types from a variety of sources used in automobiles calculated using a life cycle approach (EIA Bioenergy, 2011).

Summary

Renewables, including bioenergy, have the advantage of producing less greenhouse gas than fossil fuels. This becomes most apparent when a life cycle approach is used to calculate emissions. This approach takes into account all emissions from “cradle to grave” at all stages in a fuel’s production, through to use and disposal of materials (Figures 6 and 7).

When used in conjunction with other renewable sources, bioenergy has the potential to address growing energy needs. Poor people depend on firewood and charcoal, and despite great efforts to shift to different energy systems, will evidently continue to depend upon them for decades.

Firewood meets the basic needs of poor rural inhabitants for cooking (and sometimes heating), while charcoal is primarily used in the growing cities of developing countries.

To be lifted out of poverty, however, people require energy for enterprises, including agriculture, rural and urban businesses, computers and mobile telephones. Trees have the potential to provide energy for these in the form of biofuels and electricity. Providing firewood and charcoal sustainably will require considerable research. In addition, significant research and technology development will be needed to understand and achieve the full potentials of liquid biofuels and biomass-fueled electricity generation. .

Tree-based bioenergy and agroforestry

Tree-based biomass energy production and biofuel production might be ensured through large plantations, smaller local woodlots or in agroforestry systems. Unless extensive “land sparing” approaches are being used, however, large-scale production is probably to be avoided as the space taken could interfere with local food production and compete with natural forests. Better options include local woodlots in productive landscapes, agroforestry systems or, in the case of biofuels, collection of seeds from the wild.

The high wood yields of some agroforestry systems, including woodlots in productive landscapes, point to their potential to meet local woodfuel demands and thereby possibly conserve natural forests. Agroforestry systems can also improve other aspects of life for smallholder farmers through an integrated food-energy

approach. According to the FAO, an “Integrated Food-Energy System (IFES) is a diversified farming system that incorporates agro-biodiversity and builds on the principles of sustainable production intensification” (Integrated Food-Energy Systems, 2015).

An FAO study of *Cajanus cajan*, or pigeon peas, in Malawi found that, when intercropped with maize, they improved the quality of the soil via nitrogen fixation, mulching with leaves, and decreased soil erosion. The leguminous shrub also increased maize yields and supplied communities with an additional source of protein and a large supply of fuel. Community members reported that they had not purchased firewood in over five years, as the introduction of pigeon peas provided them with a convenient and effective source (Bioenergy and Food Security, 2015).



Left. A farmer in his *Grevillea-Calliandra*-livestock agroforestry system in western Kenya. The green leafy vegetable is fertilized by biogas slurry and the N-fixing *Calliandra*, which is fodder for stall-fed cows. Right. A farmer in Karnataka knocks oil rich seed seeds from a *Pongamia* tree. Photos © ICRAF/C.Watson

In India, the dry matter production of pigeon peas is reported as more than 15 t/ha/year (Daniel and Ong, 1990). In another example from India, trees outside forests supply an estimated 49% of the 201 million tonnes of fuelwood consumed by the country per year (IFES, 2015).

In central Rwanda, the Projet Agropastoral de Nyabisindu found that with 350 trees of *Grevillea robusta* per hectare, after nine years, the yield was 14.6 m³/ha/year of wood and 3.07 t/ha/year of fresh leaves (Ndayambaje and Moren, 2011). In Tanzania, prunings from *Grevillea robusta* planted on the contours of an average farm size of 1.64 ha were found to meet the entire annual household demand for fuel wood (Mwihomeke and Chamshama, 2004).

These studies cannot be generalized but demonstrate the extent to which agroforestry can provide woodfuel. Fast-growing and coppicing species are particularly promising and, where

land permits, may also be grown in woodlots. In Rwanda, ICRAF scientists report that the first coppicing produces little biomass but the second can produce double or triple the production of year 1. Depending on planning and farm size, farmers can be self-sufficient in firewood.

Biomass growth can be vigorous. Uganda could “sustainably harvest over 45 million tonnes of biomass a year by including bushes, shrubs and a small portion of vegetal waste in its biomass energy mix”(Biomass Energy Strategy, 2014).

Production of biofuels lends itself to agroforestry systems as well. Planting oil seed-bearing trees with food crops and on farm boundaries and bunds has had success. Plots of biofuel trees have potential too. However, the fruits and seeds of some biofuel species are collected from natural forests. Given the massive production of fruits and seeds by these species, wild collection is unlikely to lead to significant ecological effects.



Grevillea robusta shades coffee, provides timber and is compatible with many food crops. However, fuelwood scarcity drives excessive pruning of these trees.
Photo © ICRAF/C Watson



Fuelwood from a cocoa in SW Côte d'Ivoire. One ha of cocoa trees can produce 8-10 t of prunings a year, according to ICRAF scientists.
Photo © ICRAF/C Watson

Theories of change and place

The theory of change for ICRAF's involvement in bioenergy research is based on the following testable assumptions.

1. Lack of access to energy is associated with poverty and prevents people from escaping poverty, improving their livelihoods and increasing their incomes. Providing energy can raise people out of poverty and contribute to the improvement of their livelihoods and their adoption of strategies that lead to greater incomes. The poorest people in the world are dependent upon biomass for cooking and heating. Collecting firewood is drudgery that takes up women's time which could be used in caring for children and doing more productive work (WHO, 2006). Children occupied in collecting firewood should be at school (Overseas Development Institute, 2007). Lack of access to firewood can prevent food from being properly cooked or people may burn potentially dangerous materials (Gathui and Ngugi, 2010; Kholin et al, 2011). There are severe health hazards caused by burning firewood indoors (Household air pollution, 2011; WHO, 2010).
2. The demand for charcoal in urban centres is high and still growing. Current charcoal production is largely unsustainable and results in loss of woody vegetative cover, especially in semi-arid parts of the world (State of the World's Forests, 2007). Making charcoal sustainable will require science and technology (maintaining stocks of the right trees and improving the efficiency of production) and improvement of the effectiveness of the value chain (Adam, 2009). More importantly, there is need to provide clean cooking solutions that are accessible and affordable.
3. Trees can provide energy that fit into modern systems. Biofuels have the potential to provide energy for enterprises, including agriculture, rural economic activities and modern businesses. Locally produced biodiesel can drive pumps, tractors and vehicles, and liquid biofuels can power income-generating enterprises. Off-grid electricity can be provided at community level through the use of biomass to generate electricity
4. There are perceived and real issues relating to the sustainability of tree production for bioenergy. There could be competition between energy production and food production; large-scale bioenergy production has often been associated with intensive production systems that have damaged biodiversity, competed with other land uses and destroyed ecosystem services (Bogdanski et al, 2010). On the other hand, bioenergy has the potential to be renewable and could contribute to climate change mitigation.
5. A cross-cutting assumption, affecting all of the above, is that global and national policies are either nonexistent or unfriendly to bioenergy and will need reform based on scientific evidence.

Thus, the theory of change is based on an **overall aspirational goal**:

To ensure improved access to energy among poor people and give rural populations opportunities to profit from producing bioenergy and gain access to improved energy supplies to reduce poverty, improve food and nutritional security, improve livelihoods and increase incomes while maintaining the integrity of ecosystems and contributing to climate change mitigation.

The following sections discuss tree-based bioenergy in terms of firewood, charcoal, liquid biofuels and electricity generation. Theories of change and place are outlined for each category. An approach to a programme structure is provided in the form of tables of interventions, where the interventions are sorted in terms of potential impacts on poverty, incomes, ecosystems, food security and climate change.

Firewood

Theory of change

By understanding the dynamics of wood supply for cooking at global, national and local levels, it will be possible to design interventions that ensure that wood is available near where it is used. This will be achieved by using agroforestry systems, woodlots and natural regeneration. Understanding the full production-to-combustion system will allow improvements to be made in cooking systems, including better fuel management and the judicious introduction of improved stoves. Local firewood markets will bring income to poor communities, and the costs (including opportunity costs) of cooking with firewood will be reduced. Shifting firewood collection from the general environment to managed plots will reduce pressure on existing forests and encourage the

growth of biodiversity. All of these interventions will tackle some of the most basic and intractable issues of poverty, including the need for women to spend time collecting firewood. Children, similarly will be freed, ideally to attend school. It will be important that national policies provide the enabling environment, which should be achieved by ensuring that firewood for cooking features in national energy plans. There is also likely to be an increase in the use of firewood for industrial purposes, such as cement-making and crop processing. This will possibly lead to the need for large-scale woodlots and plantations, which may in turn improve the supply of firewood for cooking. Alternatively, there will be occasions where out-growing of wood is feasible.

Theory of place

The regions where firewood use is projected to grow most are Africa and South Asia, while other major regions of the world are expected to see a reduction in use. Firewood for cooking will continue to be used mostly by poor rural communities for domestic purposes. The main drivers for improving access to firewood in such settings will be the need to ensure that families have reliable and sustainable access to firewood and the urgent

need to reduce harm from indoor air pollution. An additional driver of firewood use is likely to be a growth in demand for firewood for industrial processes, particularly where industrially suitable fuels like gas are unavailable and wood remains the best option. There will be opportunities along the forest transition curve to restore forest land that has been degraded, and also for land users in productive landscapes to integrate trees into their land use systems.

	Access to firewood: interventions
Poverty	<ul style="list-style-type: none"> • Short rotation wood production and agroforestry systems that produce prunings • Improved cooking systems including stoves • High quality planting materials of the best species made available • Reduce ill health from indoor air pollution
Incomes	<ul style="list-style-type: none"> • Wood marketing • Reduced costs (including opportunity costs) to the consumer
Food security	<ul style="list-style-type: none"> • Reduce the time spent collecting firewood by women to permit more productive activities including agriculture and food preparation • Improve cooking systems by making firewood easily available • Improve cooking systems through improved kitchen management, including maintenance of the quality of fuelwood and the introduction of improved stoves
Ecosystems	<ul style="list-style-type: none"> • Shift wood collection from the natural environment to managed plots • Where appropriate, restore degraded areas • Apply agroforestry methods that maximize biodiversity including agrobiodiversity
Climate change	<ul style="list-style-type: none"> • Reduce emissions by shifting to sustainable sources of firewood
Policy	<ul style="list-style-type: none"> • Ensure that basic energy needs are recognized in national energy policies

Charcoal

Theory of change

Understanding the charcoal value chain is a fundamental first step in transforming charcoal from an illegal, or partially illegal, enterprise to a valid and sustainable business that improves income for producers, brings about equitable and fair benefits along the value chain and maintains reasonable costs for consumers. The most effective interventions are likely to be in policy frameworks and legislation designed to legalize and regularize charcoal production and use. Increased efficiency in charcoal production will result from improving the techniques of charcoal production and providing woody feedstock from agroforestry, woodlots and natural regeneration. This will have an impact on greenhouse gas emissions and provide incentives to manage feedstocks sustainably. Increasing incomes from charcoal will provide incentives for producers to manage resources in a sustainable fashion. The resulting improvement in resource management will remove pressures that have led to degradation of the environment. There will be opportunities along the forest transition curve to restore forest land that has been degraded, and also for land users in productive landscapes to integrate trees into their land use systems.

Theory of place

Charcoal in developing countries is the fuel of choice in urban areas. Its easy transport and clean burning makes it attractive to city dwellers. However, the effects of the production of charcoal are evident in rural areas, sometimes quite distant from the conurbations where it is used. There are projections that charcoal use will increase most in Africa, followed by South America (where much of the growth may be for industrial use). Charcoal use is relatively low in East Asia, Southeast Asia and even South Asia. The potential to grow wood for charcoal will vary across agro-ecological zones, and different strategies will be needed for each area. The main driver to improve the charcoal business will come from increasing urban demand. There will be opportunities along the forest transition curve to restore forestland that has been degraded and for land users in productive landscapes to integrate trees into their land use systems

	The charcoal value chain: interventions
Poverty	<ul style="list-style-type: none"> • Informal nature of charcoal regularized
Incomes	<ul style="list-style-type: none"> • Increase incomes, especially for producers • Improve charcoal production techniques that reduce use of wood
Ecosystems	<ul style="list-style-type: none"> • Shift wood collection from the natural environment to managed plots • Where appropriate, restore degraded areas • Apply agroforestry methods that maximize biodiversity including agrobiodiversity • Increase efficiency of production, reducing pressures on the environment by introducing improved charcoal production techniques • Improve efficiency through use of briquettes from various feedstocks • Ecosystems services conserved
Climate change	<ul style="list-style-type: none"> • Reduce emissions through the efficiency measures listed above
Policy	<ul style="list-style-type: none"> • Ensure that the importance of charcoal is recognized in national energy policies • Tackle distortions in value chains through participatory studies, participatory identification of problems and participatory governance reform and improved policy and legislation

Liquid biofuels

Theory of change

Poor rural and urban people need access to energy that can fuel the transformation of their livelihoods from subsistence users of resources to entrepreneurs who develop enterprises that raise incomes and improve standards of living. Energy is needed for pumping water, preparing land, post-harvest management, processing, packaging, transportation and many other income-generating activities. Liquid biofuels can provide energy for all of these purposes and contribute significantly to people's potential to earn an adequate income. When grown in the many different energy-food systems that have been developed, liquid biofuels can be produced without compromising food production. Biodiesel can be produced and processed locally, providing income through the selling of biofuels and giving farmers access to mechanization and expeller

materials to improve soil fertility. Value chains for other fuels that provide incomes for those who collect fruits from forests or who grow oilseeds on their land can be established. Value chains will include income-generating processing and will provide the public with sustainable fuels at a reasonable cost. The substitution of sustainable liquid biofuels will have a significant effect on the emission of greenhouse gases. While some biofuels, such as oil palm, have been associated with major forest degradation, it is possible to reduce impacts by growing oilseed trees with other trees and crops, and maintaining biodiversity in areas of production. Biofuels compete directly with more conventional fossil fuels, which often benefit from supportive policies, including subsidies. Therefore, policy and legislative reform will greatly increase the viability of biofuels development schemes.

Theory of place

Liquid biofuels have the potential to be grown and used globally. Southeast Asia and Latin America have the greatest current potential for biofuel production and progress is being made in South Asia. There is abundant promise for biofuel industries to grow in Africa, but, at present, there are obstacles related to weak and inappropriate policies and governance, and lack of investment. Drivers of demand will vary greatly from place to place. Where farms are already mechanized, they

will benefit from locally grown and processed biodiesel. Similarly, local value-adding enterprises will serve as markets for the product. National policies for blending biofuels into road fuels will be the most likely drivers of larger scale production of biofuels. The real economic benefits of biofuels over unsubsidized fossil fuels are still to be determined, but where markets are not distorted, biofuels have great potential.

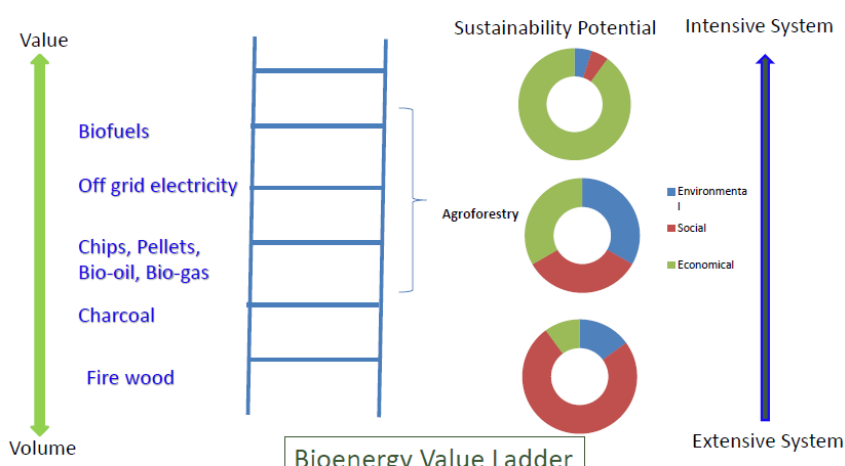


Figure 8. Bioenergy Value Ladder

	Liquid biofuels: interventions
Poverty	<ul style="list-style-type: none"> Identify species with biofuel potential that can be collected for sale from the natural environment by poor people Include collectors in value chains
Incomes	<ul style="list-style-type: none"> Involve rural communities in income-earning parts of the value scale including growing and selling, bulking and selling, and early processing Tailor rural bioenergy schemes to the needs of local communities Introduce pilot schemes (possibly based on multifunctional platforms) to demonstrate the income-earning potential of biofuels
Ecosystems	<ul style="list-style-type: none"> Prospect for, collect and characterize trees with potential to become biofuels feedstocks Domesticate the most promising species Develop agroforestry systems and woodlots for biofuels production Maintain high levels of biodiversity and agricultural diversity where growing biofuels Plan biofuels production at a landscape level, adopting energy-food models and using land-sharing and land-sparing models as appropriate Further develop biofuels production processes that efficiently produce expeller suitable for livestock feed or soil amendment
Climate change	<ul style="list-style-type: none"> Model various scenarios of biofuels use in different places and calculate savings in greenhouse gas emissions to be used in the justification of developing biofuels
Policy	<ul style="list-style-type: none"> Ensure that biofuels are included in national energy policies Eliminate perverse subsidies on fossil fuels that compete with biofuels.

Electricity generation

Theory of change

The United Nations *Sustainable Energy for All* initiative anticipates universal access to electricity by 2030. This is an ambitious goal and will be most challenging in remote areas where it will be expensive to extend the electricity grid. “Mini-grids” supplying communities is a viable option for remote areas and are spreading throughout the world, often driven by micro-hydro. Woody biomass, sometimes in conjunction with crop wastes, has a high potential to provide energy for electricity production in gasifying generators. Their potential has been demonstrated in India and Sri Lanka. It is postulated that trees grown in short rotation plots for biomass can be sustainably produced and provide a perennial source of energy for electricity production. Research will be needed to demonstrate this and to develop the biomass production and generating systems suited to different places and agro-ecological

conditions. It is anticipated that such systems might include the use of crop waste in places where it is produced seasonally, with wood being used during the rest of the year. Biomass-generated electricity will supply households with light and businesses with energy for productive purposes. Poverty impacts will be indirect: providing light for studying and power for mobile telephones and computers. Impacts on income generation could be substantial as income-generating enterprises are able to use electricity. Natural forests should not be used for woody biomass production, except in a well-managed, renewable fashion. Instead, fast-growing species in short rotation lots will provide a sustainable supply of fuel. This will prevent environmental degradation in wooded areas, and the substitution of biomass-generated electricity for electricity from petroleum-driven generators will reduce greenhouse gas emissions.

Theory of place

Woody biomass is used for electricity generation throughout the world, including the use of forest wastes and internationally-traded wood pellets for burning in large power stations. In terms of developing countries, it will likely have most potential for growth where it can provide the energy needs for agricultural enterprises (such as drying and processing). It has great potential

for powering small-scale electrical grids in places where extending the national grid is uneconomical and other sources of energy, such as hydropower, do not compete. There are other sources of biomass, especially agricultural waste; however, these are seasonal and woody biomass has a strong competitive potential in places where it can provide a perennial feedstock to complement the use of seasonally-available feedstocks.

	Electricity generation: interventions
Poverty	<ul style="list-style-type: none"> Supply electricity across mini-grids to households to extend the period during which people can study. Supply electricity to charge and operate mobile telephones and computers
Incomes	<ul style="list-style-type: none"> Supply electricity across mini-grids to small-scale enterprises and businesses (including farming) to enable the development of income-earning activities and increase the length of the business day
Ecosystems	<ul style="list-style-type: none"> Develop short rotation biomass production systems, including selection of the most appropriate species for different locations. Develop combined generating systems that use woody biomass and agricultural waste
Climate change	<ul style="list-style-type: none"> Model various scenarios of biomass-generated electricity use in different places and calculate savings in greenhouse gas emissions to be used in the justification of developing generating capacity
Policy	<ul style="list-style-type: none"> Ensure that the importance of biomass generation is recognized in national energy policies Eliminate perverse subsidies on fossil fuels that compete with biomass



Charcoal production in India from coconut shells: the process takes place in a hole in the ground. Little air enters, so it is fairly efficient. Photo © ICRAF/C Watson



In Kenya, a stack of wood is readied to be set alight and covered with a layer of earth. Most will burn rather than be converted to charcoal. Photo © ICRAF/M Njenga

Gender aspects

The provision of energy is one of the most pressing gender issues in development. As discussed, poor women (and children) bear the greatest burden in providing and using energy for the family. Apart from the work and time involved in collecting firewood, women and children are tasked with cooking and suffer most from indoor air pollution. Any lack of firewood leads to a reduction in the quantity and nutritional quality of the family's food. Women often also bear the greatest burden in growing the family's staple foods, and suffer when ecosystem services suffer, for example, when land degradation or land use change affects water availability for crops. Women are likely to be the greatest beneficiaries of this strategy when it leads to better access to energy and the conservation of productive landscapes.

In addition, women are usually responsible for processing crops, especially pounding grains to de-hull them and make flour. Energy to run grinders and mills would greatly lighten this task. Furthermore, women are the family caregivers. Their quality of life and the ease of caregiving will be substantially improved by access to light, which will also permit children and youth to study after dark. Children and youth will benefit from energy to mechanically power the tasks that currently often prevent them from going to school.

Simply reducing women's burdens would be an inadequate aim for this strategy, however. Women are often excluded from income-earning activities, whether it is growing cash crops or engaging in profitable enterprises. It is therefore important to plan activities under the strategy that maximize the opportunities available to women, and not to assume that any benefits derived will be to the

advantage of women. The experience of UNDP's "Multi-functional Platform" programme can point the way to energy interventions that benefit women. A multi-functional platform is a diesel engine, often mounted in a shipping container, designed so that a number of implements can be mounted on the engine at different times of the day. The implements can be run directly from the engine or by electricity generated by the engine. They include pumps, mills, oil presses, battery chargers and soldering and welding equipment. Batteries can provide lighting or lights can be run directly from a generator.

Multi-functional platforms were designed with women in mind, and women have participated fully in defining the jobs and implements they need. Women have been responsible for the management of the platforms, including when certain services will be made available during the day. The increased shea butter production in a village in Mali from 3kg to 10kg per day demonstrates an example of the success achieved by providing energy (UNDP, 2014).

Access to energy alone will not create opportunities for women to become involved in businesses or other enterprises. It is vital that research involves understanding the specific needs of women, and women must be involved in defining the scope and focus of projects. Equally, implementation of projects should involve women in the project design and be managed in a participatory manner. The context-specific and distinct roles of men should also be fully understood, so that an appropriate gender-relevant programme can be designed.

A DFID case study on the relationship between gender, biomass energy, and poverty in Sri Lanka showed significant impacts of food-energy systems in raising the economic and social stature of women.

In a socio-economic study on the biomass power project in Kumbalgamuwa, the power plant was found to act as a source of secondary income for women, with participation rates of women often

exceeding 40% of the total number of participants involved in the project.

Another study observed that community-level organizations handling production and supply of biomass have the capacity to empower women. Men respect and accept women's contributions to the traditional biomass system, and consider electricity generated by converting farm biomass to be an enabling opportunity for women.

Bioenergy and the CGIAR

Bioenergy has not featured heavily in the CGIAR portfolio of projects. Although the project document for the CGIAR Research Programme on Forests, Trees and Agroforestry (FTA) refers to energy, in practice, little research on bioenergy has been carried out under this CRP. The CGIAR focuses on: the improvement of its mandate crops; livestock; water resources; fish, farming systems; biodiversity; ecology; forest policy; and, agroforestry. The creation of the CGIAR was driven by a growing global concern about the threat of famine. Originally, CGIAR was focused on breakthroughs in plant breeding that would make it possible to greatly increase crop production. The subsequent expansion of the CGIAR and its various changes in focus mirrored changes in policies of the international community at large, particularly a growing environmental consciousness and a recognition of the importance of healthy ecosystems to humanity. Currently the System Level Objectives of the CGIAR are: *Reduced Rural Poverty, Improved Food Security, Improved Nutrition and Health and Sustainably-managed Natural Resources*. The breadth of these objectives reflects an understanding that reducing poverty and achieving food security requires a multidisciplinary approach, including health and nutrition and management of the resource base that people depend upon.

The new CGIAR Results Framework explicitly refers to energy, but the emerging new CRPs do not reflect energy to the extent necessary. There is good alignment between the objectives of the CGIAR and the draft Sustainable Development Goals, with their references to ending hunger, achieving food security, improving nutrition and promoting sustainable agriculture. The SDGs include an important addition to the MDGs: energy. Energy has often been referred to as the

“forgotten MDG”. This has been corrected in the SDGs, which at the time of writing this strategy included Goal number 7: “Ensure access to affordable, reliable and modern energy for all”. Although the goal does not refer explicitly to sustainability, one of its targets is to “increase substantially the share of renewable energy in the global energy mix by 2030”. The need for energy to be sustainable is also recognized by the United Nations at the highest level in the Secretary General’s *Sustainable Energy for All* initiative (SE4ALL). There is scope for CGIAR Centres to branch out into bioenergy research, including but not restricted to FTA.

Global policies on energy have certain internal inconsistencies. While the need for sustainability is generally recognized, policies (as epitomized by the SDGs and SE4ALL) pay greater attention to the rights of all to access modern energy systems. This is the result of decades-long discussions about whether it is fair to require developing countries and emerging economies to forgo the benefits of coal, gas and oil, even though developed countries grew their economies by using fossil fuels and still burn prodigious amounts. As a result, the energy policies of most developing countries are based on the use of fossil fuels, with far less attention paid to renewables. The conundrum for ICRAF and the CGIAR is whether enabling greater use of firewood and charcoal is consistent with efforts to achieve sustainability, and whether liquid biofuels and woody biomass can contribute to modern energy systems. *This strategy will set out to establish that the use of firewood and charcoal by the poor will persist for many years, that it can be made sustainable, and that woody biomass can provide access to modern energy systems.*

Rationale for ICRAF to undertake the programme

The strategy is well aligned with the CGIAR Strategic Results Framework (Table 4).

Table 4. CGIAR Strategic Results Framework: contribution of bioenergy strategy to Intermediate Development Objectives

Intermediate Development Objective	Sub-Intermediate Development Objective	Contribution of Bioenergy Strategy
SLO Reduced poverty		
Increased resilience of the poor to climate change and other shocks	Household capacity to cope with shocks	More stable energy supply, improved nutritional security, improved health
	Reduced production risk	Diversified crop/energy systems
Enhanced smallholder market access	Reduced market barriers	Bioenergy value chains developed and functioning
Increased incomes and employment	Diversified enterprise opportunities	Options for growing energy crops and integrated food-energy systems Access to energy opens new enterprise possibilities
	Increased livelihood opportunities	Options to participate in value chains for energy feedstocks
	Increased value capture by smallholders	Access to bioenergy markets
Increased productivity	Enhanced genetic gain	Domestication and improvement of trees for increased biofuel production and rate of biomass growth
	Closed yield gaps through improved agronomic and animal husbandry practices	By-products from bioenergy fuel processing available as animal food and soil amendment material
SLO Improved food and nutritional security for health		
Increased dietary quality	Optimized consumption of diverse nutrient-rich foods	Assured supply energy improved cooking systems
SLO Improved natural resources systems and ecosystems services		
Natural capital enhanced and protected, especially from climate change	Land, water and forest degradation (including deforestation) minimized and reversed	Agroforestry production of bioenergy feedstocks and improvement of bioenergy production processes reduces pressure on natural forests
Enhanced benefits from ecosystem goods and services	Agricultural systems diversified and intensified in ways that protect soils and water	Diversified fuel-food systems in productive landscapes lead to greater introduction of trees
More sustainable managed ecosystems	Increased resilience of agro-ecosystems and communities, especially those including smallholders	Diversified agro-ecosystems to include trees for bioenergy increases plant and animal diversity and provides more economic options for communities
	Reduced net greenhouse gas emissions from agriculture forests and other forms of land use.	Adoption of renewable bioenergy systems

Table 4. CGIAR Strategic Results Framework: contribution of bioenergy strategy to Intermediate Development Objectives for cross-cut

Intermediate Development objective	Sub-Intermediate Development Objective	Contribution of Bioenergy Strategy
Cross-cutting issue – climate change		
Mitigation and adaptation achieved	Increased above- and below-ground biomass for carbon sequestration	Use of trees for bioenergy increases carbon sequestration and substitutes for use of fossil fuels
Cross-cutting issue – gender and youth		
Equity and inclusion achieved	Technologies that reduce women's labour and energy expenditure developed and disseminated.	Efficient cooking systems reduce drudgery among women and children in collecting cooking fuel Biofuels provide energy for agricultural mechanization, food production, pumping water and numerous economic enterprises
Cross-cutting issue – policies and institutions		
Enabling environment improved	Conducive agricultural policy environment	National agricultural and energy policies integrated
Cross-cutting issue – Capacity development		
National partners and beneficiaries enabled	Increased capacity for innovation in partner development organizations and in poor and vulnerable communities	Enhanced capacities along bioenergy value chains Improved individual and community capacity to benefit from bioenergy development

Of all of the CGIAR Centres, ICRAF is best positioned to manage this strategy. The strategy specifically focuses on tree-based energy and how energy can be supplied by trees under agroforestry systems without imposing greater pressure on forested ecosystems. This matches ICRAF's mandate, experience and skills. Additionally, ICRAF brings a great deal of relevant experience to bear. Within ICRAF, each Science Domain will make important contributions to research into bioenergy.

SD1. Systems Science

- Sustainability requirements will determine that trees for energy will seldom be taken from natural forests. Instead, they will be grown in productive landscapes, either in woodlots or as elements in agroforestry systems.
- There will be need to develop short rotation production systems and to understand how to grow sufficient biomass to meet different demands in different places.

- Trees for biofuels may be collected from the wild in some situations, but when demand increases, there will be an increased need to incorporate trees into agroforestry systems.

SD2. Markets, value chains and institutions

- Value chains will be at the heart of using trees as sources of bioenergy.
- A particular challenge will be to adapt charcoal value chains to eliminate rent-seeking and corruption and to provide incentives for sustainability through equitable distribution of benefits.
- New value chains will be developed for biofuel feedstocks. These will stretch from the collection of nuts and fruits to collection from farms to accumulation for marketing to local or large-scale producers.

SD3. Tree diversity, domestication and delivery

- The availability of the best species of trees for firewood, charcoal and dendrothermal

plants will require empirical research, tree selection, production of planting materials and systems for delivery.

- The development of biofuels will require the identification of trees with high oil and by-product potential and their domestication and improvement.

SD4. Land health decisions

- There will be different options for introducing different energy systems in different places along the forest transition curve. Knowledge of the health of the various places will be vital to understanding options for different systems.
- The trees associated with the energy systems will contribute to improved land health.

SD5. Environmental services

- The programme focuses strongly on the creation of multifunctional landscapes. It will address the sustainable management of landscapes, including their ecosystem services and production of energy, including liquid biofuels..
- Research will focus on understanding tree-based energy options and how they interact with ecosystem services.

SD6. Climate change

- The underlying premise of the research is that, if properly understood and exploited, tree-based bioenergy is renewable and its increased use will contribute to low carbon emissions.
- Considerable research will be needed on life-cycle assessments of the various bioenergy options that will be investigated.

Congruence with ICRAF's research philosophy

ICRAF's vision is a rural transformation in *the developing world as smallholder households increase their use of trees in agricultural landscapes to improve food security, nutrition, income, health, shelter, social cohesion, energy resources and environmental sustainability*. This

strategy is a contribution to that vision.

ICRAF is a CGIAR Centre that takes a systems approach to its work. This strategy sets out to go beyond simply providing energy feedstocks to establishing energy systems, including cooking systems, production systems, biofuels systems and generating systems.

Implementation of this strategy will lead to the identification of many options for improving energy systems under a large number of contexts. ICRAF's leadership in identifying the most promising options through context analytical matrices will be invaluable to the research.

ICRAF is pioneering a *Research in Development* approach to ensuring impacts from its work. This will be applied throughout the implementation of this strategy.

Partnerships

The strategy covers disciplines and topics that ICRAF is not well set-up to cover on its own. This strategy will need to become a model within the CGIAR of a research in development initiative that is carried out through partnerships with research and development partners. The themes where strong partners will be needed include:

CGIAR Centres

- Forests policy (CIFOR)
- Crop-based biofuels (several Centres)
- Integrating energy production into food policies (IFPRI)

Research institutions

- Energy options analysis
- Life cycle energy production efficiency
- Life cycle greenhouse gas emissions analysis
- Biofuels processing
- Electricity generation from biomass

Development institutions

- Energy policy
- Value chains
- Institutional strengthening
- Capacity development
- Finance

Private sector

- Large private sector companies who are members of the Sustainable Energy for All High Impact Opportunity on Bioenergy (of which ICRAF is a member)
- Small entrepreneurial enterprises in developing countries
- Investors

Perceived risks and costs of inaction

Bioenergy is a gateway to many areas of development, such as livelihoods, quality of life for women and children, women's health, energy security, food production, nutrition security, and abatement of greenhouse gas emissions. It is also linked to the development of alternative land use systems for long-term sustainable development. We realize that there are far more positives to this strategy than perceived risks.

The perceived risks may come from engaging in liquid biofuel areas, particularly with monoculture approaches (in an intensive system) with food crops that may lead to land use change. Several negative impacts of first generation biofuels have been identified, and efforts are underway to address these challenges. Biofuels derived from food crops have been blamed for the food crisis in 2008 because of a diversion of food crops to biofuel production. However, if managed sustainably and produced via non-food or multiple-use feedstocks, biofuels can potentially be a part of efforts to mitigate climate change risks (EA, 2008; Berndes et al, 2011; WEC, 2013).

To address the issue of LUC and the 'fuel vs. food' debate, it is important to avoid displacing commercially attractive food crops from their most suited agro-ecologies and to use marginal land unfit for agriculture or surplus land suitable for production of second generation biofuels. It is now very clear that current biofuel crops

(food crops) are not sustainable. Moreover, in their current form and implementation, such as monoculture in agricultural landscapes, they have limitations in their ability to achieve targets for oil product substitution, climate change mitigation, and, more importantly, economic growth of smallholder farmers. However, if non-food or multiple use crops, notably well proven and locally adapted tree species, are considered and smart farming systems are developed that can address food security and livelihoods of smallholder farmers and can provide local energy for agriculture production, it has the potential to address both mitigation and adaptation aspects of climate change risks.

Trees on farms or outside forests will be the basis of future biofuels; smart agroforestry systems will be crucial to addressing the challenges faced by first generation biofuels. Clearly, the cost of inaction for ICRAF outweighs the perceived risks.

As FAO Director General Graziano da Silva remarked, "It is important not to forget that biofuel emerged with strength as an alternative energy source because of the need to mitigate fossil fuel production and greenhouse gases – and that need has not changed"¹. He also emphasized the need to rethink the whole area as 'food and fuel' and not food vs. fuel.

¹ <http://www.fao.org/news/story/it/item/275009/icode/>

Programme implementation

It is initially proposed that the strategy be established as a cross-Science Domain activity, under the direction of a coordinator who will be accountable to the Deputy Director General, Research.

At the time of writing this strategy, work had started on defining the structure of a revised set

of CGIAR Research Programmes. This strategy could lead to the inclusion of energy into the Forest and Agroforestry Landscapes CRP. It should also have links to Climate Change, Policies Institutions and Markets and Water Land Soils and Ecosystems.

Final draft (edited and improved)

2 September 2015

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