NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Bioenergy Assessment Toolkit

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Technical Report
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October 2012
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Introduction

Bioenergy is the most widely used renewable source of energy in the world, providing about 10% of the world primary energy supplies. Biomass energy is derived from plant-based material whereby solar energy has been converted into organic matter. Sources include forestry and agricultural crops and residues; byproducts from food, feed, fiber, and materials processing plants; and post-consumer wastes such as municipal solid waste, wastewater, and landfill gas.

Biomass can be used in a variety of energy-conversion processes to yield power, heat, steam, and transportation fuels (Figure 1). Traditional biomass already provides the main source of energy for household heating and cooking in many developing nations. It is also used by food processing industries, the animal feed industry, and the wood products industry, which includes construction and fiber products (paper and derivatives), along with chemical products made by these industries that have diverse applications including detergents, fertilizers, and erosion control products.

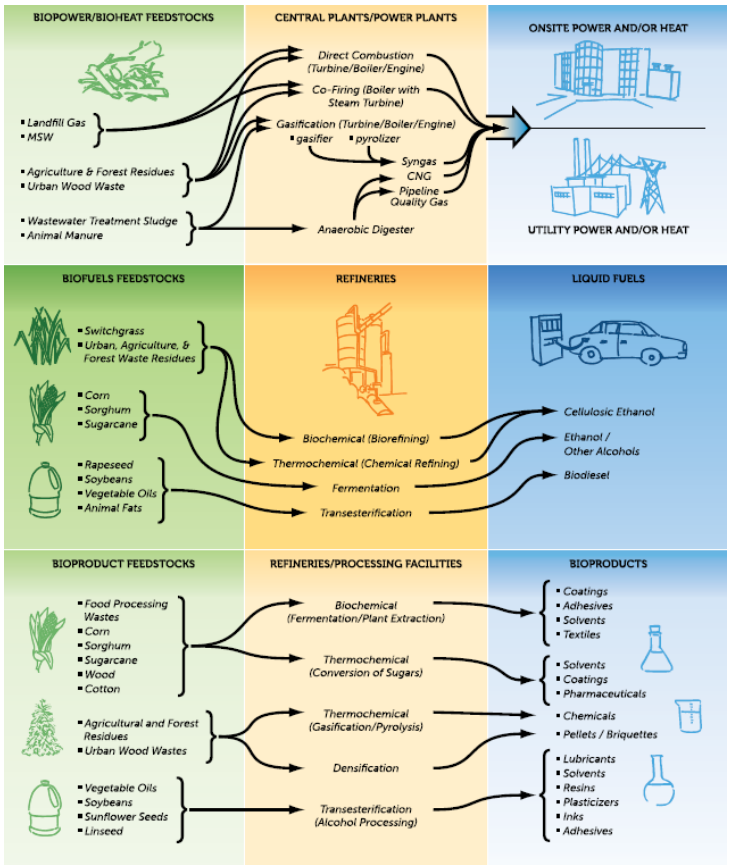

Figure 1. Biomass conversion pathways

Source: U.S. Environmental Protection Agency (EPA) State Bioenergy Primer (2009)
http://www.epa.gov/statelocalclimate/resources/bioenergy-primer.html

Here we describe a process by which bioenergy opportunities can be assessed along with a set of resources to assist in this process. The first step in identifying bioenergy opportunities in a given area is to examine feedstock availability – their quantity, location, and costs. An assessment of biomass resources is best followed by an assessment of the potential markets and competition for those feedstocks. This step includes technology evaluation, high-level cost estimates, assessment of socio-economic and environmental impacts, as well as review of existing/proposed policies and import/export opportunities. Once a promising bioenergy opportunity is identified, a detailed feasibility study can be performed to determine its economic viability--or a roadmap is developed to outline steps necessary for implementation of national research, development, and deployment efforts.

Step 1. Assess Biomass Resource Availability

The development and scale-up of any bioenergy project begins with an analysis of the resource potential. Generally speaking, there are three types of biomass resource potential: theoretical, technical, and economic.

- *Theoretical:* Illustrates the ultimate resource potential based on calculations of all existing biomass, with no constraints on access or cost-effectiveness.
- *Technical:* Limits the theoretical resource potential by accounting for terrain limitations, land use and environmental considerations, collection inefficiencies, and a number of other technical and social constraints. This type of potential is also called accessible biomass resource potential.
- *Economic:* Economic parameters are applied to the technical resource potential, which results in a subset of the technical potential along with an estimate of the cost of biomass resources either at the field or forest edge. The final outcome of this type of assessment is a supply curve ($/tonne).

Products that assess biomass resources have different information characteristics and applicability. The assessments vary depending on the purpose and the level of detail required. The purpose of an assessment is to identify resource potential within a given area for a particular end use, for example, power or transportation fuels. The level of detail also varies between biomass resource assessments. High-level, aggregated information--such as assessments at national, regional, and state/province level--are usually required by policy makers, whereas more detailed information at a county/district or site-specific level is required by energy planners and project developers. The purpose of a biomass resource assessment and the required level of detail should dictate the method for assessing resources. The current evaluation methods include geospatial technologies (geographic information systems and remote sensing), field surveys, and modeling (linear, statistical, geospatial, etc.). These products can be presented in a different format: tabular, graphic (charts or graphs), geographic (maps), or as analytical tools and software products.

Table 1 contains links to data to support biomass resource assessments, tools to conduct such work, and examples of relevant studies.

Table 1. Biomass Resource Assessment Tools and Studies

Resource	Description	URL
Food and Agriculture Organization (FAO)	FAOSTAT provides time-series and cross sectional data related to food and agriculture for some 200 countries.	http://faostat.fao.org/site/291/default.aspx
The Food and Agricultural Policy Research Institute (FAPRI)	FAPRI provides data, tools, and models to support analysis of the food and agriculture industry. It maintains Commodities Database (which provides historic and projected information for several countries, products, and variables such as acreage, yield, and demand), Elasticity Database, and modeling structure for grains, oilseeds, livestock, dairy, sugar, and U.S. crop insurance model.	http://www.fapri.org/
USDA Foreign Agricultural Service (FAS)	This site offers world production information as well as markets and trade data and reports. It also offers the Crop Explorer tool and Global Agricultural Information Network (GAIN) reports.	http://www.fas.usda.gov/default.asp
ECN Phyllis	Phyllis is a database containing information on the composition of biomass and waste. It enables you to make analysis data of individual biomass or waste materials available and offers the possibility to obtain the average composition of any combination of groups and/or subgroups.	http://www.ecn.nl/phyllis/
Bioenergy Atlas	The BioEnergy Atlas includes two interactive maps, BioPower and BioFuels. These interactive geospatial applications allow users to view biomass resources, infrastructure, and other relevant information, as well as query the data and conduct initial screening analyses.	http://maps.nrel.gov/bioenergyatlas/
Biomass Inventory Mapping and Analysis Tool (BIMAT)	The Biomass Inventory Mapping and Analysis Tool (BIMAT) was developed to allow users to learn more about the availability of Canadian herbaceous and woody opportunity biomass as well as the spatial variability of the resource across Canada. This application provides internet-based GIS functionality that allows users to query and visualize biomass inventory data. They will have the ability to make well informed decisions based on spatially explicit information that presents a nationally comprehensive picture of biomass quantity and opportunity across Canada. Biomass supply and location information is made available through a collection of thematic maps and interactive queries of the herbaceous and woody databases.	http://www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1226509218872&lang=eng
The Woodfuel Integrated Supply/Demand Overview Mapping (WISDOM)	WISDOM is a spatial-explicit method for highlighting and determining priority areas of intervention and supporting wood energy / bioenergy planning and policy formulation.	http://www.wisdomprojects.net/global/

Resource	Description	URL
The Biomass Assessment Handbook	The handbook is intended to provide a practical, common methodology for measuring and recording the consumption and supply of biomass energy. It mainly emphasizes traditional bioenergy use, but modern uses are also considered. It provides guidance on how to measure biomass potential, volume of trees and biomass flows, etc.	http://www.earthscan.co.uk/
Integrated Biomass Supply Analysis & Logistics (IBSAL) Model	The IBSAL model is a simulation of the biomass supply chain. It is made of a network of operational modules and connectors threading the modules. Each module represents a process or event. For example grain combining, swathing grasses, baling, grinding and sizing, storing, and transporting are each separate modules. Modules may also be processes such as drying, wetting, and chemical reactions such as breakdown of carbohydrates. In addition, costing and energy calculations common to all operations are gathered into individual modules. Each module is independently constructed with a set of inputs and outputs. The module may also interact with an external Excel spreadsheet that receives or writes data. The biomass flows from one module to the next through a connector. The time the biomass spends in the system is determined by the modules and not by the connectors.	https://bioenergy.ornl.gov/
Global Agro-Ecological Zones (GAEZ)	GAEZ is a system that enables rational land use planning on the basis of an inventory of land resources and evaluation of biophysical limitations and potentials. It provides data on soil terrain and climate constraints to rain-fed agricultural production, suitability results for 27 crops under rain-fed conditions, and land with cultivation potential for major agricultural crops.	http://www.iiasa.ac.at/Research/LUC/GAEZ/
Interactive Compete Maps	The Interactive COMPETE Maps synthesize information from a range of high quality sources that have categorized and evaluated land use patterns in Africa with a view to identify land (a) suitable for biomass production for energy, (b) suitable for biomass production for other uses, and (c) land that can be filtered out because it is not available or not suitable for inclusion in future bioenergy land use scenarios.	http://www.compete-bioafrica.net/current_land/current_land.html

Automated Land Evaluation System (ALES)	The Automated Land Evaluation System, or ALES, is a system, which allows countries to determine the crops that are physically and economically best suited to their respective land units. ALES allows land evaluators to build expert systems to evaluate land according to the method presented in the Food and Agriculture Organization *Framework for Land Evaluation* (FAO 1976). It is intended for use in project or regional scale land evaluation. The entities evaluated by ALES are map units, which may be defined either broadly (e.g., in reconnaissance surveys and general feasibility studies) or narrowly (e.g., in detailed resource surveys and farm-scale planning).	http://www.un.org/esa/sustdev/natlinfo/indicators/idsd/infosyst/ales.htm
Examples		
U.S. Billion-Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry	This report is an economic assessment of the current and potential biomass resources in the United States that includes projections by 2030 and a spatial county-by-county inventory of primary feedstocks. It also contains prices and available quantities (e.g., supply curves) for the individual feedstocks such as crop residues, forest residues, primary mill residues, urban wood waste, and dedicated energy crops.	http://www1.eere.energy.gov/biomass/pdfs/billion_ton_update.pdf
A Geographic Perspective on the Current Biomass Resource Availability in the United States	This is a technical assessment of the current biomass resources in the United States by county. Biomass feedstock data are analyzed both statistically and graphically using GIS. The following feedstock categories are evaluated: crop residues, forest residues, primary and secondary mill residues, urban wood waste, and methane emissions from manure management, landfills, and domestic wastewater treatment.	http://www.nrel.gov/docs/fy06osti/39181.pdf
International Biomass Resource Assessments	This resource contains biomass resource assessments conducted for several countries by the U.S. National Renewable Energy Laboratory (NREL): China, Liberia, India, Afghanistan, and APEC economies.	http://www.nrel.gov/international/biomass_resource.html
Survey of Biomass Resource Assessments and Assessment Capabilities in APEC Economies	Here, one can find biomass resource assessments for 21 countries along the Pacific Rim that are members of the Asia-Pacific Economic Cooperation (APEC).	http://www.nrel.gov/international/pdfs/43710.pdf
A Modeling Framework for the Analysis of Biomass Production in a Land Constrained Economy - The Example of Austria	The aim of this discussion paper is to explore consequences for land use and environment if biomass production will be expanded for non-food purposes in Austria. We assess the biophysical and economic production potentials of energy crops and explore the trade-offs between bioenergy and food production on arable lands in Austria.	http://www.wifo.ac.at/wwa/downloadController/displayDbDoc.htm?item=S_2011_BIOMASSPRODUCTION_41748$.PDF

Step 2. Conduct Market Analysis

Analyzing the existing and potential markets for biomass resources, along with barriers, is critical when planning a bioenergy program. A thorough understanding of the market size, growth, regional segmentation, and trends relies on many different inputs such as:

- State of technology and the country's experience with each technology
- Production cost
- Socio-economic and environmental impacts of biomass production and use
- Policy framework in support of the biomass industry
- Trade opportunities.

Evaluate the State of Technology

A variety of technologies can transform biomass into energy for residential, commercial, and industrial uses. Generally, these technologies fall into four categories, each appropriate for specific biomass types and resulting in specific energy products:

- *Thermal Conversion:* The use of heat to convert biomass material into other forms of energy. This type of conversion includes direct combustion, pyrolysis (heating biomass in the absence of oxygen to produce a liquid bio-oil), and torrefaction (a process of mild pyrolysis resulting in a solid product with a lower moisture content and a higher energy content compared to those in the initial biomass).
- *Thermo-chemical Conversion:* The use of heat and chemical processes in the production of energy products from biomass. An example of such process is gasification (heating biomass with about one-third of the oxygen necessary for complete combustion, which produces a mixture of carbon monoxide and hydrogen, known as syngas).
- *Biochemical Conversion:* The use of enzymes, bacteria, and other microorganisms to break down biomass into liquid fuels, chemicals, heat, and electricity. This conversion type includes anaerobic digestion and fermentation.
- *Chemical Conversion:* The use of chemical agents to transform biomass into other forms of useable energy. An example is the transesterification process, which causes the feedstock (vegetable oils) to react with alcohol (usually methanol) to produce chemical compounds known as fatty acid methyl esters (FAME). Biodiesel is a common end-product of transesterification, as are glycerin and soaps.

The biomass conversion technologies are in various stages of development. Some of these technologies are in commercial or pre-commercial production, making them cost-competitive, while others are still in the research and development phase. For example, biofuels production from starches and sugars via fermentation and from vegetable oils through transesterification are well-established technologies, while the production of biofuels and drop-in fuels (fuels that can make use of existing refining and distribution) from lignocellulosic material are still in the demonstrational and pilot stages. Although some of the conversion processes (e.g., gasification of biomass followed by synthesis to liquid fuels) have been known for the past few decades, low

petroleum prices have prevented their further development during that time. Increasing oil prices and energy security concerns have renewed the interest in bioenergy in the past few years, thus reviving the R&D in conversion technologies. The advanced technologies being developed have the potential to substantially expand the feedstock base for bioenergy in the future (e.g., lignocellulosic biomass, non-edible vegetable oils, algae) and alleviate some of the environmental and social concerns associated with the industry. Research and technology deployment over the next several years are likely to answer many questions about the economic viability of these technologies. A lot will depend on the rate of recovery of world economies, oil prices, carbon market, and political climate.

Table 2 contains links to informational sources for different biomass conversion pathways.

Table 2. Technology Evaluation Tools and Studies

Resource	Description	URL
Thermo-chemical conversion of biomass	This page contains a description and videos of the thermo-chemical conversion processes.	http://www.nrel.gov/biomass/thermochemical_conversion.html
Bio-chemical conversions of biomass	This page contains a description and video of the bio-chemical conversion processes.	http://www.nrel.gov/biomass/biochemical_conversion.html
Examples		
Bioenergy Conversion Technology Characteristics (Western Governors' Association)	This source investigates the biofuel conversion technologies that are currently available, as well as the technologies under development that could potentially be available by 2015.	http://www.westgov.org/component/joomdoc/doc_download/214-wga-bioenergy-assessment-conversion-tech
Algae as a Feedstock for Biofuels	Here can be found an assessment of the status and potential for algal biofuels production.	http://www.ieabioenergy.com/MediaItem.aspx?id=6965
Energy from Biomass: A Review of Combustion and Gasification Technologies (World Bank Technical Papers)	This report reviews the state-of-the-art of biomass combustion and gasification systems and their advantages and disadvantages. It also encourages investment in use of these technologies to enable developing countries to better utilize their biomass resources and help close the gap between their energy needs and their energy supplies.	http://www-wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2000/07/08/000094946_99033105581764/Rendered/PDF/multi_page.pdf
Market Opportunities for Biogas Recovery Systems at US Livestock Facilities	This document assesses the market potential for biogas energy projects at swine and dairy farms in the United States. For the top ten swine and dairy states, the guide characterizes the sizes and types of operations where biogas projects are technically feasible, along with estimates of potential methane production, electricity generation, and greenhouse gas emission reductions.	http://www.epa.gov/agstar/documents/biogas_recovery_systems_screenres.pdf
Mini Biogas Plants for Households	This manual aims to support the development of biogas programs as Clean Development Mechanism (CDM) Program of Activities (PoA) and to assist in determining the most suitable setup for them.	http://cd4cdm.org/Publications/PoAManualBiogasHouseholds.pdf

Assess Production Cost

Important considerations for any project are costs and the expected revenues. The cost of energy produced from biomass depends on a wide range of factors including the type and availability of feedstock, end product (power or fuel), conversion technology involved, cost of labor, price of fossil fuels, cost of storage, size of the plant, location of the plant (transportation costs), etc. The existence of relevant national and sub-national incentives can also greatly impact the cost of producing fuels and power from biomass. Given that the cost of feedstock frequently makes up a high percentage of energy costs, volatility of agricultural markets must also be assessed.

Table 3 contains links to models and tools to support cost analysis, as well as examples of relevant studies.

Table 3. Techno-Economic Analysis Tools and Studies

Resource	Description	URL
Aspen Process Economic Analyzer	This is a powerful project-scoping tool that enables process engineers to evaluate the economic impact of their process designs (including generation of overall investment cash flow curves to quantify the contribution of the plant or the owner's business). Aspen Process Economic Analyzer is most valuable in the early phases of the conceptual design to compare competing technologies and/or evaluate alternative process configurations. It can expand unit operations from simulator output to equipment models using proprietary mapping technology, and calculate preliminary sizes for these equipment items.	http://www.aspentech.com/products/aspen-icarus-process-evaluator.aspx
Biochains Economic Evaluation (BEE)	Bee is a packaged computerized model that performs full economic evaluation of bioenergy chains based on the cultivation and production of biomass from different bioenergy crops. It examines the whole chain from farm to useful energy or fuel delivered at the conversion plant gate and it may analyze more than one crop and more than one conversion technology at the same time. The analysis consists of all the steps necessary for decision making and capital budgeting (i.e. cost analysis), and investment appraisal. For this purpose, it maintains monthly balance sheets, cash flows, and income statements of each and all of the project modules. It also estimates and analyzes the full cost of biomass production and calculates the most important financial indices and criteria of investment appraisal.	http://www.aua.gr/tmhmata/oikonom/soldatos/Bee/BeeHelp/meth_bee.htm

Resource	Description	URL
RET Finance	RET is a levelized cost-of-energy model, which simulates a detailed 20-year nominal dollar cash flow for renewable energy power projects including project earnings, cash flows, and debt payment to calculate a project's levelized cost-of-electricity after-tax nominal Internal Rate of Return and annual Debt-Service-Coverage-Ratios.	http://analysis.nrel.gov/retfinance/
Energy Technology Cost and Performance Data	Recent cost estimates for utility-scale and distributed generation (DG) renewable energy technologies are available across capital costs, operations and maintenance (O&M) costs, capacity factor, and levelized cost of energy (LCOE). Where applicable, links to utility-scale and DG data are available under the tab headings. The LCOE tab provides a simple calculator for both utility-scale and DG technologies that compares the combination of capital costs, O&M, performance, and fuel costs.	http://www.nrel.gov/analysis/tech_cost_data.html
Examples		
Techno-Economic Analysis of Autotrophic Microalgae for Fuel Production	The present study aims to establish baseline economics for two microalgae pathways by performing a comprehensive analysis using a set of assumptions for what can reasonably be achieved within a five-year timeframe. Specific pathways include autotrophic production via both open pond and closed tubular photobioreactor (PBR) systems. The production scales were set at 10 million gallons per year of raw algal oil, subsequently upgraded to a "green diesel" blend stock via hydrotreating. Rigorous mass balances were performed using Aspen Plus simulation software, and associated costs were evaluated on a unit-level basis.	Source: Applied Energy. Vol. 88(10) October 2011 Pages/Volumes: pp. 3524-3531 Publication Year: 2011 http://www.sciencedirect.com/science/article/pii/S0306261911002406
Techno-Economic Analysis of Biochemical Scenarios for Production of Cellulosic Ethanol	A techno-economic analysis on the production of cellulosic ethanol by fermentation was conducted to understand the viability of liquid biofuel production processes within the next five to eight years. Initially, 35 technologies were reviewed, and then a two-step-down selection was performed to choose scenarios to be evaluated in a more detailed economic analysis.	http://www.nrel.gov/docs/fy10osti/46588.pdf
Techno-Economic Analysis of Biomass Fast Pyrolysis to Transportation Fuels	This study develops techno-economic models for assessment of the conversion of biomass to valuable fuel products via fast pyrolysis and bio-oil upgrading.	http://www.nrel.gov/docs/fy11osti/46586.pdf
Biofuel Costs, Technologies and Economics in APEC Economies	The objective of this study is to analyze and compare the cost of production of various biofuels against the petroleum-based fuels they displace, factoring out the impact of subsidies wherever possible.	http://www.biofuels.apec.org/pdfs/ewg_2010_biofuel-production-cost.pdf

Assess Socio-Economic Impacts

Particularly because of its potential impact on food production, rural development, and poverty alleviation, a bioenergy project needs to be evaluated based on the benefits it can provide to the society and the economy involved. Bioenergy initiatives affect the communities in which they are implemented in various ways. Potential impacts may include creation or loss of jobs and greater access to energy, as well as impacts on food, feed, and land prices. Bioenergy has the potential to stimulate agricultural productivity, thus it can lead to improving the livelihood of rural populations. The large-scale use of bioenergy may directly compete with land use, water resources, and labor for food production, which may affect food security if not properly managed. This could have an adverse effect on a country's economy, particularly in the developing parts of the world, thus it is essential to capture, evaluate, and numerate the social and economic impacts associated with bioenergy production.

Table 4 contains links to models and tools to support socio-economic impact analysis, as well as examples of relevant studies.

Table 4. Socio-Economic Impact Analysis Tools and Studies

Resource	Description	URL
Jobs and Economic Development Impacts (JEDI)	The JEDI biofuel models include a JEDI Dry Mill Corn Ethanol and a JEDI Lignocellulosic Ethanol. These JEDI models allow users to estimate economic development impacts from biofuel projects. Each of the JEDI models have default information that can be utilized to run a generic impact analysis assuming industry averages. Model users are encouraged to enter as much project-specific data as possible.	http://www.nrel.gov/analysis/jedi/about_jedi_biofuels.html
Biomass Socio-Economic Multiplier Model (BIOSEM)	BIOSEM facilitates existing data so that the employment and income benefits from bioenergy development and deployment in rural areas can be measured. The model simulates the interaction between agricultural crops, biomass production, energy production, and other sectors of the economy.	http://ec.europa.eu/research/agro/fair/en/uk1389.html
Evaluation of Local Value Impacts for Renewable Energy (ELVIRE)	ELVIRE is a socio-economic model that outlines a project's likely impact on regional economic development, employment, the return on public finances, and sustainable development.	http://www.fedarene.org/
Strategic Assessment Framework for the Implementation of Rational Energy (SAFIRE)	SAFIRE is an engineering-economic bottom-up model for assessing the impact of energy technology and associated policies on a number of economic indicators: market penetration; net employment creation; pollutant emissions; value added; import dependency; capital expenditure; external costs; and government expenditure. It provides policymakers and decision makers with a tool to evaluate the market and impact of new energy technologies and policies.	http://safire.energyprojects.net/
Global Bioenergy Partnership Indicators of Sustainable	The Global Bioenergy Partnership developed 24 sustainability indicators and the corresponding methodology sheets to provide policymakers and other stakeholders with a tool that can support the	http://www.globalbioenergy.org/fileadmin/user_upload/gbep/docs/Indicators/The_GBEP_S

Resource	Description	URL
Bioenergy Production and Use	development of national bioenergy policies and programs. This tool also helps users interpret and respond to the environmental, social, and economic impacts of bioenergy production and use. The indicators take a holistic approach to assessing many important aspects of the intersection of bioenergy and sustainability, including greenhouse gas emissions, biological diversity, the price and supply of a national food basket, access to energy, economic development, and energy security.	ustainability_Indicators_for_Bioenergy_FINAL.pdf
Examples		
Socio-Economic Impacts of Biomass Feedstock Production	This report provides an overview of the most relevant socio-economic impacts of raw material from biomass production for a set of selected case studies.	http://www.globalbiopact.eu/images/stories/publications/Global-Bio-Pact%20D2.1__2010-12-06-b.pdf
Case Studies for Socio-Economic Impact Analysis	These studies assess the socio-economic impacts of various feedstock material and different conversion: • Biodiesel from soy in Argentina • Palm oil and biodiesel in Indonesia • Jatropha oil and biodiesel in Tanzania • Jatropha oil and biodiesel in Mali • Bioethanol from sugarcane in Brazil • Bioethanol from sugarcane in Costa Rica • Lignocellulosic ethanol refinery in Canada.	http://www.globalbiopact.eu/index.php?option=com_content&view=article&id=60&Itemid=72
A Study of Employment Opportunities from Biofuel Production in APEC Economies	To determine the potential impact of the biofuel industry on employment opportunities in APEC economies, a model was built to capture the input costs of operating an ethanol or biodiesel plant and then translate them into employment figures. Such figures include not only the people involved in operating the plant, but also those involved in supplying it with feedstock and for feedstock transportation. Because the biofuels industry is subject to many socio-economic and political influences, the model is constructed to accommodate a wide range of inputs.	http://www.biofuels.apec.org/pdfs/ewg_2010_biofuels_employment.pdf
Socio-Economic Analysis of the Firewood Market	The scope of this report is to present the socio-economic impacts of the firewood use in Europe. These include employment, creation of local industry, enhancement of the local economy, and the competitive development of renewable energy projects in comparison with fossil fuel technology projects.	http://www.eufirewood.info/GetItem.asp?item=digistorefile;135545;985&params=open;gallery
Bioenergy and Food Security (BEFS)	The main objective of the BEFS Project is to ensure that food security concerns are taken into account within the bioenergy sector. The website describes the BEFS analysis methodology and examples of such analysis for several countries including Peru, Tanzania, and Thailand.	http://www.fao.org/bioenergy/foodsecurity/befs/en/

Assess Environmental Impacts

The modern production and use of biomass resources, when managed properly, offers many benefits to the environment including offsetting GHG emissions associated with burning fossil fuels, waste utilization, reduced indoor air pollutants, and erosion control, among others. On the other hand, biomass production and use could have some negative environmental impacts, such as deforestation, loss of biodiversity, soil erosion, and reduced water quality. Therefore, it is necessary to conduct an assessment prior to the implementation of bioenergy technologies in order to reveal opportunities for minimizing negative impacts and optimizing positive impacts on the environment.

Table 5 contains links to models and tools for environmental impact analysis, as well as examples of relevant studies.

Table 5. Environmental Impact Analysis Tools and Studies

Resource	Description	URL
Global Bioenergy Partnership Indicators of Sustainable Bioenergy Production and Use	The Global Bioenergy Partnership developed 24 sustainability indicators and the corresponding methodology sheets to provide policymakers and other stakeholders with a tool that can support the development of national bioenergy policies and programs. This tool also helps users interpret and respond to the environmental, social, and economic impacts of bioenergy production and use. The indicators take a holistic approach to assessing many important aspects of the intersection of bioenergy and sustainability, including greenhouse gas emissions, biological diversity, the price and supply of a national food basket, access to energy, economic development, and energy security.	http://www.globalbioenergy.org/fileadmin/user_upload/gbep/docs/Indicators/The_GBEP_Sustainability_Indicators_for_Bioenergy_FINAL.pdf
The Greenhouse Gases, Regulated Emissions, and Energy use in Transport (GREET) Model	The GREET is a freely available life cycle model developed by the U.S. Argonne National Laboratory. It integrates energy and emission impacts of advanced and new transportation fuels, the fuel cycle from well to wheel, and the vehicle cycle through material recovery and vehicle disposal. It allows researchers and analysts to evaluate various vehicle and fuel combinations on a full fuel-cycle/vehicle-cycle basis.	http://greet.es.anl.gov/
SimaPro	SimaPro is a widely used tool for life cycle assessment (LCA), allowing the collection, analysis, and monitoring of environmental information for products and services. The software follows the ISO 14040 series and has integrated databases and impact assessment procedures.	http://www.pre.nl/simapro/
IDB Biofuels Sustainability Scorecard	The Scorecard addresses environmental and social sustainability issues specific to biofuels projects; it is based on the sustainability criteria of the Roundtable on Sustainable Biofuels. The primary objective is to provide a tool for thinking through the complex issues associated with biofuels throughout their entire life cycles. The Scorecard is designed to be a living document, improving and evolving over time as additional issues are incorporated.	http://www.iadb.org/biofuelsscorecard/index.cfm?language=English

Resource	Description	URL
Sustainability Quick Check for Biofuel	This tool is designed for a rapid assessment of environmental impacts of individual biofuels by combining key factors of individual production chains with life cycle data from reference data sets. It enables producers to check the compatibility of their biofuels productions with sustainability certification criteria. It facilitates access to the international market for producers of biofuels in emerging countries, and therefore contributes to a more sustainable implementation of biofuels production.	http://www.sqcb.org/
Biomass based Climate Change Mitigation through Renewable Energy Systems (BIOMITRE)	The aim of BIOMITRE is to develop a standard, user-friendly software tool that can be used to analyze GHG balances and cost-effectiveness of different biomass energy technologies.	http://www.ieabioenergy-task38.org/softwaretools/
Examples		
Using an LCA approach to estimate the net GHG emissions of bioenergy	This report addresses the key methodological aspects of LCA with respect to greenhouse gas (GHG) balances of bioenergy systems. It includes results via case studies for some important bioenergy supply chains in comparison to fossil energy systems. The purpose of the report is to produce an unbiased, authoritative statement aimed especially at practitioners, policy advisors, and policy makers.	http://www.ieabioenergy.com/MediaItem.aspx?id=7099
A Compilation of Tools and Methodologies to Assess the Sustainability of Modern Bioenergy	The FAO's Bioenergy and Food Security Criteria and Indicators (BEFSCI) project has developed a set of criteria, indicators, good practices, and policy options on sustainable bioenergy development that foster rural development and food security. BEFSCI aims to inform the development of national frameworks aimed at preventing the risk of negative impacts—and increasing the opportunities--of bioenergy development on food security and help developing countries monitor and respond to the impacts of bioenergy development on food security.	http://www.fao.org/docrep/015/i2598e/i2598e.pdf
Bioenergy Environmental Impact Analysis (BIAS)	The BIAS framework combines Strategic Environmental Assessment with life cycle analysis elements, designed to help decision makers (mainly at the national level) to guide bioenergy toward low-risk and environmentally safe development.	http://www.fao.org/docrep/013/am303e/am303e00.pdf
General environmental impacts, principals, criteria and indicators of biomass production and conversion	This report presents a general overview of the environmental impacts associated with biofuels and bioproducts as well as the principles, criteria, and indicators of the existing certification systems.	http://www.globalbiopact.eu/images/stories/1_pr/WP5_D5.1_Global-Bio-Pact_General%20environmental%20impacts.pdf

Policy Framework in Support of the Biomass Industry

National strategic policies and laws that aim to improve the attractiveness and security of bioenergy investments (such as renewable portfolio standards, carbon cap-and-trade policies, blending mandates, and vehicle fuel standards) help achieve the cost-effective and efficient use of biomass resources. Long-term financial incentives and a well-established policy framework for bioenergy are key for attracting investors. Tax incentives can help overcome the high up-front costs for both producers and distributors. Establishing a low carbon fuel standard can help create a local market for biofuels. A strong, long-term institutional framework is also necessary to ensure the coordination and coherence of policies affecting energy, environment, and agricultural practices.

Table 6 contains links to tools and information in support of policy analysis.

Table 6. Policy Analysis Tools and Studies

Resource	Description	URL
Bioenergy Decision Support Tool (DST)	The DST provides step-by-step guidance for government decision makers to develop sustainable bioenergy policies and strategies and to assess investment proposals. It was created for interactive use. Beyond an entry page introducing key issues, the user is guided to an e-book function that provides the printable full text.	http://bioenergydecisiontool.org/
RTI Applied Dynamic Analysis of the Global Economy (ADAGE) Model	ADAGE is a dynamic computable general equilibrium (CGE) model capable of investigating economic policies at the international, national, U.S. regional, and U.S. state levels. CGE models such as ADAGE combine economic theory and empirical data to estimate policy effects while accounting for all interactions among businesses and consumers. ADAGE typically solves in five-year time intervals from 2005 to around 2050, and it can be used to explore dynamic effects of many types of energy, environmental, and trade policies. Of particular note is its ability to investigate climate change mitigation policies at a range of geographic scales.	http://www.rti.org/page.cfm?objectid=DDC06637-7973-4B0F-AC46B3C69E09ADA9
UNEP Handbook for Drafting Laws on Energy Efficiency and Renewable Energy Resources	The Handbook describes the key environmental and implementation issues associated with efficiency and renewable energy resources and presents legislative options from both developed and developing countries for dealing with them, including sample excerpts from legislation.	http://www.unep.org/environmentalgovernance/LinkClick.aspx?fileticket=wpreHraAXGM%3D&tabid=383&mid=1024
EC Sultan	The SULTAN (**SU**stainab**L**e **TrAN**sport) Illustrative Scenarios Tool has been developed as a high-level calculator (not an in-depth model) to help provide indicative estimates of the possible impacts of policy on transport in the EU (addressing primarily energy use, GHG emissions, costs, and NOx and PM emissions). The purpose of the tool is to allow the quick scoping of a wide range of transport policy options to help instill a sense of appropriate scale of action for a particular project. It can also be used as part of the analysis for the final written technical outputs of a project.	http://www.eutransportghg2050.eu/cms/illustrative-scenarios-tool/

Resource	Description	URL
BioEnergy Evaluation Tool (BEET)	The BEET project, a component of the U.S.–Brazil Biofuels Initiative, aims to produce a user-friendly decision support tool for evaluating the national/energy security, economic, and environmental and agricultural impacts stemming from bioenergy policies and strategies. As a decision support tool, BEET offers a quick completion analytic capability to express trade-off and "what if" analyses of bioenergy policy options intended to support country-level priorities and goals. Capabilities continue to expand, currently in the direction of support for development and evaluation of strategic ethanol plans for El Salvador and the Dominican Republic.	http://climate.society.gmu.edu/seminar/155
SADC Bioenergy Policy Development Tool	Upon requests from SADC Member States, the SADC biofuel taskforce commissioned GTZ-ProBEC to develop this policy support tool, designed to fit SADC specific conditions and priorities, but relevant because it draws on existing international policy support material. The tool acknowledges the SADC Framework for Sustainability and other important SADC policy documents, and it has been developed jointly with the SADC biofuel taskforce members and selected Member States.	http://www.probec.org/fileuploads/fl1110201003332 5_GTZ_ProBEC_SADC__BIOENERGY_POLICY_DEVELOPMENT_Aug_2010.pdf
Examples		
Advancing Bioenergy for Sustainable Development: Guideline for Policymakers and Investors	This report provides a broad review of the issues that a policymaker or project developer may face when endeavoring to advance biomass energy for sustainable development. The report provides guidance with respect to multiple dimensions of bioenergy project design and implementation for policymakers, entrepreneurs, and other actors. Its main focus is on less developed countries, although some lessons and methods from industrialized countries are included where appropriate. The report divides these issues among three volumes.	http://www.energycommunity.org/documents/SustainableBioenergyFinal.pdf
Sustainable Biofuel Development Policies, Programs, and Practices in APEC Economies	This report presents current policies, programs, and practices in APEC economies that aim to ensure that biofuels are sustainable. Information was gathered through a survey of those involved with biofuels in APEC economies, follow-up interviews, and an extensive literature review.	http://www.biofuels.apec.org/pdfs/ewg_2010_sustainable_biofuels.pdf

Trade Opportunities

The growing bioenergy industry provides many opportunities for local, regional, and international trade. These opportunities come from the diverse nature of the industry–from various feedstocks (including forest products, agricultural products, and biodegradable wastes) to several end products such as power, heat, fuels, and chemicals. Assessing trade opportunities is an important part of the market analysis: a reliable supply of biomass and a reliable demand for bio-energy is vital to developing stable market activities. In some areas, biomass production potential either cannot meet or exceed the local demand; therefore, a country's role in the international bioenergy market should be considered when building a bioenergy program.

Table 7 contains links to information and data in support of international trade analysis.

Table 7. Trade Analysis Tools and Studies

Resource	Description	URL
Global Trade Analysis Project (GTAP)	GTAP has successfully integrated global energy data—in particular, extended energy balances and energy prices and taxes, compiled by the International Energy Agency (IEA)--into the GTAP input/output tables and bilateral trade data. With its database now covering inputs/outputs and bilateral trade of 57 commodities (and producing industries) and 113 countries/regions, GTAP is able to capture broad sectoral interactions within domestic economies as well as international trade effects. Growing research demands for integrated assessment (IA) of climate change issues and biofuels have motivated construction of databases and models related to GHG emissions, land use, and biofuels that can be used with computable general equilibrium models.	https://www.gtap.agecon.purdue.edu/models/energy/default.asp
INTradeBID	The Integration and Trade Sector of the Inter-American Development Bank develops specialized databases, models, and tools to monitor and assess the impact that integration and trade has on the Latin America and the Caribbean region. This portal provides public access to these data and tools.	http://www.iadb.org/int/intradebid/
IEA Bioenergy Task 40: Sustainable International Bioenergy Trade	This website provides information and publications related to international bioenergy trade including country reports, assessment of opportunities and barriers, and analytical tool development.	http://www.bioenergytrade.org/
World Trade Organization (WTO)	The WTO is the only global international organization dealing with the rules of trade between nations. At its heart are the WTO agreements, negotiated and signed by the bulk of the world's trading nations and ratified in their parliaments. The goal is to help producers of goods and services, exporters, and importers conduct their business.	http://www.wto.org/
International Trade Center	ITC's mission is to enable small business export success in developing and transition-economy countries, by providing, along with partners, sustainable and inclusive development solutions to the private sector, trade support institutions, and policymakers.	http://www.intracen.org/

Examples		
Developing Sustainable Trade in Bioenergy	This publication provides the summary and conclusions from the workshop 'Developing Sustainable Trade in Bioenergy' held in conjunction with the meeting of the Executive Committee of IEA Bioenergy in Nara City, Japan in May 2010. The purpose of the workshop was to provide the Executive Committee with perspectives on bioenergy trade in a world where there are progressively more quantitative targets for bioenergy deployment, including incentives for production of biofuels on a sustainable basis. The aim was to stimulate discussion between the Executive Committee and invited experts and thereby enhance the policy-oriented work within IEA Bioenergy.	http://www.ieabioenergy.com/MediaItem.aspx?id=6880
Bioenergy and Biomass Trade: Evaluation of Models' Suitability for Analyzing International Trade of Biomass and Bioenergy Products	This report evaluates existing international economic models of the forest sector, the agricultural sector, and/or the energy sector in order to assess their strong and weak points for analyzing international trade of biomass and bioenergy products. The overview is mainly focused on public models used by academia, based on publicly available data sources. These models usually have a time horizon of several decades. Commercial trade models, which typically have a time horizon of a month or a few years, are not considered.	http://www.bioenergytrade.org/downloads/solbergetal.modelingbiomasstrade.pdf

Step 3. Conduct Feasibility Studies and Roadmap Activities

Once a promising bioenergy opportunity is identified, the next step is to conduct a feasibility study or prepare a roadmap. Feasibility studies are comprehensive analyses that provide in-depth details about a project or technology and determine if, and how, it can succeed. A technology roadmap is an illustrative high-level plan that outlines opportunities, barriers, and action items (including necessary R&D activities and policy framework) to achieve desired outcome. Effective roadmaps are built on existing assets in a country that can be leveraged to drive growth in the region proposed. Feasibility studies are used primarily by industry developers while roadmaps are generally developed by policymakers.

Table 8 contains links to tools that support feasibility studies and roadmap activities, as well as examples of relevant documents.

Table 8. Feasibility Study and Roadmap Tools and Examples

Resource	Description	URL
Biomass Allocation Model	The goal of this research, culminating in this report, is to model and discuss alternative uses of scarce biomass energy resources, assuming that these resources reduce energy sector carbon emissions and can produce non-petroleum-based liquid transportation fuels.	http://www.netl.doe.gov/energy-analyses/pubs/Biomass%20Allocation%20Model%20Report%20R2%20(10-01-08).pdf
Market Allocation Model (MARKAL)	MARKAL is a dynamic bottom-up optimization model that aims at choosing the optimal mixture of technologies and fuels in order to minimize net present value system-wide cost. The biomass feedstocks considered in MARKAL are corn grain, corn stover, agricultural residues, energy crops, forest residues, primary mill residues, urban wood waste, municipal solid waste, soybean oil, and waste oil. Conversion technologies include two pathways: liquid fuels and heat combined with power. Liquid fuels include ethanol (dry mill, wet mill, cellulosic), biodiesel (Fatty Acid Methyl Ester [FAME]), and thermochemical (pyrolysis to bio-oil, gasification to syngas). Heat and power includes power generation (biomass gasification, coal/biomass co-firing, biomass direct combustion, landfill gas combustion, waste-to-energy), industrial heat and power (pulp and paper, other industrial heat/steam), and residential heating (wood stoves, outdoor wood boilers).	http://www.iea-etsap.org/web/Markal.asp
Model of Energy Supply Systems and their General Environmental Impacts (MESSAGE)	MESSAGE is used to formulate and evaluate alternative energy supply strategies for user- defined constraints on, for example, new investment limits, market penetration rates for new technologies, fuel availability and trade, and environmental emissions. MESSAGE is extremely flexible and can also be used to analyze energy/electricity markets and climate change issues.	http://www.iiasa.ac.at/Research/ENE/model/message.html

Resource	Description	URL
System Advisor Model (SAM)	The System Advisor Model (SAM) is a performance and financial model designed to facilitate decision making for people involved in the renewable energy industry. SAM makes performance predictions and cost of energy estimates for grid-connected power projects based on installation and operating costs and system design parameters that a user specifies as inputs for the model. Projects can be on either the customer side of the utility meter, buying and selling electricity at retail rates, or on the utility side of the meter, selling electricity at a price negotiated through a power purchase agreement (PPA).	https://sam.nrel.gov/
HOMER	HOMER is a computer model that simplifies the task of evaluating design options for both off-grid and grid-connected power systems for remote, stand-alone, and distributed generation (DG) applications. HOMER's optimization and sensitivity analysis algorithms allow users worldwide to evaluate the economic and technical feasibility of a large number of technology options and account for uncertainty in technology costs, energy resource availability, and other variables. HOMER can be used for designing and analyzing hybrid power systems, which contain a mix of conventional generators, cogeneration, wind turbines, solar photovoltaics, batteries, fuel cells, hydropower, biomass, and other inputs.	http://www.homerenergy.com/
RETScreen	The RETScreen Clean Energy Project Analysis Software is a unique decision support tool. The free software can be used worldwide to evaluate the energy production and savings, costs, emission reductions, financial viability, and risk for various types of renewable energy and energy efficiency technologies.	http://www.retscreen.net/ang/home.php
RESolve Model	The RESolve Model was developed by the Energy Research Centre of the Netherlands (ECN), and it addresses the issue of market competition for biomass resources. It is divided into three sub-models for different sectors: RESolve-T for the transportation sector, RESolve-E for the energy sector, and RESolve-H for the heat sector. Each model has a sector-specific demand. The model finds the most economical way to allocate the biomass among the three sectors.	http://www.ecn.nl/docs/library/report/2011/o11011.pdf
GCAM	GCAM is a partial-equilibrium model of the global industrial and energy system, including agriculture and land use. GCAM solves for the equilibrium prices in 14 main global regions. The model runs from 1990 to 2095 in 15-year time steps. Population and GDP are drivers to the model and are exogenously specified for each region. Competition between energy sources is simulated using the market share, based on the probability that a certain energy source and technology has the least cost for a given application.	http://www.globalchange.umd.edu/models/gcam/

STELLA	STELLA is used for system dynamics modeling of policy and market scenarios. It provides endless opportunities to explore "what if" questions and allows users to communicate how a system works–what goes in, how the system is impacted, and outcomes.	http://www.iseesystems.com/softwares/Education/StellaSoftware.aspx
Examples		
Biodiesel Feasibility Study	This study evaluates the feasibility of producing biodiesel in Wisconsin.	http://www.aae.wisc.edu/pubs/sps/pdf/stpap481.pdf
Feasibility study of biofuel production in Ghana	The purpose of this project is to assess the viability of creating a biofuels industry in Ghana.	http://elliott.gwu.edu/assets/docs/acad/ids/capstone/ghana07.pdf
IEA Technology Roadmap – Biofuels for Transport	This roadmap identifies technology goals and defines key actions that stakeholders must take to expand biofuels production and to promote sustainability. It describes the role for government policy in adopting measures for the sustainable expansion of both conventional and advanced biofuel production. The document also provides additional focus and urgency to international discussions about the importance of biofuels to a low CO_2 future.	http://www.iea.org/papers/2011/Biofuels_Roadmap.pdf
U.S. National Algal Biofuels Technology Roadmap	This roadmap presents information from scientific, economic, and policy perspectives that can support and guide RD&D investment in algal biofuels. While addressing the potential economic and environmental benefits of using algal biomass for the production of liquid transportation fuels, the roadmap describes the current status of algae RD&D. In doing so, it lays the groundwork for identifying challenges that likely need to be overcome for algal biomass to be used in the production of economically viable biofuels.	http://www1.eere.energy.gov/biomass/pdfs/algal_biofuels_roadmap.pdf

Step 4. Benchmarking: Best Practices and Lessons Learned

In the benchmarking phase, gaps and strengths of the project being developed are identified by comparing it with best practices and lessons learned from existing bioenergy programs. When doing a benchmark analysis, it is important to consider similar country conditions in natural resources availability, climate conditions, and market trends. Some countries' bioenergy programs serve as great benchmarks for assessing the effectiveness of a project.

Table 9 contains examples of best practices and lessons learned from various bioenergy development programs.

Table 9. Best Practices and Lessons Learned Examples

Resource	URL
Bioenergy	
Opportunities for Biomass Energy Programmes – Experiences and Lessons Learned by UNDP in Europe and the CIS	http://www.undp.org/content/dam/aplaws/publication/en/publications/environment-energy/www-ee-library/sustainable-energy/opportunities-for-biomass-energy-programmes-lessons-learned-in-europe---the-cis/Opportunities%20for%20BiomassECIS_2007.pdf
Bioenergy: Environmental Impact and Best Practices	http://www.wcl.org.uk/docs/Bioenergy_Final_Report_01Jan07.pdf
Report on Good Practices on Integrated Bioenergy Planning	http://www.makeitbe.eu/Portals/0/Caricati/Report%20ENGLISH.pdf
Biofuels	
Brazilian Sugar Cane Ethanol: Lessons Learned	http://www.sciencedirect.com/science/article/pii/S0973082608605293
Best Practices for Implementing a Biodiesel Program	http://library.modot.mo.gov/RDT/reports/Ri06045/or08006.pdf
Targets and Mandates: Lessons Learned from EU and US Biofuels Policy Mechanisms	http://www.agbioforum.org/v13n4/v13n4a13-ziolkowska.pdf
Biofuels Best Practices from European Countries	http://www.biomasseenergie.ch/Portals/0/1_de/08_News%20and%20Agenda/BITES%20Final%20Conference%20Programme%20-%20EN%20-%20Provisional%20v2.pdf
Promoting Favorable Conditions to Establish Biodiesel Market Actions	http://www.cres.gr/biodiesel/downloads/reports/Other/Biodiesel%20emerging%20best%20practices.pdf
Policies to Stimulate Biofuel Production in Canada: Lessons from Europe and the United States	http://www.biocap.ca/rif/report/Walburger_A.pdf

Biomass Power	
Lessons Learned from Existing Biomass Power Plants	http://www.nrel.gov/docs/fy00osti/26946.pdf
Lessons Learned in Landfill Gas-to-Energy	http://www.scsengineers.com/Papers/Pierce_Lessons_in_LFGTE.pdf
Case Studies from the Climate Technology Partnership: Landfill Gas Projects in South Korea and Lessons Learned	http://www.nrel.gov/docs/fy07osti/40428.pdf
Energy Benchmark for Wastewater Treatment Processes	http://www.iea.lth.se/publications/MS-Theses/Full%20document/5247_full_document.pdf
The Nepal Biogas Support Program: A Successful Model of Public Private Partnership For Rural Household Energy Supply	http://siteresources.worldbank.org/INTENERGY/Publications/20918309/NepalBiogasSupportProgram.pdf